Long Sleep Duration and Social Jetlag are Associated Inversely with a Healthy Dietary Pattern in Adults: Results from the UK National Diet and Nutrition Survey Rolling Programme Y1-4

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Abstract

Limited observational studies have described the relationship between sleep duration and overall diet. The present study investigated the association between sleep duration at weekdays and empirically derived dietary patterns in a nationally representative sample of UK adults, aged 19-64 years old, participating in the 2008-2012 UK National Diet and Nutrition Survey Rolling Programme. Survey members completed between three to four days of dietary records. Sleep duration at weekdays was categorised into tertiles to reflect short, normal and long sleep duration. Social jetlag was calculated as the difference between sleep duration at weekends and weekdays. The association between sleep duration/ social jetlag and dietary patterns, derived by principal components analysis, was assessed regressing diet on sleep whilst accounting for the complex survey design and adjusting for relevant confounders. Survey members in the highest tertile of sleep duration had on average 0.45 (95% CI -0.78, -0.12) lower healthy dietary pattern score compared to middle tertile (p =0.007). There was an inverted u-shaped association between social jetlag and a healthy dietary pattern, such that when sleep at weekends exceeded weekday sleep by 1h 45min, scores for indicating a healthy dietary pattern declined (p =0.005). In conclusion, long sleep duration at weekdays and an increased social jetlag are associated with a lower healthy dietary pattern score. Further research is required to address factors influencing dietary patterns in long sleepers.

Keywords: Sleep; Social Jetlag; Diet Food and Nutrition; Nutrition Surveys; Cross-sectional; Epidemiology; Adults; Public Health

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1. Introduction

Sleep has been a relatively neglected component in nutritional epidemiology with limited nutritional surveys and cohorts collecting data on sleep timing, duration or quality (1, 2). In recent years, however, sleep has emerged as a potential critical modulator of metabolic pathways involved in glucose homeostasis (3), energy metabolism and appetite regulation (4, 5), as well as a potential important modifiable factor influencing eating behaviour (5, 6), nutritional status and diet quality (7). Against this , multiple cross-sectional studies emerged describing associations between short or long sleep duration and poorer nutritional status and diet quality, though the direction of the association is yet to be established due to limited longitudinal evidence (2, 7). In a cross-sectional analysis of the UK National Diet and Nutrition Survey Rolling Programme (NDNS RP), British adults with a sleep duration ranging from seven to eight hours reported higher intakes of vitamin C, fibre and iron, and higher levels of serum total carotenoids, selenium and urinary nitrogen compared to short (≤6 h/night) or long sleepers (≥9 h/night) (8). Similarly, normal sleep duration has been associated with higher fruit and vegetable intake in one analysis of the NDNS RP (9) but not in another (10). The latter inconsistency may arise from differences in the methodologies used to analyse dietary data wherein most of the focus has been on single foods or nutrients.

In the past, investigating associations between single foods or nutrients has provided invaluable insight into potential molecular pathways by which food may influence health or vice versa (11). Yet, it is recognised that intake of one food group or nutrient may correlate with intake of other food groups or nutrients (11). Thus, analyses focusing on single foods or nutrients may potentially mask associations with more relevant foods or nutrients (12). Indeed, foods and nutrients are often consumed

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in combination and form part of complex dietary patterns for which they act as markers (12). Exploring the association between sleep and dietary patterns is essential since dietary strategies based on dietary patterns are more easily deployable in a public health framework and have been shown to be more effective compared to strategies focusing on specific foods or nutrients (11, 13). To date, few studies have described the relationship between sleep duration and overall dietary patterns (14). Moreover, to our knowledge, no study has addressed how variations between sleep duration at weekends and weekdays, referred herein as social jetlag, may relate to overall diet. The latter is important considering that social jetlag is a common feature of the modern society (15) wherein, under the constraints of social and working schedules, individuals sleep for shorter durations during weekdays compensated by longer sleep duration at weekends (16, 17). Given the known adverse effects of social jetlag on human health (15) accounting for sleep duration at weekends and investigating the association between social jetlag and diet may be important in informing future policies in terms of both sleep and diet.

The present study investigated the association between sleep duration and social jetlag and empirically derived dietary patterns in a nationally representative sample of UK adults.

2. Methods

2.1 Study Population

Excluding the variable for mental illness, the study population consisted of a complete-case sample size of 2,433 adults, aged 19-64yrs old, who participated in the 2008-2012 NDNS RP and who completed three or four days of dietary assessment (18). The NDNS RP is a cross-sectional rolling survey that collects information on all food and drinks consumed from a representative sample of the British population including, at each round, approximately 1000 randomly sampled individuals living in private households across the four regions in the UK i.e. England, Scotland, Wales and Northern Ireland (18).

Individuals were selected from a random sample of 21,573 addresses from 799 postcode sectors obtained between April 2008 and March 2011 from the Royal Mail's Postcode Address File. Within each selected address, one household was randomly sampled. The overall response rate for individuals completing three or four days of dietary records was 56% in Year 1, 57% in Year 2, 53% in Year 3 and 55% in Year 4, respectively. Details of the survey methodology have been published previously (18). Ethical approval for the NDNS RP was obtained from Oxfordshire Research Ethics Committee (18) and data is available from the UK data archive (www.ukdataservice.ac.uk, accession number 123803).

2.2 Dietary assessment

Interviewers visited participants in their home, wherein they provided an estimated food diary to be completed over four consecutive days by survey members (18). Survey members were provided with written instructions and asked to record everything they ate and drank over the four days, both at home and outside. To ensure compliance and completeness of recording, follow-up checks were scheduled by the interviewer on the second or third day of recording either in person or by telephone (18). Home visits were carried out continuously throughout each year, from February 2008 to August 2012, to ensure that seasonal variations in dietary intake were captured (18). Diary entries were coded and analysed by trained dietary coders using an in-house dietary assessment system DINO (Data In, Nutrients Out) (18). This

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system is based on food composition data from the Department of Health's NDNS Nutrient Databank which contains over 7000 regularly updated food codes (18).

2.3 Sleep

Data on sleep were collected by asking individual survey member: "Over the last seven days, that is since last (seven days), how long did you usually sleep for on week nights. That is Sunday to Thursday nights?", "And over the last seven days, how long did you usually sleep for on weekend nights. That is Friday and Saturday nights?" (19). If respondent worked on night shifts during the last one week, the average time slept during the day was recorded. If the pattern of time spent in sleep varied widely, interviewers coded the response as 'don't know'. In Year 1-2, duration of sleep was recorded into a single variable reflecting time spent asleep in hours and minutes (19). In Years 3-4, sleep duration was recorded into two separate variables one to reflect the hours spent asleep and the second to reflect minutes. To enable data analyses from all years, a new sleep variable was derived to reflect time spent in sleep in hours and fraction of hours. Given that the association between sleep and health (20) or diet may be non-linear (21), the derived sleep duration variable was split into tertiles to generate three sleep categories based on the sleep duration distribution of the survey sample.

Social jetlag was calculated as the difference in sleep duration between weekends and weekdays in hours and fraction of hours.

2.4 Additional measures and covariates

Height and weight were measured using a portable stadiometer and weighing scales. Body Mass Index (BMI) was calculated as weight in kilograms divided by

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height in square meters. A Computer Assisted Personal Interview (CAPI) was also conducted during the initial visit by trained interviewers to obtain information on respondent's health status including limiting long-term illnesses; smoking habits (current smoker, ex-regular smoker, never smoker); socio-economic characteristics; and ethnicity (white *vs.* non-white). Socio-economic status was defined based on the National Statistics Socio-economic Classification (NS-SEC) as: (1) Managerial and professional occupations, (2) Intermediate occupations, (3) Small employers and own account workers, (4) Lower supervisory and technical occupations, (5) Semi-routine and routine occupations, and (6) Never worked and long-term unemployed. A variable for mental illness was calculated and coded as 'Yes' or 'No' based on self-reported presence or absence of limiting long-term illness, more specifically depression, anxiety, or nervousness.

2.5 Statistical Methods

2.5.1 Principal Component Analysis

Within the sample included in the analyses, seven survey members reported consuming foods within the 'Commercial Toddlers Foods and Drinks' food group. These foods were inspected and recoded into more relevant main food groups which were 'Biscuits' or 'Crisps and savoury snacks' so as not to exclude any survey members' data. A total of 60 main food groups were included in the Principal Component Analysis (PCA) to derive dietary patterns. These food groups reflect the main food group classification used in the NDNS RS. Data were inputted as mean daily intake in grams (g/d) for each individual. PCA produces linear combinations of food groups which account for the highest possible variance in the data set and are mutually independent. They are deemed to represent discrete dietary patterns

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specific to the population analysed. Scree plots were used to plot eigenvalues to visualise the amount of variance captured by the dietary patterns. Based on this, only the initial three components were retained which had an Eigen value above 1.5, and which together accounted for 11% of the variance in food intake.

A dietary pattern score was calculated for each survey member for each of the derived dietary patterns. These scores were calculated by multiplying the component loadings by the corresponding standardized value for each food and summing across the food groups. A higher score indicated closer adherence to the corresponding dietary pattern. Dietary patterns were named based on food groups with component loadings above the 0.2 or below -0.2 threshold. Such food groups were deemed to have a stronger influence on the respective dietary pattern and were most informative in describing dietary patterns.

2.5.2 Multiple regression

Differences in sociodemographic characteristics and dietary intake between survey members across sleep duration tertiles at weekdays were assessed using one-way ANOVA for continuous variables or χ^2 tests for categorical variables. These analyses were adapted for complex survey design using the variables for clusters, strata and individual weights. The centered method was used to deal with singleton units in the initial stage of the analysis.

Associations between sleep duration or social jetlag as exposure variables and dietary patterns as outcomes were investigated using multiple regression models accounting for complex survey design. Data were weighed to correct for unequal sample selection, non-response for household and individual interview and non-response to individual visit (23). This weighing factor adjusts for differences in socio-

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demographic variables, such as age, sex, ethnicity and region, between participants and non-participants to the individual visit to ensure survey sample is representative of the UK population (23). Analyses were conducted both using the centered method for complex survey design and by re-assigning singleton units to nearest Primary Sampling Unit. Only results for the latter models are presented. The crude model included only the variables for sleep duration at weekdays and weekends. Model 1 adjusted for sex, ethnicity, NS-SEC, age, smoking status and mean daily energy intake. Model 2 additionally adjusted for BMI, while Model 3 further included mental illness as a covariate. These covariates were selected as potential confounders on the basis of their association with sleep and potential influence on diet. Overall, 108 (4%), 110 (4%), 7 (0.03%), 340 (13%), 173 (6%) and 1809 (67%) survey members had missing data on sleep duration at weekdays, sleep duration at weekends, NS-SEC, BMI, and mental illness respectively. These values were assumed to be missing at random and consequently imputed using multiple imputations. Fifty imputed data sets were created and fitted by using the “ice” and “mim” packages in Stata (StataCorp LP, College Station, TX) (24). This gave an imputed sample of 2697 survey members. Sensitivity analyses were conducted comparing the coefficients derived from imputed data and the complete case analyses. Additional sensitivity analyses including interactions between sleep duration at weekdays or social jetlag and BMI, age or mental illness were conducted. The significance of interactions was assessed by Wald tests and the global predictive power of different models by R^2. These interactions were subsequently dropped from the final model. Sensitivity analyses using sleep duration expressed as a quadratic continuous term or as a categorical term defined as short sleep duration (≤6 h/night), normal sleep duration (7–8 h/night) and long sleep duration (≥9 h/night) were also conducted.

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In relation to social jetlag, analyses were conducted using models with social jetlag expressed either in tertiles or as a quadratic continuous term. Model fit was better for the model including the quadratic term. Thus, the final model included a a linear and quadratic term for social jetlag, sex, ethnicity, NS-SEC, smoking, age, BMI and total energy intake.

All statistical analyses were carried out by using Stata Statistical Software version 13 (StataCorp LP, College Station, TX). To reduce the effect of multiple testing on type I error, a more stringent *p*-value of ≤0.01 was deemed significant for all tests.

3. Results

3.1 Sleep duration and social jetlag

Characteristics of the complete-case study sample are provided in Table 1 according to tertiles of sleep duration at weekdays. Overall, survey members within the lowest tertile of sleep duration (short sleep) during weekdays reported a mean 6.3h (SD±0.9) of sleep compared to 7.8h (SD±0.2) and 9.2h (SD±0.7) of sleep reported by survey members in the middle (normal sleep) and highest tertile (long sleep), respectively (p<0.001). Compared to individuals within the lower and middle tertile, survey members within the highest tertile were more likely be of a younger age (p<0.001) and have lower BMI (tertile 3: 26.6kg/m^2 (SD±5.3) *vs.* tertile 1: 28.2kg/m^2 (SD±5.5) p<0.001). There was tendency for women to be in the highest tertile of sleep (70% of women vs. 31% of men, p =0.017). Sleep duration at weekends were correlated with sleep duration at weekdays, such that a higher proportion of short, normal and long sleepers at weekdays were also short, normal, or long sleepers at weekends (p<0.001). Survey members in the lowest tertile of sleep duration at weekdays reported sleeping on average 36min (SD±1h12min) more on weekends compared to

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those in the highest tertile of sleep who reported sleeping 12min (SD±1h12min) less during weekends (p<0.001).

3.2 Diet and dietary patterns

Univariate analyses (χ^2) showed statistically significant association between the sleep duration tertiles and the proportion of consumers *vs.* non-consumers of 'beer, lager, cider, perry' (p=0.003). There was tendency for survey members in the upper tertile of sleep duration to report lower intake of 'nuts & seeds' (p=0.019), 'oily fish' (p=0.018), 'brown, granary & wheatgerm bread' (p=0.020) but these differences did not reach statistical significance.

Three dietary patterns were derived using PCA accounting together for 11% of variance of food intake (Figure 1). The first dietary pattern accounted for the largest proportion of variation in food intake (5.0%). This dietary pattern resembled a 'healthy' dietary pattern and had positive correlations with the food groups: 'fruit', 'salad & other raw vegetables', 'tea, coffee & water', 'vegetables not raw', 'yoghurt, fromage frais & dairy dessert', 'oily fish', 'high-fibre breakfast', and 'nuts & seeds'.

The second dietary pattern explained 3.0% of the variance of food intake and was termed 'sugar, bread & milk' dietary pattern. It had positive correlations with 'sugar, preserves and sweet spreads', 'white bread', 'whole milk', 'butter', 'bacon & ham' and 'chips, fried & roasted potatoes'.

The third dietary pattern resembled a 'snacks' dietary pattern and explained 3.0% of the variance. It had positive correlations with 'soft drinks not low calorie', 'crisps and savoury snacks', 'chocolate confectionery', 'sugar confectionery' and 'soft drinks low calorie'.

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Peer-reviewed version available at *Nutrients* **2018**, *10*, 1131; doi:10.3390/nu10091131

3.3 Sleep and relationship with dietary patterns

In the unadjusted models, a longer sleep duration was associated with a lower 'healthy' dietary pattern score (β -0.60, 95% CI -0.95, -0.26, *p* =0.001). After adjustment for initial covariates in Model 1, the inverse association between a longer sleep duration and the 'healthy' dietary pattern remained significant (β -0.48, 95% CI -0.82, -0.15, *p* =0.005). This association was significant even after adjustment for BMI in Model 2 (β -0.45, 95% CI -0.78, -0.12, *p* =0.007) and mental illness (β -0.44, 95% CI -0.77, -0.11, *p* =0.009. Full model included in supplementary material). Removing sleep duration at weekends from the final model resulted in a decrease in the value of the coefficient for the association between the upper tertile of sleep duration at weekdays and the healthy dietary pattern (Data included in supplementary material). Compared to the final model with complete cases, the final model with imputed data had a similar coefficient for the long sleep duration tertile but narrower confidence interval (Table 3). Using alternative sleep duration cut-offs did not change the value of the coefficient (Data included in supplementary material). However, the global predictive power of the model as assessed using R^2 was reduced.

There was a tendency for long sleep duration at weekdays to be positively associated with the 'sugar, bread & milk' dietary pattern (β 0.29, 95% CI 0.06, 0.51, *p*=0.013). No significant association between sleep duration and the 'snacks' dietary pattern were observed (β -0.13, 95% CI -0.37, 0.11, *p*=0.300).

There was a significant concave nonlinear association between social jetlag and the healthy dietary pattern (Table 4). As shown in Figure 2, the positive association between social jetlag and the healthy dietary pattern was levelled when sleep duration at weekends exceeded sleep duration at weekdays by 1 h 45 min (-

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b/2a). The association between social jetlag and the 'healthy' dietary pattern reversed beyond this point such that any further increase in sleep duration at weekends compared to weekdays was associated inversely with the 'healthy' dietary pattern. This association remained significant after adjustment for potential covariates including BMI and mental illness (β for quadratic term -0.03, 95% CI -0.04, -0.01, p =0.006). No associations between social jetlag and the remaining dietary patterns were observed (data not shown).

4. Discussion

4.1 Main findings

The current study addressed a major gap in the research literature on sleep and nutrition by investigating the relationship between sleep duration and overall dietary patterns in a nationally representative sample of UK adults. Addressing this research gap is important since previous research has focused on describing the relationship between sleep duration and individual nutrients or foods (7). Such a reductionist approach often ignores complex interconnections between the various food groups, thereby potentially undermining more relevant associations and rendering a public health campaign centred on sleep and diet challenging. In the present study, we identified an inverse relationship between long sleep duration at weekdays and a 'healthy' dietary pattern characterised predominantly by higher intakes of 'fruit', 'salad & other raw vegetables', 'tea, coffee & water', 'vegetables not raw', 'oily fish', 'high-fibre breakfast', and 'nuts & seeds'. This association remained significant even after adjustment for relevant confounders including BMI, mean daily energy intake and sleep duration at weekends. This is in contrast to a previous analysis of the NDNS RP wherein sleep duration was not found to be related to diet (25). Such inconsistency

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may be ascribed to the single-nutrient/food approach adopted by the previous analysis (25).

Our findings complement the observations made by Dashti who found that normal sleep duration was associated with more favourable dietary behaviour (26). Our findings are also consistent with previous observations made by Mossavar-Rahmani and colleagues who found that long sleepers had lower intake of caffeine in a sample of 16,415 Hispanic/Latino participants living in the US (27). Similar observations have been made by Grandner who reported lower intake of theobromine, a metabolite of caffeine and marker of tea and coffee intake in long sleepers (28). Contrary to Grandner and colleagues (28), however, we did not observe a U-shaped relationship between sleep duration and energy intake in the univariate analysis. Similarly, we did not observe an inverse association between short sleep duration and the healthy dietary pattern. This is in contrast to previous research that has demonstrated associations between short sleep duration and reduced fruit (29, 30) and/or vegetable intake (29). In the Shanghai Women's Health Study, which included 68,832 Chinese women, an inverse association between short sleep duration (<6 h) and tea and fruit intake was also found (31). In our study, the lack of findings of an association between short sleep duration and dietary patterns may be explained by differences in the cut-offs used for defining the sleep duration tertiles, as well as the lack of objective measures of sleep. In the former case, redefining the tertiles using 6h or 9h as the cut-off for the lower or upper tertile, respectively, did not alter the findings. Concerning measures of sleep, we were unable to differentiate between short sleep duration associated with circadian misalignment and sleep disturbance versus short sleep that is not associated with circadian misalignment and sleep disturbance. The latter is important considering that the combination of short sleep and circadian

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misalignment is associated with more adverse health outcomes (32). Moreover, growing evidence suggests that sleep duration, sleep quality and social jetlag may be modulated by an individual's circadian type or so-called chronotype (33). Accordingly in a study of obese short sleepers, Lucassen and colleagues found that only individuals with an evening chronotype were more likely to have an unhealthy eating pattern characterised by larger food portions, less frequent meals and greater energy intake later in the day (34). This may imply the need for controlling for chronotype in nutrition epidemiological studies investigating the association between sleep duration and diet.

In the present study, no significant association between shorter sleep duration and the 'snacks' dietary pattern was observed. This is in contrast to intervention studies that have reported an impact of sleep restriction on the intake of snacks (35, 36), particularly carbohydrate-rich snacks and dessert (36, 37). This is also in contrast to epidemiological studies that have described positive association between short sleep duration and snack intake after dinner (38, 39). Future analyses of the NDNS RP should attempt to examine differences in food intake according to time-of-day using methods such as correspondence analysis (40). Differences in eating occasion-based dietary patterns may likewise warrant exploration (21).

A novel finding of the current study, is the inverted u-shape relationship between social jetlag, defined in the present study as the difference between sleep duration at weekends and weekdays, and the health dietary pattern. We found that beyond a 1h 45min positive social jetlag at weekends, scores for the healthy dietary pattern declined. These findings are interesting as they, albeit speculatively, indicate that sleep compensation at weekends is associated with an improved diet up to a certain threshold. This analysis is further supported by the sensitivity analyses we

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conducted wherein the negative relationship between long sleep duration at weekdays and the health dietary pattern was attenuated when sleep duration at weekends was not accounted for. Such findings suggest the importance of collecting data on sleep duration at weekends. Moreover, there is a need for characterising potential factors influencing social jetlag in order to gain an understanding of the characteristics of the individuals who exhibit a long positive social jetlag. In particular, work patterns, mental illness, and psychosocial aspects such as stress, fatigue and mood as potential factors underlying social jetlag warrant investigation.

Although not the primary objective of our analyses, differences in sleep duration according to BMI were noted. In particular, individuals with a lower BMI were more likely to be in the highest tertile of sleep duration. These findings are in line with the observations made previously in a cross-sectional analysis of NHANES 2007-2008 (28). They are also consistent with an earlier analysis of the NDNS RP (25), wherein Potter and colleagues found that for every additional hour of sleep, there was a 0.46kg/m^2 and 0.9cm reduction in BMI and waist circumference, respectively. However, in our study, we observed that despite the inverse association between sleep duration and BMI in the univariate models, long sleep duration was associated with a lower healthy dietary pattern score compared to normal sleep duration.

To date, inconsistencies remain with regard to the best categorisation of sleep duration. These discrepancies have been highlighted by a recent review by Al-Khatib and colleagues (4). The current National Sleep Foundation defines normal sleep for adults as a range of 7-9h, while sleep duration equal or below 6h is deemed to be short sleep and 10h and above is defined as long sleep (41). Other studies utilise 9h as the cut-off for defining long sleep duration (39). In the present study, we assessed model fit based on multiple approaches including categorising sleep duration into

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tertiles and use of a quadratic term. We found that the model that included tertiles of sleep duration at weekdays *vs.* weekends provided the best fit when examining the association between sleep duration and diet. This was despite the unequal sample distribution within the tertiles which arose as a result of the Stata xtile command being confronted with ties (42). Redefining the lowest and highest tertile using 6h and 9h, respectively, as cut-offs did not improve the model fit or change the value of the coefficient. In contrast, when analysing social jetlag data, categorising the social jetlag variable into tertiles did not provide the best model fit. Moreover, the categorisation was difficult to interpret as it was unclear as to what constitutes a normal range of social jetlag. Consequently, the final model with the quadratic term was selected as it provided a better fit and interpretation. The implication of using the different methodologies to define sleep duration or social jetlag warrant further investigation. Such research may be important in understanding potential differences in the definition of short, normal and long sleep duration or social jetlag in different global regions.

4.2 Strengths and weaknesses of the study

A main strength of the current study is the national representativeness of the survey sample and the use of detailed dietary data which has been collected over 3-4 days. Data on sleep duration at weekends were also available, which allowed us to adjust for sleep duration at weekends and explore how sleep compensation at weekends may confound or modify the association between sleep during weekdays and overall diet. Previously such analysis has not been possible as most nutritional surveys don't collect data on sleep during at weekends (1). This is an important strength as research has shown that the relationship between sleep duration and diet

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may differ when taking into account sleep duration at weekends (28). A further strength of the present study is the use of multiple imputation to account for missing data compared to previous studies which focused only on individuals with complete data (25). Multiple imputation has the advantage of providing narrower confidence interval and reducing bias associated with the use of a selective sample (43).

Concerning limitations, one of the main limitation of NDNS RP is the cross-sectional design which does not permit investigating the direction of the causality in the association between sleep and dietary patterns. Indeed, whilst sleep duration has been shown to influence eating behaviour and nutritional status in a number of experimental studies, certain foods or nutrients may equally impact sleep duration and quality, as reviewed by Dashti (7) and Pot (44). In addition, the NDNS RP includes data from all participants regardless as to whether the dietary data collected during the three to four days of food recordings is reflective of habitual intake (45). This aspect of the study design means that differentiating between under-reporters and under-consumers (for instance due to ill health) may not be possible (45). Nevertheless, mis-reporting is a common limitation of dietary surveys and cohorts. A further limitation is the absence of data on shift work, timing of sleep onset or sleep quality in the adult population. Finally, in the NDNS RP, data on sleep duration were self-reported and no objective measures on sleep duration and quality were available in the adult population. As such findings from our study may differ from studies that utilise more objective measures of sleep duration (28).

5. Conclusion and future directions

In conclusion, long sleep duration at weekdays and a positive social jetlag are associated inversely with a healthy dietary pattern. Future studies should investigate

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the factors influencing differences in dietary patterns based on different sleep duration categories. Moreover, research should address how sleep duration relates to timing of food intake and explore differences in eating occasion-related dietary patterns. Such research will permit the development of more effective dietary strategies to improve the overall diet of individuals at the different spectrums of sleep duration.

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Supplementary Materials:

Table 1S Coefficient estimates from the regression model of the association between sleep duration at weekdays and the healthy dietary pattern including mental illness as a covariate. Variables with $p \leq 0.01$ were deemed to be significant

Table 2S Coefficient estimates from the regression model of the association between sleep duration at weekdays and the healthy dietary pattern excluding sleep at weekends as a covariate. Variables with $p \leq 0.01$ were deemed to be significant

Table 3S Coefficient estimates from the regression model of the association between sleep duration at weekdays and the healthy dietary pattern. Lower tertiles defined using ≤ 6h as cut-off and upper tertile defined using ≥ 9h as cut-off. Variables with $P \leq 0.01$ were deemed to be significant

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Table 1 Study population characteristics of the complete case study sample by tertiles of sleep duration at weekdays. Continuous data is shown as mean and standard errors. Categorical data is shown as counts and percentages.

		Sleep duration tertile			
Factor	Level	T1 (short ≤7h)	T2 (normal >7 and ≤8h)	T3 (long >8h)	*p*-value*
N unweighed†		1350	798	285	
Sleep duration at weekdays (hours)		6.3 (0.9)	7.8 (0.2)	9.2 (0.7)	<0.001
Sleep duration at weekends (hours)		6.9 (1.5)	8.1 (1.1)	9.0 (1.3)	<0.001
Social jetlag (hours)		0.6 (1.2)	0.2 (1.1)	-0.2 (1.2)	<0.001
Sleep duration at weekends	T1 (short)	911 (67.5%)	87 (10.9%)	27 (9.5%)	<0.001
	T2 (normal)	261 (19.3%)	490 (61.4%)	33 (11.6%)	
	T3 (long)	178 (13.2%)	221 (27.7%)	225 (78.9%)	
Healthy dietary pattern		0.0 (1.6)	0.1 (1.7)	-0.4 (1.5)	0.060
Sugar, milk & bread dietary pattern		0.1 (1.4)	-0.1 (1.3)	0.0 (1.3)	0.055
Snacks dietary pattern		0.0 (1.4)	0.0 (1.3)	-0.1 (1.3)	0.102
Total energy (MJ) diet only		7.7 (2.5)	7.6 (2.4)	7.1 (2.3)	0.011
Age (years)		43.9 (11.9)	41.5 (12.4)	38.7 (13.1)	<0.001
BMI (kg/m^2)		28.2 (5.5)	27.2 (5.4)	26.6 (5.3)	<0.001
Sex	Male	610 (45%)	322 (40%)	87 (30%)	0.017
	Female	740 (55%)	476 (60%)	198 (70%)	
Ethnic group	White	1262 (94%)	731 (92%)	267 (94%)	0.742
	Non-white	88 (6%)	67 (8%)	18 (6%)	
Cigarette Smoking Status	Current cigarette smoker	378 (28%)	186 (23%)	89 (31%)	0.307
	Ex-regular cigarette smoker	274 (20%)	163 (21%)	51 (18%)	
	Never regular cigarette smoker	698 (52%)	449 (56%)	145 (51%)	
Socioeconomic Status	Managerial & professional occupations	564 (42%)	343 (43%)	92 (32%)	0.094
	Intermediate occupations	127 (9%)	76 (10%)	25 (9%)	
	Small employers & own account workers	128 (9%)	88 (11%)	38 (13%)	
	Lower supervisory & technical occupations	148 (11%)	52 (6%)	26 (9%)	
	Semi-routine & routine occupations	360 (27%)	218 (27%)	98 (35%)	
	Never worked & long-term unemployed	23 (2%)	21 (3%)	6 (2%)	
Mental Illness	No	432 (93%)	195 (91%)	93 (88%)	0.159
	Yes	31 (7%)	19 (9%)	13 (12%)	

* P-values are provided taking into consideration complex survey design and weighed sample. Singleton units were centered to enable estimation of standard errors based on the distance of strata from the grand mean.

† N unweighed for complete-case model including mental illness as a covariate is 783.

Table 2. Proportion of consumers within each food group according to sleep duration tertile.

Food Group	Sleep duration at weekdays tertile			*p*-value*
	T1	T2	T3	
	n (%)	n (%)	n (%)	
Bacon & ham	832(61.6%)	483(60.5%)	175(61.4%)	0.610
Beef, veal, &, dishes	692(51.3%)	399(50%)	141(49.5%)	0.823
Beer, lager, cider, perry	445(33%)	238(29.8%)	63(22.1%)	0.003
Biscuits	858(63.6%)	504(63.2%)	169(59.3%)	0.276
Browngranary & wheatgerm bread	481(35.6%)	263(33%)	80(28.1%)	0.020
Buns, cakes, pastries, fruit, pies	698(51.7%)	388(48.6%)	125(43.9%)	0.260
Burgers & kebabs	175(13%)	111(13.9%)	40(14%)	0.546
Butter	454(33.6%)	268(33.6%)	104(36.5%)	0.865
Cheese	822(60.9%)	500(62.7%)	163(57.2%)	0.897
Chicken & turkey dishes	884(65.5%)	548(68.7%)	198(69.5%)	0.695
Chips, fried, roast, potatoes, &, potato	858(63.6%)	497(62.3%)	192(67.4%)	0.140
Chocolate confectionery	605(44.8%)	365(45.7%)	122(42.8%)	0.300
Coated chicken	221(16.4%)	125(15.7%)	48(16.8%)	0.587
Crisps	659(48.8%)	404(50.6%)	129(45.3%)	0.386
Dry weight beverages	181(13.4%)	96(12%)	28(9.8%)	0.026
Eggs & eggdishes	681(50.4%)	395(49.5%)	158(55.4%)	0.185
Fruit	1021(75.6%)	633(79.3%)	196(68.8%)	0.040
Fruit juice	483(35.8%)	314(39.3%)	94(33%)	0.222
High fibre breakfast cereals	584(43.3%)	376(47.1%)	114(40%)	0.492
Icecream	247(18.3%)	145(18.2%)	43(15.1%)	0.656
Lamb & dishes	168(12.4%)	113(14.2%)	37(13%)	0.422
Liver dishes	61(4.5%)	33(4.1%)	9(3.2%)	0.834
Low fat spread	239(17.7%)	142(17.8%)	49(17.2%)	0.233
Low fat spread not PUFA	75(5.6%)	42(5.3%)	11(3.9%)	0.903
Meatpies & pastries	316(23.4%)	183(22.9%)	71(24.9%)	0.735
Nuts & seeds	241(17.9%)	153(19.2%)	38(13.3%)	0.019
Oily fish	279(20.7%)	188(23.6%)	40(14%)	0.018
One percent milk	28(2.1%)	14(1.8%)	9(3.2%)	0.125
Other bread	127(9.4%)	88(11%)	24(8.4%)	0.898
Other breakfast cereals	389(28.8%)	262(32.8%)	97(34%)	0.629
Other margarine fats & oils	110(8.1%)	93(11.7%)	25(8.8%)	0.103
Other meat & meat products	189(14%)	108(13.5%)	41(14.4%)	0.635
Other potatoes, potato, salads, dishes	252(18.7%)	144(18%)	45(15.8%)	0.547
Other rmilk & cream	910(67.4%)	543(68%)	195(68.4%)	0.942
Other white, fish, shellfish, fish, dishes	442(32.7%)	292(36.6%)	96(33.7%)	0.457
Pasta, rice & other cereals	1021(75.6%)	617(77.3%)	216(75.8%)	0.303
Pork & dishes	259(19.2%)	151(18.9%)	61(21.4%)	0.201
Puddings	301(22.3%)	170(21.3%)	51(17.9%)	0.091
PUFA margarine oils	34(2.5%)	26(3.3%)	6(2.1%)	0.635
Reduced fat spread not PUFA	606(44.9%)	361(45.2%)	131(46%)	0.671
Reduced fat spread PUFA	190(14.1%)	103(12.9%)	37(13%)	0.643
Salad & other raw vegetables	957(70.9%)	595(74.6%)	199(69.8%)	0.376
Sausages	469(34.7%)	254(31.8%)	103(36.1%)	0.900
Savoury sauces, pickles & condiments	1076(79.7%)	656(82.2%)	229(80.4%)	0.629
Semiskimmed milk	970(71.9%)	604(75.7%)	196(68.8%)	0.435
Skimmed milk	212(15.7%)	107(13.4%)	36(12.6%)	0.623
Soft drinks low calorie	489(36.2%)	319(40%)	113(39.6%)	0.650
Soft drinks not low calorie	659(48.8%)	396(49.6%)	150(52.6%)	0.657
Soup homemade & retail	421(31.2%)	269(33.7%)	112(39.3%)	0.064
Spirits & liqueurs	201(14.9%)	105(13.2%)	27(9.5%)	0.063
Sugar confectionery	196(14.5%)	123(15.4%)	33(11.6%)	0.813
Sugars, preserves & sweet spreads	839(62.1%)	512(64.2%)	169(59.3%)	0.313
Tea, coffee & water	1325(98.1%)	786(98.5%)	280(98.2%)	0.529
Vegetables not raw	1200(88.9%)	719(90.1%)	248(87%)	0.226
White bread	1069(79.2%)	632(79.2%)	230(80.7%)	0.328

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White fish, coated or fried	276(20.4%)	177(22.2%)	71(24.9%)	0.027
Wholemeal bread	478(35.4%)	301(37.7%)	97(34%)	0.094
Wholemilk	268(19.9%)	144(18%)	76(26.7%)	0.329
Wine	431(31.9%)	274(34.3%)	80(28.1%)	0.161
Yogurt, fromage frais & dairy dessert	504(37.3%)	321(40.2%)	98(34.4%)	0.354

* P-values are provided taking into consideration complex survey design and weighed sample.

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Figure 1 Factor loadings for dietary patterns

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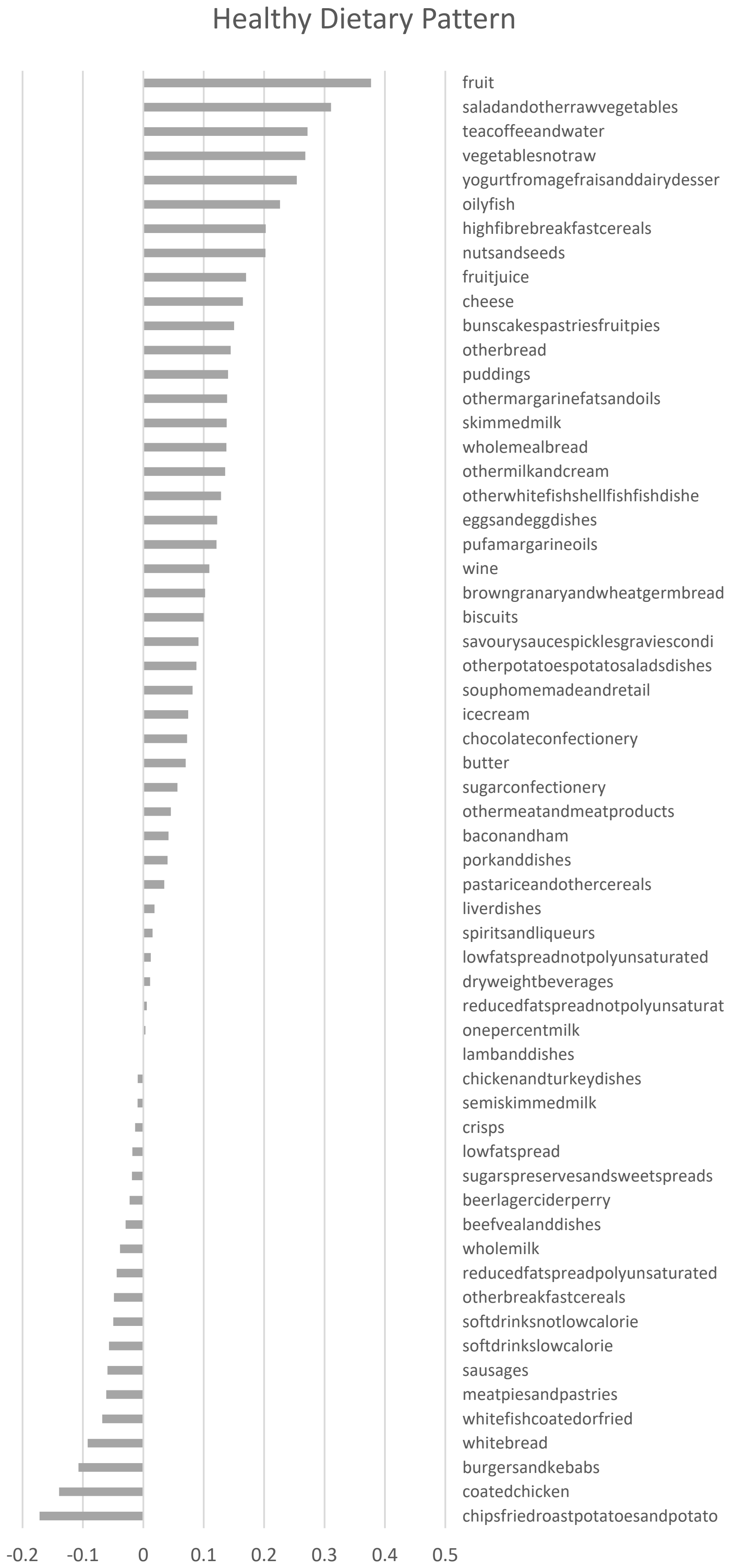

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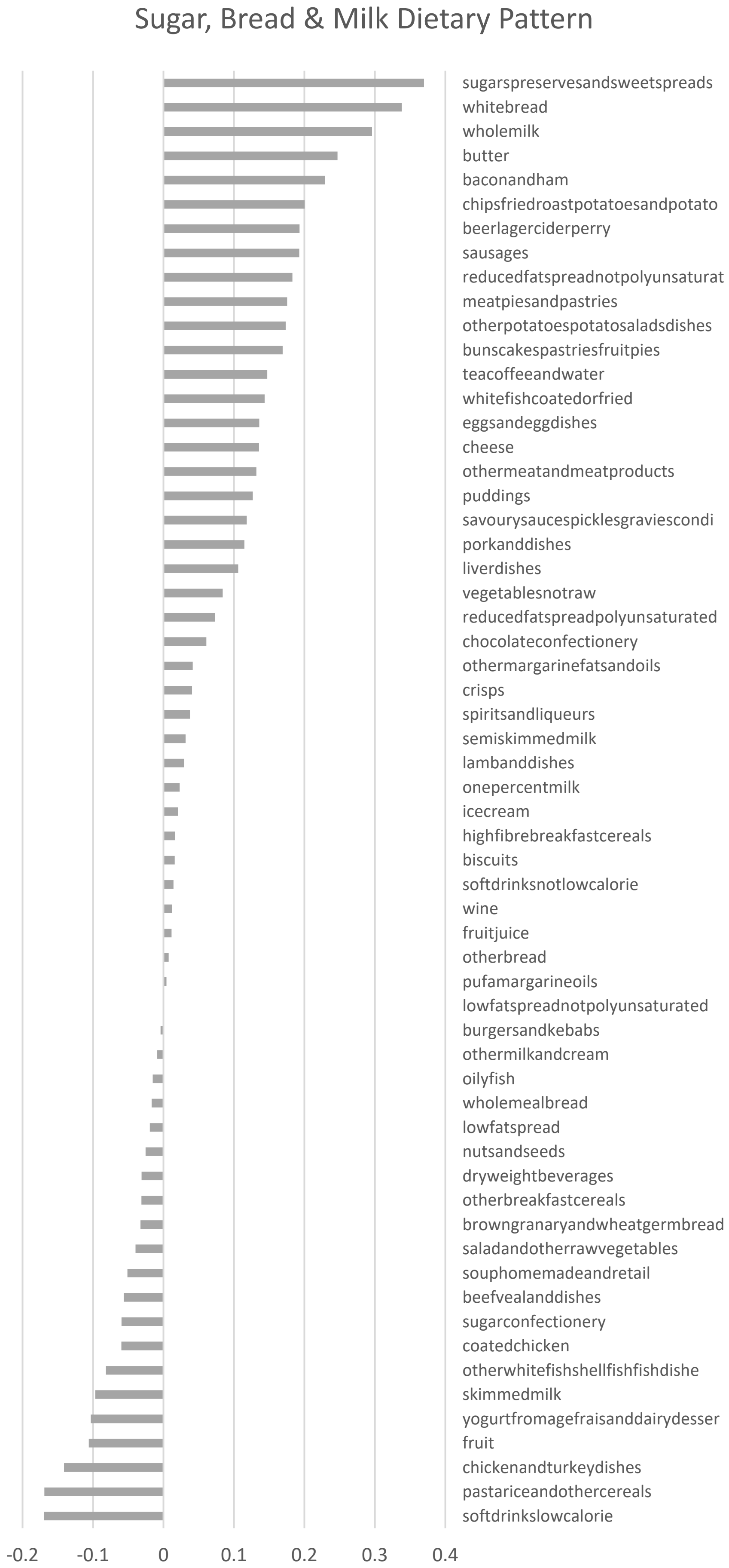

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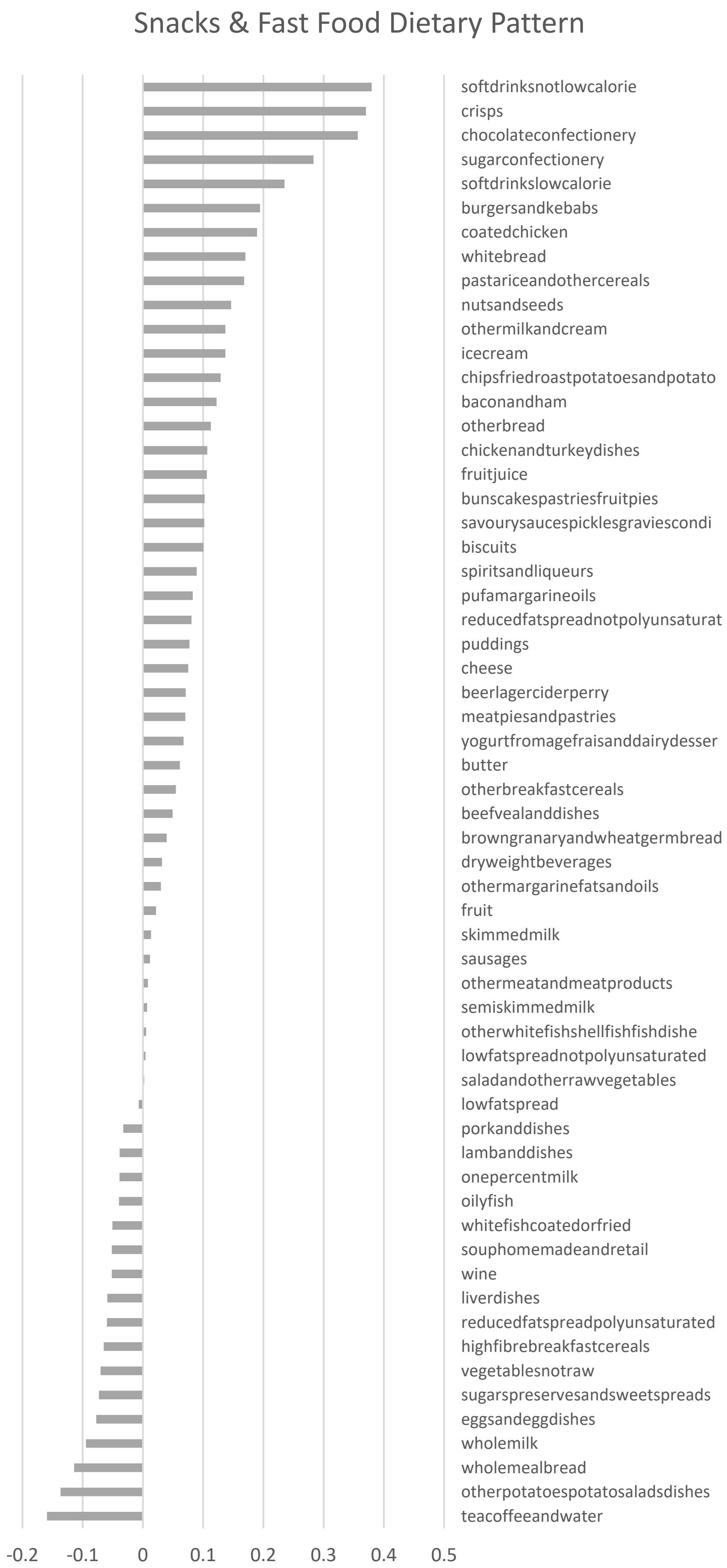

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Table 3 Coefficient estimates from the multiple regression models of the association between sleep duration at weekdays and the healthy dietary pattern as outcome. Variables with $P \leq 0.01$ were deemed to be significant.

Model	Parameter		Coefficient	Lower CI	Upper CI	*p*-value
Crude	Sleep Weekday	T1	-0.07	-0.33	0.19	0.595
	Sleep Weekday	T2 (Reference)	0.00	.	.	.
	Sleep Weekday	T3	-0.60	-0.95	-0.26	0.001
	Sleep Weekend	T1	-0.17	-0.42	0.09	0.207
	Sleep Weekend	T2 (Reference)	0.00	.	.	.
	Sleep Weekend	T3	-0.09	-0.38	0.21	0.553
	Intercept		0.29	0.10	0.49	0.004
Model 1	Sleep Weekday	T1	-0.12	-0.36	0.12	0.325
	Sleep Weekday	T2 (Reference)	0.00	.	.	.
	Sleep Weekday	T3	-0.48	-0.82	-0.15	0.005
	Sleep Weekend	T1	-0.10	-0.33	0.13	0.395
	Sleep Weekend	T2 (Reference)	0.00	.	.	.
	Sleep Weekend	T3	0.10	-0.18	0.38	0.473
	Sex	women vs men	0.63	0.46	0.80	<0.001
	Ethnicity	non-white vs white	0.40	0.15	0.64	0.002
	Age	(years)	0.04	0.04	0.05	<0.001
	Total Energy Intake	(MJ)	0.19	0.15	0.24	<0.001
	Intercept		-3.42	-3.93	-2.91	<0.001
Model 2	Sleep Weekday	T1	-0.12	-0.35	0.11	0.301
	Sleep Weekday	T2 (Reference)	0.00	.	.	.
	Sleep Weekday	T3	-0.45	-0.78	-0.12	0.007
	Sleep Weekend	T1	-0.04	-0.26	0.18	0.729
	Sleep Weekend	T2 (Reference)	0.00	.	.	.
	Sleep Weekend	T3	0.17	-0.10	0.44	0.215
	Sex	women vs men	0.57	0.40	0.73	<0.001
	Ethnicity	non-white vs white	0.34	0.10	0.59	0.006
	Smoking status	Ex-regular cigarette smoker	0.71	0.47	0.95	<0.001
		Never smoker	0.81	0.61	1.01	<0.001
	Socioeconomic Status	Q1	0.00	.	.	.
		Q2	-0.34	-0.60	-0.08	0.010
		Q3	-0.38	-0.65	-0.10	0.007
		Q4	-0.24	-0.52	0.04	0.093
		Q5	-0.64	-0.84	-0.44	<0.001
		Q6	0.17	-0.42	0.75	0.579
	Age	(years)	0.04	0.04	0.05	<0.001
	BMI	(kg/m^2)	-0.02	-0.04	-0.01	0.001
	Total Energy Intake	(MJ)	0.17	0.13	0.22	<0.001
	Intercept		-2.94	-3.59	-2.28	<0.001
Complete-cases model	Sleep Weekday	T1	-0.12	-0.35	0.11	0.304
	Sleep Weekday	T2 (Reference)				
	Sleep Weekday	T3	-0.41	-0.77	-0.06	0.021
	Sleep Weekend	T1	-0.04	-0.26	0.18	0.742
	Sleep Weekend	T2 (Reference)				
	Sleep Weekend	T3	0.18	-0.10	0.45	0.199
	Sex	women vs men	0.52	0.35	0.69	0
	Ethnicity	non-white vs white	0.33	0.13	0.54	0.001
	Smoking status	Ex-regular cigarette smoker	0.68	0.42	0.94	<0.001
		Never smoker	0.77	0.55	0.99	<0.001
	Socioeconomic Status	Q1				
		Q2	-0.34	-0.62	-0.07	0.014
		Q3	-0.39	-0.67	-0.11	0.007
		Q4	-0.21	-0.52	0.09	0.175
		Q5	-0.69	-0.90	-0.49	<0.001
		Q6	0.09	-0.54	0.71	0.785
	Age (years)		0.04	0.04	0.05	<0.001
	BMI	(kg/m^2)	-0.02	-0.04	-0.01	<0.001
	Total Energy Intake		0.18	0.13	0.22	<0.001
	Intercept		-2.91	-3.58	-2.24	<0.001

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Table 4 Coefficient estimates from the multiple regression models of the association between social jetlag and the healthy dietary pattern as outcome. Variables with $P \leq 0.01$ were deemed to be significant.

Model	Parameter		Coefficient	Lower	Upper	*p*-value
Crude Model	Sleeplag		0.12	0.04	0.20	0.002
	Sleeplag squared		-0.04	-0.06	-0.01	0.002
	Intercept		0.11	0.01	0.21	0.036
Model 1	Sleeplag		0.12	0.04	0.19	0.003
	Sleeplag squared		-0.04	-0.05	-0.02	<0.001
	Sex	women vs men	0.64	0.46	0.81	<0.001
	Ethnicity	non-white vs white	0.37	0.12	0.63	0.004
	Age	(years)	0.04	0.03	0.05	<0.001
	Total Energy Intake	(MJ)	0.21	0.16	0.25	<0.001
	Constant		-3.59	-4.07	-3.11	<0.001
Model 2	Sleeplag		0.11	0.03	0.18	0.005
	Sleeplag squared		-0.03	-0.04	-0.01	0.005
	Sex	women vs men	0.57	0.41	0.73	<0.001
	Ethnicity	non-white vs white	0.32	0.08	0.57	0.011
	Smoking status	Ex-regular cigarette smoker	0.73	0.48	0.97	<0.001
		Never smoker	0.81	0.60	1.01	<0.001
	Socioeconomic Status	Q1	0.00	.	.	.
		Q2	-0.35	-0.61	-0.08	0.011
		Q3	-0.37	-0.64	-0.11	0.006
		Q4	-0.28	-0.55	0.00	0.050
		Q5	-0.61	-0.81	-0.42	<0.001
		Q6	0.17	-0.42	0.77	0.564
	Age	(years)	0.04	0.03	0.05	<0.001
	BMI	(kg/m2)	-0.02	-0.04	-0.01	0.001
	Total Energy Intake	(MJ)	0.18	0.14	0.22	<0.001
	Intercept		-3.05	-3.67	-2.43	<0.001
Complete-cases	Sleeplag		0.11	0.03	0.19	0.005
	Sleeplag squared		-0.03	-0.05	-0.01	0.002
	Sex	women vs men	0.52	0.35	0.69	<0.001
	Ethnicity	non-white vs white	0.31	0.10	0.52	0.004
	Smoking status	Ex-regular cigarette smoker	0.70	0.44	0.95	<0.001
		Never smoker	0.76	0.55	0.98	<0.001
	Socioeconomic Status	Q1				
		Q2	-0.34	-0.63	-0.06	0.017
		Q3	-0.39	-0.66	-0.11	0.006
		Q4	-0.25	-0.55	0.05	0.103
		Q5	-0.65	-0.86	-0.45	<0.001
		Q6	0.09	-0.55	0.72	0.787
	Age	(years)	0.04	0.03	0.05	<0.001
	BMI	(kg/m2)	-0.02	-0.04	-0.01	<0.001
	Total Energy Intake	(MJ)	0.19	0.14	0.23	<0.001
	Intercept		-3.01	-3.66	-2.36	<0.001

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Figure 2 Inverse u-shaped relationship between social jetlag and the fitted values (with confidence bands) for the healthy dietary pattern scores from the multiple regression model 2.