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# Recommended sleep duration is associated with higher consumption of fruits and vegetables; cross-sectional and prospective analyses from the UK Women's Cohort Study

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## Abstract

**Background:** High intakes of fruit and vegetable has been shown to protect against diseases and all-cause mortality however, the associations between sleep and fruit and vegetable consumption are not well characterized. This study aims to explore both cross-sectional and prospective associations between sleep duration and fruit and vegetable intakes in UK women. This is the first study to demonstrate the prospective association between sleep duration and fruit and vegetable consumption.

**Methods:** Cross–sectional and prospective data were obtained from the UK Women's Cohort Study. Sleep duration was assessed by self-report of average hours slept on weekdays and weekends and diet was assessed by a 4-day food diary at baseline and follow-up (~ 4 years later). Sleep duration was categorized as short (≤6 h/d), recommended (7–9 h/d) and long (≥9 h/d). Regression analyses adjusting for age, socio-economic status, smoking, ethnicity and total energy intake were used and restricted cubic spline models were developed to explore potential non-linear associations between sleep duration and fruit and vegetable intakes.

**Results:** In adjusted cross-sectional analyses, short sleepers had on average 17 g/d (95% CI -30 to-4, $p = 0.01$) and long sleepers had 25 g/d (95% CI -39 to − 12, $p < 0.001$) less total fruits and vegetables compared to Recommended Sleepers (RS). In adjusted prospective analyses, short sleepers had on average 85 g/d (95% CI -144 to − 26, $p = 0.005$) less total fruits and vegetables in comparison to RS. Restricted cubic spline models showed that the cross-sectional ($p < 0.001$) and prospective ($p = 0.001$) associations between sleep duration and fruit and vegetable intakes were non-linear with women sleeping 7–9 h/d having the highest intakes.

**Conclusions:** Fruit and vegetable consumption differed between sleep duration categories with UK women sleeping the recommended 7–9 h/day having the highest intake of fruits and vegetables in cross-sectional and prospective analyses. These findings suggest that sleeping the recommended duration is associated with higher consumption of fruits and vegetables. Sleep is an overlooked lifestyle factor in relation to fruit and vegetable consumption and more notice is vital. Further studies are required to clarify the underlying mechanisms for these associations.

**Keywords:** Sleep, Fruits and vegetables, Nutritional epidemiology

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## Background

Increased consumption of fruits and vegetables protect against diabetes (Muraki et al. 2013), coronary heart disease (He et al. 2007), stroke (Dauchet et al. 2005; He et al. 2006; Hu et al. 2014) and some cancers (World Cancer Research Fund/American Insitute for Cancer Research 2007) . The World Health Organization recommends consuming 400 g or more of fruits and vegetables per day to improve overall health and reduce the risk of chronic diseases (WHO 2003). Recent evidence from a dose-response meta-analysis of prospective studies suggest that the consumption of 800 g per day (10 portions per day) of fruits and vegetables are associated with lower risks of cardiovascular disease, cancer and all-cause mortality (Aune et al. 2016). Despite these studies, fruit and vegetable consumption remain below the recommended levels (5 portions per day) in the UK (National Diet and Nutrition Survey Results 2014; National Diet and Nutrition Survey Results 2018) and a substantial burden of disease globally is attributable to low consumption (Aune et al 2016). Consequently, identifying lifestyle factors, which may influence fruit and vegetable intakes, is a public health priority.

Epidemiological studies have shown that short sleep duration is associated with hypertension (Stranges et al. 2010), type 2 diabetes (Chaput et al. 2007), cardiovascular disease (Cappuccio et al. 2011) all-cause mortality (Cappuccio et al. 2010; Yin et al. 2017) and a 45% increased risk of obesity compared to normal sleep duration (Wu et al. 2014). These associations may be mediated through changes in dietary intake including fruits and vegetables (Dashti et al. 2015a). Several studies have explored the relationship between sleep duration and/or quality and dietary intake in children (Westerlund et al. 2009; Moreira et al. 2010; Shi et al. 2010) and adolescents (Garaulet et al. 2011; Golley et al. 2013; Beebe et al. 2013; Kruger et al. 2014). Shorter sleep duration was associated with higher consumption of energy-rich foods than nutrient dense foods which were fruits and vegetables measured by a food frequency questionnaire in 10–11 years old children (Westerlund et al. 2009). Similarly, longer sleep duration were positively associated with dietary patterns that included fruits and vegetables in Portuguese children aged 5–10 years old (Moreira et al. 2010). In European adolescents, short sleepers (< 8 h/d) consumed less fruits and vegetables compared to those who slept ≥8 h/d (Garaulet et al. 2011). Using cross-sectional data from the National Longitudinal Study of Adolescent Health ($n$ = 13,284), short sleep duration (< 7 h/night) was associated with reduced odds of fruit and vegetable consumption compared with the recommended sleep duration (> 8 h/night) (OR 0·66, $P$ < 0·001) (Kruger et al. 2014).

However, this relationship is different in adults due to dissimilar sleep requirements (Hirshkowitz et al. 2015). Few studies explored the relationship between sleep measures and fruit and vegetable intakes in adults (Adams and Colner 2008; Imaki et al. 2002; Tu et al. 2012) and no prospective study has been done to assess this association. In a retrospective study design, it has been reported that increased hours of sleep in American college students was a significant predictor for higher intakes of fruit and vegetable (Adams and Colner 2008). In a study involving 2000 Japanese workers, short sleepers (< 6 h) consumed fewer vegetables than those sleeping 6–9 h assessed by a dietary habit questionnaire (Imaki et al. 2002). Similar associations were identified in Chinese women from the Shanghai Women's Health Study (Tu et al. 2012) that assessed diet using a Food Frequency Questionnaire; in young female adults from Iran measured diet quality indices (Haghighatdoost et al. 2012); and in US adults that assessed fruit and vegetable consumption by average daily servings over the past month (Stamatakis and Brownson 2008). The previous studies have shown that sleep duration is associated with dietary intakes and may play an important role in the mediation of association between sleep and health among adults (St-Onge et al. 2018). Therefore, there is a need for more studies to assess the longitudinal associations between sleep duration and fruit and vegetable intakes using detailed dietary data (Dashti et al. 2015a; Frank et al. 2017).

The associations between sleep and dietary intake may be due to multifactorial mechanisms (Knutson et al. 2007; Patel and Hu 2008; Chaput 2014; Lundahl and Nelson 2015). These mechanisms include changes in appetite-related hormones ghrelin and leptin (Lundahl and Nelson 2015) due to lack/disrupted sleep that may increase the preference for energy-dense foods (Chaput 2014) leading to potentially lower intakes of fruit and vegetable. Experimental studies suggest that sleep restriction enhances hedonic stimulus processing in the brain and alters brain connectivity leading to food reward, food craving and affecting food decisions (St-Onge et al. 2014). The enhanced reward mechanism may mediate energy-dense food consumption leading to lower intakes of fruit and vegetable. These mechanisms have long-term effects on dietary intake (Frank et al. 2017) which contribute to weight-related outcomes, obesity (Wu et al. 2014) and other risk factors for the development of chronic diseases such as type 2 diabetes (Chaput et al. 2007) and cardiovascular disease (Cappuccio et al. 2011). Thus, exploring the prospective associations between sleep measures and fruit and vegetable intakes is essential.

Therefore, this study aims to explore both cross-sectional and prospective associations between sleep duration and fruit and vegetable intakes in women from the UK Women's Cohort Study (UKWCS). To our knowledge, we are the first to report on prospective associations between sleep duration and fruit and vegetable intakes in UK women. This study may clarify whether sleep duration is an attributable factor to low consumptions of fruits and vegetables. We hypothesized that short and long sleep would be associated with lower intakes of fruits and vegetables compared to recommended sleep duration (Tan et al. 2018).

## Materials and methods

### Study population

The UKWCS was established to explore links between diet and chronic diseases. Participants were taken from responders to the World Cancer Research Fund's direct mail survey including those living in England, Wales, Scotland and Northern Ireland. Ethical approval was granted at its initiation in 1993 (Research Ethics Committee reference number is 15/YH/0027). The National Research Ethics Committee for Yorkshire and the Humber, Leeds East has now taken on responsibility for the ongoing cohort. The cohort had two main contact phases; baseline (Phase 1) and follow-up (Phase 2) (Fig. 1). Baseline data was not used in this study since sleep duration was only measured in Phase 2. Phase 2 data (1999 to 2002) was obtained by re-contacting the whole cohort and 14,172 (40% of baseline) women aged 33–73 years completed a follow-up health and lifestyle questionnaire which included questions on sleep. A total of 12,453 women (88% of Phase 2 responders) also completed a 4-day food diary and a 1-day activity diary.

Cross-sectional analyses used Phase 2 data for the association between sleep duration and fruit and vegetable intakes. Fruit and vegetable biomarker data (vitamin C, α and β carotene and lycopene) also representing cross -sectional information, were used from the non-starch polysaccharide (NSP) intake and serum micronutrient concentrations sub-study conducted during the same period of Phase 2 data collection. The NSP sub-study investigated the associations between NSP intakes and plasma micronutrients in 283 women. NSP fiber and micronutrient intakes were assessed by 4-day food diaries and blood samples were taken and analyzed for plasma micronutrient concentrations including carotenoids, vitamin A, vitamin E, thiamine, riboflavin, vitamin B6, vitamin B12, folic acid, and vitamin C and trace metals. The study is described in detail elsewhere (Cade et al. 2015; Greenwood et al. 2004).

Prospective data were provided from a follow up sub-study (Snacking Study) (Cade et al. 2015). After ~4 years of Phase 2 (2006), the Snacking sub-study contacted 3596 women from Phase 2 respondents for whom we had not received a notification of death, who had completed a food diary and for whom we had previously captured total eating frequency. A total of 2253 women responded and

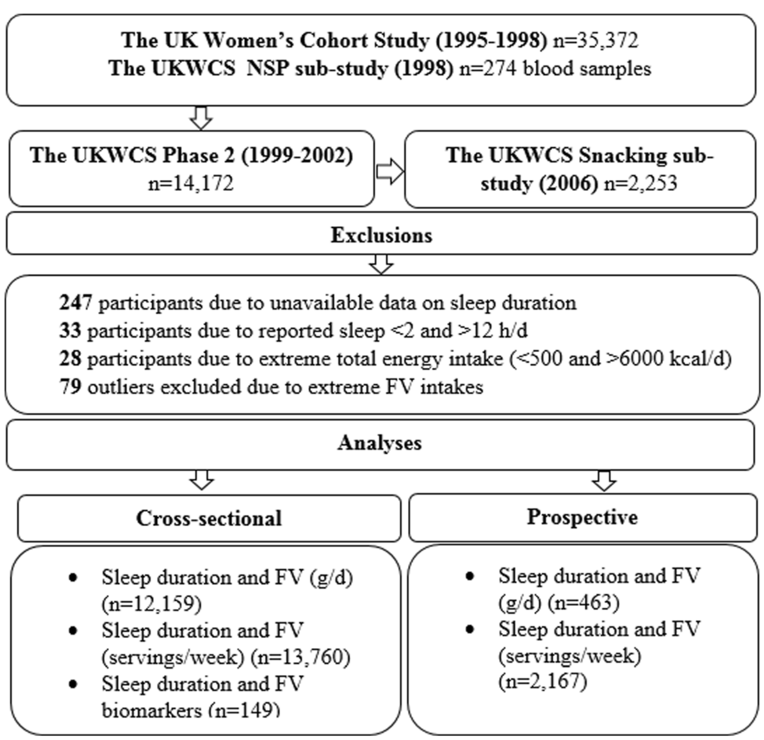


**Fig. 1** Participants' flow chart. Legend: UKWCS (The UK Women's Cohort Study), NSP (non-starch polysaccharide), h (hours), d (day), g (grams)

completed a questionnaire to explore snacking habits with a further 4-day food diary. Sleep duration data from Phase 2 was used as an exposure and fruit and vegetable intake data from the Snacking sub-study was used as an outcome in this prospective analyses.

### Sleep duration

Participants were asked about sleep duration in two separate questions in the following form;

"*On an average weekday how is your day spent?*"

"*On an average weekend how is your day spent?*"

Participants were asked to record number of hours and/or minutes that were spent sleeping in an average weekday and weekend (see Additional file 1: Figure S1). Two separate variables were generated for sleep duration based on weekdays and weekends for all women. Average sleep duration for weekdays and weekends was calculated using the following equation ((minutes slept during the week* 5) + (minutes slept during weekends *2))/7 (Noorwali et al. 2018). Sleep duration was categorized to Short Sleepers (SS) (≤6 h/day (≤360 min)), Recommended Sleepers (RS) (7-h/day (> 360 min and < 540 min) and Long Sleepers (LS) (≥9 h/day (≥540 min)). Sleep duration was used as the exposure variable in both cross-sectional and prospective analyses.

### Dietary records

Participants from both the Phase 2 follow up and the Snacking sub-study listed all drinks and foods consumed over 4 days. They were asked to start on a particular day (Friday, Saturday or Sunday) to obtain a range of days of the week. Participants recorded homemade recipes, foods consumed away from home or takeaways and supplement intake. Food records were coded using the Diet and Nutrition Tool for Evaluation (DANTE) (Dahm et al. 2010) that contained standard nutrient intakes from *McCance & Widdowson's The Composition of Foods* (5th Edition) (Holland et al. 1991) supplementary information from food manufacturers, food labels and homemade recipes. DANTE also contained typical portion sizes for each food derived from *Food Portion Sizes* (Crawley 1993). Total grams of fruit and vegetable per day were obtained from the 4-day food diaries in Phase 2 which was used in the cross-sectional analyses. For prospective analyses, total grams/day of fruit and vegetable intakes were obtained from the 4-day food diaries from the follow-up Snacking sub-study.

Participants were asked in the health and lifestyle questionnaire in Phase 2 and the Snacking sub-study "How many servings of fruit/vegetables or dishes containing fruit/vegetables do you usually eat in an average week?" which were used to obtain servings/week of fruits and vegetables. Total servings/week of fruits and vegetables were the sum of fruits and vegetables. Non-response to fruit and vegetable intakes in the 4-day food diaries and the question in the health and lifestyle questionnaire were taken as missing data.

### Biomarkers

Carotenoids and vitamin C levels were measured in the NSP intake and serum micronutrient concentrations sub-study (Greenwood et al. 2004). We have chosen these biomarkers based on previous studies that detected their strong correlation with fruit and vegetable consumption (Al-Delaimy et al. 2005; Souverein et al. 2015). Blood was collected at home after an overnight fast. Samples were collected into lithium heparin (8 ml) for carotenoids (α and β-carotene and lycopene) and total vitamin C analysis. Samples were kept cool, separated and prepared for storage at − 70 °C within 2 h of collection. All blood analyses were undertaken in the Division of Pathological Sciences, Department of Clinical Medicine, at the University of Leeds. Antioxidant vitamins were analyzed by high-performance liquid chromatography as previously described (Thurnham et al. 1988).

### Phase 2 characteristics

Age, height, weight, medical history, illness history, smoking habits, alcohol consumption frequency and number of children were self-reported. Supplement usage was identified by asking whether participants took any vitamins, minerals, fish oils, fibre or other food supplements. Participants also self-reported their status regarding vegetarian and vegan diets. Physical activity levels were self-reported by asking which activity class best describes their weekly activity (no weekly physical activity, light/moderate physical activity in most weeks, vigorous activity for at least 20 min once or twice a week and vigorous activity at least 20 min three or more times per week). Classification of socio-economic status (SES) was undertaken based on occupation, according to the United Kingdom National Statistics-Socio-Economic Classification (NS-SEC), where women are divided into the following categories (never had a paid job, managers and administrators, professional, technical and associate professional, clerical and secretarial, craft and skilled, personal and protective, sales, plant and machine operatives and other) (The National Statistics Socio-economic Classification User Manual 2005). Socio-demographic information such as marital status was determined by self-report questions asking for marital status (married or living as married, divorced, single, widowed, separated).

## Statistical analyses

Descriptive statistics such as means and proportions described women from the UKWCS according to sleep duration categories. $P$ values of $< 0.05$ represent statistical significance. Multiple linear regression analysis was used to assess the relationship between categorical sleep duration and fruit and vegetable intakes in both cross-sectional (data are from Phase 2 and biomarker data are from the NSP sub-study) and prospective analyses (sleep duration data from Phase 2 and fruit and vegetable intake data from the Snacking sub-study). Model 1 included adjustment for age only whereas model 2 was adjusted for potential confounders, identified using a directed acyclic graph. These variables were age, socio-economic status (SES) based on Office of National Statistics Classification of Occupations (The National Statistics Socio-economic classification n.d.), smoking (Zhang et al. 2006; Jaehne et al. 2012; Lohse et al. 2016; Palaniappan et al. 2001) (yes, no), ethnicity (Grandner et al. 2013; Bei et al. 2016) (white, non-white) and total energy intake. We did not feel that there was sufficient experimental evidence that alcohol intake independently influences fruit and vegetable consumption to include alcohol intake as an adjustment. For the same reason we did not adjust for physical activity as there is not sufficient evidence that it independently influences sleep duration and fruit and vegetable consumption.

We used restricted cubic splines to model potential cross-sectional and prospective non-linear relationships between sleep duration as a continuous exposure (h/day) and total fruit and vegetable intakes as the outcomes (g/d). Cross-sectional, prospective and biomarker splines comprised of 2 polynomial segments separated by 3 knots (at the following percentiles of sleep duration 10, 50 and 90 as recommended by Harrell (Harrell 2001) with linear regions before the first knot and after the last). $P$ values $> 0.05$ indicate linearity and $< 0.05$ indicate non-linearity.

Sensitivity analyses were conducted in the cross-sectional analyses only, due to the smaller number of participants in the prospective analyses. Sensitivity analyses included considering weekdays and weekends separately. Further sensitivity analyses were conducted separately after 1) excluding participants who consumed vitamins, minerals or/and food supplements over the last year, 2) those who self-reported currently having a longstanding illness 3) those taking prescribed medicines; 4) excluding women who self-reported being vegan or vegetarian; 5) BMI was adjusted for in addition to the potential confounders in model 2 as a further sensitivity analysis. Statistical analyses were conducted using IC Stata 14.2 statistical software (StataCorp 2015).

## Results

Cohort participants who did not provide information on sleep duration ($n = 247$) were excluded (Fig. 1). Participants who reported sleep duration < 2 or > 12 h/day ($n = 33$) were outliers given that adults normally sleep 6–9 h/day and sleeping < 2 or > 12 h/day could indicate illness or an irregular schedule therefore, they were excluded. Participants with extreme total energy intakes (< 500 and > 6000 kcal/day) were excluded from the analyses to minimize errors from under- and over-estimation of intakes ($n = 28$). Outliers were excluded by removing those who had extreme fruit and vegetable intakes (> 1600 g/d) ($n = 20$) from the 4-day food diaries, (> 50 servings/week) from the health and lifestyle questionnaire ($n = 48$) in Phase 2 and the Snacking sub-study ($n = 11$). The total number of participants in cross-sectional and prospective analyses are shown in Fig. 1. A total of 12,159 participants in the cross-sectional analyses between sleep duration and fruit and vegetable intakes (grams/day) and 13,760 for fruit and vegetable intakes (servings/week) were included in the analyses. For prospective analyses, 2167 participants were included for fruit and vegetable intakes (servings/week) and 463participants for fruit and vegetable intakes (grams/day).

## Cohort characteristics

The general characteristics of women included from Phase 2 from the UKWCS according to sleep duration category are shown in Table 1 ($n = 13,925$) with a mean age of 52 years (95% CI 52 to 53) and a mean BMI of 24.1(95% CI 24.1 to 24.2). Ten percent of the women ($n = 1403$) were SS, 81% ($n = 11,292$) of the women were RS and 9% ($n = 1230$) of the women were LS. In total, 99% of the women were white (95% CI 98 to 99), 76% (95% CI 75 to 77) of them were married, 8% (95% CI 7 to 8) of the women reported that they smoke and 32% (95% CI 31 to 33) self-reported being vegetarian or vegan. RS had the highest intakes of fruit and vegetable (g/day) compared to SS and LS. RS had a mean intake of 451 g/d (95% CI 447 to 455) compared to SS who had a mean intake of 430 g/d (95% CI 417 to 442) and LS had a mean intake of 421 g/d (95% CI 409 to 433).

The differences in characteristics between Phase 2 women and Snacking sub-study women are shown in (Additional file 1: Table S1). Women from Phase 2 had a mean age of 52 years whereas women from the Snacking sub-study had a mean age of 51 years ($p < 0.001$). In addition, Phase 2 women had a higher BMI (24.2 kg/m$^2$) than women from the Snacking sub-study (23.6 kg/m$^2$) ($p < 0.001$). Phase 2 women consumed less grams/day of fruit (225 g/day) compared with Snacking sub-study women who consumed (265 g/day) ($p < 0.001$) and less grams/day of vegetables (215 g/day) compared with women from the Snacking sub-study who consumed (234 g/day) ($P < 0.001$). Phase 2 women consumed less grams/day of total fruits and vegetables (435 g/day) compared with Snacking sub-study women who consumed

**Table 1** General characteristics of women from the UKWCS according to sleep duration category

| Characteristics | ≤6 h/day (SS) | Sleep Categories 7-9 h/day (RS) | ≥ 9 h/day (LS) | Total |
|---|---|---|---|---|
| Observations (n) | 1403 | 11,292 | 1230 | 13,925 |
| | Mean (95% CI) | Mean (95% CI) | Mean (95% CI) | Mean (95% CI) |
| Age (years) | 55 (54,55) | 51 (51,52) | 54 (53,54) | 52 (52,53) |
| BMI (kg/m$^2$) | 24.7 (24.5,24.9) | 24.0 (23.9,24.1) | 24.8 (24.6,25.1) | 24.1 (24.1,24.2) |
| Fruit (g/d) | 229 (220,238) | 235 (232, 238) | 217 (208,226) | 232 (229,234) |
| Vegetables (g/d) | 209 (202,215) | 222 (219,224) | 208 (202, 215) | 218 (216,220) |
| Total fruits and vegetables (g/d) | 430 (417,442) | 451 (447,455) | 421 (409,433) | 445 (441,448) |
| Total energy intake (kcal/d) | 2329 (2289,2368) | 2371 (2359,2384) | 2331 (2293,2368) | 2362 (2351,2374) |
| | % (95%CI) | % (95%CI) | % (95%CI) | % (95%CI) |
| Alcohol consumption frequency (once a week or more) | 39 (37,42) | 47 (46,48) | 37 (34,40) | 46 (45, 46) |
| Has longstanding illness (yes) | 33 (31,36) | 25 (24,25) | 29 (27,32) | 26 (25,27) |
| Taking prescribed medicine (yes) | 40 (37,42) | 29 (28, 30) | 40 (37,43) | 31 (30, 32) |
| Smoking (yes) | 10 (9,12) | 8 (7,8) | 8 (6, 9) | 8 (7, 8) |
| Vitamins, minerals, food supplements (yes) | 63 (61,66) | 59 (58, 60) | 57 (54,60) | 60 (59, 61) |
| Vegetarian or vegan(yes) | 33 (30,36) | 32 (31, 33) | 28 (25,31) | 32 (31, 33) |
| Ethnicity (white) | 98 (97, 98) | 98 (98, 99) | 99 (98,99) | 99 (98, 99) |
| Employer (employed) | 47 (45,50) | 62 (61,63) | 45 (43,48) | 59 (58,60) |
| Socio-economic status (professional) | 21 (19,23) | 28 (27,29) | 26 (24,29) | 28 (27,28) |
| Physical activity (light/moderate) | 49 (46,52) | 49 (48,50) | 56 (53,59) | 50 (48,50) |
| Marital status (married or living as married) | 68 (65,70) | 77 (76, 78) | 77 (75,80) | 76 (75,77) |
| Number of children (2 children) | 48 (45, 51) | 51 (50,52) | 50 (47,53) | 50 (49, 51) |

*BMI* body mass index, *CI* Confidence interval, *d* day, *g* gram, *kg* kilogram, *LS* long sleepers, *m* metre, *n* number, *RS* recommended sleepers, *SS* short sleepers

(492 g/day) ($p < 0.001$). This may be due to the self-report of 29% ($n = 3498$) of women in Phase 2 being vegetarian or vegan compared with 47% ($n = 1043$) of women in the Snacking sub-study ($p < 0.001$). Other characteristics that were significantly different between Phase 2 women and Snacking sub-study women included long-term illness, smoking, supplement intake, employment and physical activity that are shown in (Additional file 1: Table S1).

### Cross-sectional analyses between sleep duration and fruit and vegetable intakes

In cross-sectional analyses (model 1) (Table 2), SS had on average 8 g/d (95% CI -18 to 0.8, $p = 0.07$) less fruit, 10 g/d (95% CI -17 to − 3, $p = 0.003$) less vegetables and 23 g/d less of total fruits and vegetables (95% CI -36 to − 10, $p < 0.001$) compared with RS. LS had on average 18 g/d less of fruits (95% CI -28 to − 8, $p < 0.001$), 12 g/d less of vegetables (95% CI -19 to − 4, $p = 0.001$) and 30 g/d (95% CI -43 to − 17, $p < 0.001$) less of total fruits and vegetables reported in the food diaries compared to RS. The questionnaire data showed that SS had on average 0.7 serving/week less (95% CI -1 to − 0.3, $p = 0.001$) of fruit, 0.4 serving/week less of vegetables (95% CI -0.8 to-0.01, $p = 0.04$) and 1 serving/week less (95% CI -1 to − 0.5, $p = 0.001$) of total fruits and vegetables compared with RS. LS had on average 1 serving/week less (95% CI -1 to − 0.6, $p < 0.001$) of fruit, 0.04 serving/week less of vegetables (95% CI-0.8,-0.01$p = 0.05$) and 1 serving/week less (95% CI -2 to − 0.9, $p < 0.001$) of total fruits and vegetables.

In the fully adjusted cross-sectional analyses (model 2) (Table 2), the food diaries data showed SS had on average 5 g/d (95% CI -15 to 4, $p = 0.2$) less of fruits, 8 g/d (95% CI -15 to − 1, $p = 0.01$) less of vegetables and 17 g/d (95% CI -30 to − 4, $p = 0.01$) less of total fruits and vegetables compared to RS. LS had on average 15 g/d less of fruit (95% CI -25 to − 5, $p = 0.003$), 11 g/d (95% CI -18 to − 3, p = 0.003) less vegetables and 25 g/d less of total fruits and vegetables (95% CI -39 to − 12, $p < 0.001$) compared to RS. The questionnaire data showed SS had 0.4 serving/week less (95% CI -0.8 to − 0.02, $p = 0.04$) of fruits and 0.07 serving/week less (95% CI -1 to − 0.08, $p = 0.02$) of total fruits and vegetables compared with RS.LS had on average 1 serving/week less (95% CI -1 to − 0.5, $p < 0.001$) of fruit and 1

**Table 2** Cross-sectional associations between sleep duration categories and FV intakes of women from the UKWCS

Short sleepers (≤6 h/d) and Long sleepers (≥9 h/d) compared to the recommended group (7–9 h/d)

| Models | Model 1 | | | | | | Model 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sleep categories | ≤ 6 h/d sleep Mean difference (95% CI) | *P* value | ≥9 h/d sleep Mean difference (95% CI) | *P* value | *n* | Overall *P* value* | ≤6 h/d sleep Mean difference (95% CI) | *P* value | ≥9 h/d sleep Mean difference (95% CI) | *P* value | *n* | Overall *P* value* |
| Fruits and vegetables (grams/day)[a] | | | | | | | | | | | | |
| Fruits | -8 (− 18,0.8) | 0.07 | -18 (−28, − 8) | < 0.001 | 11,972 | < 0.001 | -5 (− 15, 4) | 0.2 | − 15 (− 25, − 5) | 0.003 | 11,571 | 0.009 |
| Vegetables | − 10 (− 17,-3) | 0.003 | − 12 (− 19,-4) | 0.001 | 12,148 | < 0.001 | −8 (− 15,-1) | 0.01 | −11 (− 18, − 3) | 0.003 | 11,738 | 0.001 |
| Total FV | −23 (− 36,-10) | < 0.001 | − 30 (− 43, − 17) | < 0.001 | 12,159 | < 0.001 | −17 (− 30,-4) | 0.01 | − 25 (− 39, − 12) | < 0.001 | 11,749 | < 0.001 |
| Fruits and vegetables (servings/week)[b] | | | | | | | | | | | | |
| Fruits | − 0.7 (− 1, − 0.3) | 0.001 | −1 (− 1, − 0.6) | < 0.001 | 13,623 | < 0.001 | − 0.4 (− 0.8,-0.02) | 0.04 | −1 (− 1, − 0.5) | < 0.001 | 13,127 | < 0.001 |
| Vegetables | − 0.4 (− 0.8, − 0.01) | 0.04 | − 0.4 (− 0.8, − 0.01) | 0.05 | 13,660 | 0.03 | − 0.3 (− 0.7, 0.1) | 0.1 | −0.3 (− 0.8, 0.07) | 0.1 | 13,164 | 0.1 |
| Total FV | −1 (− 1, − 0.5) | 0.001 | −1 (− 2, − 0.9) | < 0.001 | 13,760 | < 0.001 | −0.7 (− 1,-0.08) | 0.02 | −1 (− 2, − 0.6) | < 0.001 | 13,260 | < 0.001 |
| Fruit and vegetable biomarkers | | | | | | | | | | | | |
| Vitamin C (μg/ml) | −3 (− 6,-1) | 0.003 | 2 (− 0.03,4) | 0.05 | 149 | 0.001 | −4 (−6,-1) | 0.003 | 1 (− 0.4,4) | 0.1 | 145 | 0.001 |
| α-carotene (nmol/l) | −86 (− 191,19) | 0.1 | −54 (−144,36) | 0.2 | 149 | 0.1 | −104 (− 219, 9) | 0.07 | −51 (− 150,47) | 0.3 | 145 | 0.1 |
| β-carotene (nmol/l) | − 120 (− 542, 302) | 0.5 | 177 (− 181,536) | 0.3 | 149 | 0.5 | −120 (− 580,340) | 0.6 | 118 (− 278, 515) | 0.5 | 145 | 0.7 |
| Lycopene (nmol/l) | −56 (− 223,111) | 0.5 | 113 (− 29,255) | 0.1 | 148 | 0.2 | −83 (− 254, 86) | 0.3 | 107 (− 39,254) | 0.1 | 144 | 0.1 |

Model 1 adjusted for age
Model 2 adjusted for age, socio-economic status, smoking, ethnicity and total energy intake
*CI* confidence interval, *d* day, *FV* fruits and vegetables, *G* gram, *h* hours, *n* number
*P value for differences between sleep duration categories
[a]obtained from 4-day food diary
[b]obtained from health and lifestyle questionnaire

serving/week less (95% CI-2 to − 0.6, $p < 0.001$) of total fruits and vegetables compared with RS.

There was no evidence of association between sleep duration and fruit and vegetable biomarker concentrations except for plasma vitamin C that was 4 μg/ml (95% CI -6 to − 1, $p = 0.003$) lower in short sleepers compared with RS. However, there was a non-linear relationship between sleep duration and plasma vitamin C ($p = 0.02$) with women sleeping 7–9 h/d having the highest levels compared to SS and LS (Additional file 1: Figure S2A). Borderline linearity ($p = 0.05$) was shown between sleep duration and plasma α-carotene (Additional file 1: Figure S2B) and linear associations with plasma β-carotene (Additional file 1: Figure S2C) ($p = 0.2$) and lycopene (Additional file 1: Figure S2D) ($p = 0.8$). Fruit (g/d and servings/week) intakes, vegetable intakes (g/d) and total fruit and vegetable intakes (g/d and servings/week) differed by sleep duration categories.

### Prospective analyses between sleep duration and fruit and vegetable intakes

In prospective analyses (model 1) (Table 3), SS had on average 47 g/d less of fruit (95% CI -88 to − 5, $p = 0.02$), 44 g/d less of vegetables (95% CI -76 to − 12, $p = 0.006$) and 98 g/d less of total fruits and vegetables (95% CI -155 to − 41, $p = 0.001$) reported in the food diaries compared with RS. LS had on average 8 g/d less of fruit (95% CI -56 to 38, $p = 0.7$), 9 g/d less of vegetables (95% CI -46 to 26, $p = 0.5$) and 21 g/d less of total fruits and vegetables (95% CI -87 to 44, $p = 0.5$). The questionnaire data showed that LS had on average 1 serving/week less of fruit (95% CI -3 to − 0.2, $p = 0.02$), 0.6 serving/week less of vegetables (95% CI -2 to 0.8, $p = 0.4$) and 1 serving/week less of total fruits and vegetables (95% CI-3 to − 0.7, $p = 0.06$) compared with RS.

In fully adjusted prospective analyses (model 2) (Table 3), SS had on average 33 g/d less of fruits (95% CI -76 to 9, $p = 0.1$), 44 g/d less of vegetables (95% CI -77 to − 11, $p = 0.008$) and 85 g/d less of total fruits and vegetables (95% CI -144 to − 26, $p = 0.005$) compared with RS from the food diaries. LS had on average 5 g/d less of fruit (95% CI -55 to 44, $p = 0.8$), 22 g/d less of vegetables (95% CI -60 to 15, $p = 0.2$) and 30 g/d less of total fruits and vegetables (95% CI -98 to 38, $p = 0.3$). The questionnaire data showed that LS had on average 1 serving/week less of fruits (95% CI -2 to − 0.02, $p = 0.05$), 0.7 serving/week less of vegetables (95% CI -2 to 0.8, $p = 0.3$) and 2 servings/week less of total fruits and vegetables (95% CI -4 to − 0.2, $p = 0.07$) compared with RS. Total fruit and vegetable intakes (g/d) differed by sleep duration categories.

Restricted cubic spline modelling showed that the cross-sectional (Fig. 2a) ($p < 0.001$) and prospective (Fig. 2b) ($p = 0.001$) associations between sleep duration and total fruit and vegetable intakes (g/d) were non-linear with women sleeping 7–9 h/d having the highest intakes of total fruits and vegetables compared to SS and LS.

### Sensitivity analyses

Sensitivity analyses showed broadly similar results (Additional file 1: Tables S2-S7). After excluding supplement users ($n = 7776$) (Additional file 1: Table S2), LS had 14 g/d less of fruit (95% CI -28 to − 0.5, $p = 0.04$), 21 g/d less of vegetables (95% CI -31 to − 10, $p < 0.001$) and 33 g/d less of total fruits and vegetables (95% CI -53 to − 14, $p = 0.001$) compared with RS. In addition, LS had on average 1 serving/week less of fruit (95% CI -1 to − 0.5, $p < 0.001$), 0.8 serving/week less of vegetables (95% CI -1 to − 0.1, $p = 0.01$) and 1 serving/week less of total fruits and vegetables (95% CI -3 to − 0.9, $p < 0.001$) compared with RS. No significant difference between SS and RS was observed and fruit, vegetable and total fruit and vegetable intakes (g/d and servings/week) differed between sleep duration categories (Additional file 1: Table S2). After excluding participants who reported being vegan or/and vegetarian ($n = 4541$) (Additional file 1: Table S3), SS had on average 10 g/d less of vegetables (95% CI-18 to − 2, $p = 0.008$) and 17 g/d less of total fruits and vegetables (95% CI -32 to − 2, $p = 0.02$). LS had on average 12 g/d less of fruit (95% CI -23 to − 1, $p = 0.02$), 10 g/d less of vegetables (95% CI -18 to − 3, $p = 0.007$) and 24 g/d less of total fruits and vegetables (95% CI -39 to − 9, $p = 0.001$) compared with RS. Similar results were shown for questionnaire data and total fruit and vegetable intakes (g/d and servings/week) differed between sleep duration categories. Similar results were observed after separately excluding women who reported having a longstanding illness ($n = 3753$) (Additional file 1: Table S4), those who reported long term treatments for illness ($n = 4252$) (Additional file 1: Table S5) and after including adjustment for BMI in the fully adjusted model (Additional file 1: Table S6). After considering sleep duration separately on weekdays and weekends (Additional file 1: Table S7), SS had 13 g/d less of total fruits and vegetables on weekdays (95% CI -25 to − 0.9, $p = 0.03$). LS on weekdays had 18 g/d less of fruit (95% CI -23 to − 8, $p < 0.001$), 10 g/d less of vegetables (95% CI -18 to − 3, $p = 0.003$) and 29 g/d less of total fruits and vegetables (95% CI -42 to − 16, $p < 0.001$). Similar results were shown for the questionnaire data. Weekend sleep duration categories showed that LS had on average 16 g/d less of fruits (95% CI -23 to − 9, $p < 0.001$), 9 g/d less of vegetables (95% CI -14 to − 4, $p < 0.001$) and 26 g/d less of total fruits and vegetables (95% CI -36 to − 17, $p < 0.001$). No difference was observed in fruit and vegetable intakes between SS and RS on weekend days.

## Discussion

This study is the first to report both cross-sectional and prospective associations between sleep duration and fruit and vegetable intakes in middle-aged UK women. The results were consistent in cross-sectional and prospective associations with SS and LS having fewer grams and servings of fruits and vegetables compared with RS. No

**Table 3** Prospective associations between sleep duration categories and FV intakes of women from the UKWCS

Short sleepers (≤6 h/d) and Long sleepers (≥9 h/d) compared to the recommended group (7–9 h/d)

| Models | Model 1 | | | | | | Model 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ≤6 h/d sleep Mean difference (95% CI) | *P* value | ≥9 h/d sleep Mean difference (95% CI) | *P* value | *n* | Overall *P* value* | ≤6 h/d sleep Mean difference (95% CI) | *P* value | ≥9 h/d sleep Mean difference (95% CI) | *P* value | *n* | Overall *P* value* |
| Fruits and vegetables (grams/day)[a] | | | | | | | | | | | | |
| Fruits | − 47 (− 88,-5) | 0.02 | − 8 (− 56, 38) | 0.7 | 454 | 0.08 | − 33 (− 76,9) | 0.1 | −5 (− 55, 44) | 0.8 | 440 | 0.3 |
| Vegetables | −44 (−76,-12) | 0.006 | −9 (− 46,26) | 0.5 | 462 | 0.02 | −44 (−77,-11) | 0.008 | −22 (−60,15) | 0.2 | 448 | 0.01 |
| Total FV | −98 (−155,-41) | 0.001 | −21 (−87,44) | 0.5 | 463 | 0.003 | −85 (−144,-26) | 0.005 | −30 (−98,38) | 0.3 | 449 | 0.01 |
| Fruits and vegetables(servings/week)[b] | | | | | | | | | | | | |
| Fruits | − 0.6 (− 2, 0.6) | 0.3 | − 1 (− 3,-0.2) | 0.02 | 2162 | 0.05 | − 0.4 (− 1, 0.8) | 0.5 | −1 (− 2,0.02) | 0.05 | 2087 | 0.1 |
| Vegetables | −0.6 (−1, 0.7) | 0.3 | –-0.6 (− 2,0.8) | 0.4 | 2169 | 0.5 | − 0.4 (− 1, 0.9) | 0.5 | − 0.7 (− −2, 0.8) | 0.3 | 2094 | 0.5 |
| Total FV | −1 (−3, 0.7) | 0.2 | −2 (− 4,0.1) | 0.06 | 2167 | 0.1 | −0.9 (−3, 1) | 0.3 | − 2 (− 4, 0.2) | 0.07 | 2092 | 0.1 |

Model 1 adjusted for age

Model 2 adjusted for age, socio-economic status, smoking, ethnicity and total energy intake

*CI* confidence interval, *d* day, *FV* fruits and vegetables, *G* gram, *h* hours, *n* number

***P value for differences between sleep duration categories

[a]obtained from 4-day food diary

[b]obtained from health and lifestyle questionnaire

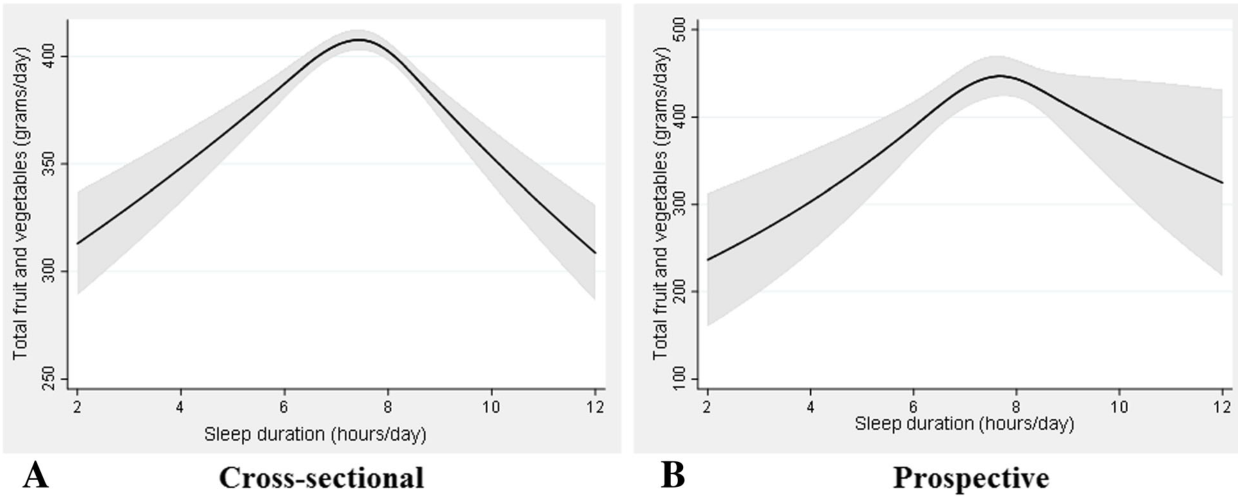


**Fig. 2** Associations between sleep duration and total FV intakes from the restricted cubic spline modelling. Legend: Black lines plot the predicted cross-sectional (**a**) and prospective (**b**) intakes of total fruit and vegetable values with 95% confidence intervals (grey shaded area) for all women from the UKWCS

associations were found between sleep duration and fruit and vegetable biomarkers except for plasma vitamin C that was lower in SS compared with RS (Table 2.). Fruit and vegetable intakes differed between sleep duration categories indicating that sleep duration may predict fruit and vegetable consumption. Although there is poor agreement between both assessment methods of fruit and vegetable intakes (4-day diaries and questionnaires) (Day et al. 2001) and dissimilar characteristics between women from Phase 2 and the Snacking Sub-study (Additional file 1: Table S1), the results remained consistent with SS and LS consuming less fruits and vegetables compared with RS providing consistency for the observed associations. The cross-sectional and prospective associations between sleep duration and fruit and vegetable intakes were significantly non-linear with RS having the highest intakes compared to SS and LS as confirmed by the restricted cubic spline modelling. These results were supported with the non-linear association between sleep duration and plasma vitamin C shown in the restricted cubic spline model (Additional file 1: Figure S2). Collectively, these findings suggest that among UK women RS have the highest intakes of fruits and vegetables compared to both SS and LS.

Our findings for UK women are in line with several cross-sectional studies from other countries (Xiao et al. 2016; Kim et al. 2011; Patterson et al. 2016; Mossavar-Rahmani et al. 2015). Among American women within 5 years of childbirth, LS (≥ 9 h) had lower quality diet, lower consumption of total fruit and whole fruit compared to adequate sleepers (Xiao et al. 2016). Similarly, a study of 27,983 women from the USA or Puerto Rico showed that women with long sleep durations (≥ 10 h) compared to shorter (< 6 h) were less likely to eat during conventional eating hours and more likely to snack which was related to lower intakes of fruit and vegetable (Kim et al. 2011). A cross-sectional study conducted with 439,933 adults in the UK Biobank project assessing fruit and vegetable intakes in the previous year by asking how many pieces of fresh fruit participants ate per day and how many heaped table-spoons of vegetables participants ate on average per day (Patterson et al. 2016) whereas, our study assessed fruit and vegetable intakes using the 4-day food diaries. Their results were consistent with some of the findings in this study; longer sleep duration (≥9 h) was negatively associated with daily fruit intake and positively associated with vegetable intake unlike our results that found an inverse u-shaped association in vegetable intake between sleep duration groups. Although the UKWCS does not represent the UK population, the results were consistent with our recent analyses conducted between sleep duration and fruit and vegetable intakes using the more recent National Diet and Nutrition Survey (NDNS) aiming to be representative of both men and women in the UK population (Noorwali et al. 2018). SS and LS had lower intakes of fruit and total fruit and vegetable (grams/day) compared with RS. The NDNS results showed SS having lower levels of plasma fruit and vegetable biomarkers compared with RS whereas this study only found lower levels of plasma vitamin C however, biomarker data ($n$ = 145) was low compared to the number of participants with 4 day diaries ($n$ = 12,159) and may be the reason of why no other associations were found between sleep duration and biomarkers. These results were supported by Beydoun et al. among US adults however, sleep measures were the outcomes (Beydoun et al. 2014). When SS (5–6 h) were compared to normal sleepers (7–8 h), total carotenoid concentration was linked to increased risk of short sleep.

Several cross-sectional studies reported low consumption of fruits and vegetables in SS only (Haghighatdoost et al. 2012; Stamatakis and Brownson 2008; Komada et al. 2017; Duke et al. 2017) whereas we also found lower fruit and vegetable intakes in LS. This might be explained by differences in methods of dietary assessment between studies such as food frequency questionnaires (Haghighatdoost et al. 2012), brief diet history questionnaire (Komada et al. 2017) or self-report of fruit and vegetable consumption in the previous month (Stamatakis and Brownson 2008; Duke et al. 2017). The UKWCS used a four-day food diary which is considered a better estimate of average intakes compared to other dietary assessment methods and was also used in the NDNS (Noorwali et al. 2018). Furthermore, different population characteristics such as sex, region (Nowakowski et al. 2013; Tang et al. 2017) and genes (Tang et al. 2017; Dashti et al. 2015b) need to be considered in comparison to the UKWCS results. Sex differences in sleep are mainly driven by biological factors and hormonal differences (Nowakowski et al. 2013). This study was conducted in middle-aged women only that may have undergone distinct hormonal and physical changes at specific time points such as puberty (Hagenauer et al. 2009), pregnancy (Hedman et al. 2002), menopause and menstrual cycle phase (LeRoux et al. 2014) that may have impacts on their sleep. However, it is important to note that our sample are more health conscious given the number of vegetarians and the professional socio-economic status as shown in the descriptive table (Table 1.) compared to the general population. Collectively, these conflicting results may be due to different categorization of sleep duration (Dashti et al. 2015a). Therefore, this study used the restricted cubic splines models with sleep duration as a continuous variable.

The prospective non-linear association in this study confirmed the cross-sectional non-linear association in the UKWCS and the NDNS (Noorwali et al. 2018) with RS having the highest intakes of fruit and vegetable compared with SS and LS. However, it is important to note that the presented study needs further confirmation due to the methodologies used in this study. Sleep duration was based on self-report and the dietary assessment method was not validated and does not represent a typical week. Larger prospective and interventional studies are required to support our results using objective assessment methods of sleep measures and a validated dietary assessment tool that represents a typical week (e.g. 7-day food diary) instead of 4 consequent days that included weekends which differ in dietary intakes compared to weekdays (Yang et al. 2014; An 2016) . In addition, further research is essential to understand the mechanisms underlying the association of RS having the highest intakes of fruit and vegetable.

Several mechanisms may underlie the association between SS and LS having low intakes of fruit and vegetable in this study (Dashti et al. 2015a; Chaput 2014; Lundahl and Nelson 2015; Tan et al. 2018), although not measured in this study. These mechanisms include hormonal (such as ghrelin and leptin) (Dashti et al. 2015a; Lundahl and Nelson 2015) and behavioral (Chaput 2014; Lundahl and Nelson 2015) (preference for energy dense foods) changes that lead to low intakes of fruits and vegetables. Recently, long sleep duration is proposed to impair energy metabolism and increase the risk of obesity and type 2 diabetes through possible mechanisms including poor sleep quality, sedentary lifestyle, unhealthy dietary choices and desynchrony between circadian and behavioral states related to exposure of evening artificial light that may delay circadian phase and sleep onset (Tan et al. 2018). Similarly, longer sleep durations have been associated with increased mortality and incident of cardiovascular disease in a dose-response meta-analyses (Jike et al. 2018) .

Several experimental sleep restriction studies in healthy adults (Markwald et al. 2013) and at risk of obesity adults (Tasali et al. 2014) reported lower fat and carbohydrate intake when transitioned from sleep restriction to adequate sleep (Markwald et al. 2013) and lower overall appetite and desire for energy-dense food when sleep was extended to 8.5 h for 2 weeks (Tasali et al. 2014). Additionally, a recent randomized controlled pilot study suggested the feasibility of sleep extension intervention in habitually SS free-living adults (Al Khatib et al. 2018). The results showed decreased intake of free sugars in the intervention group (4 weeks) compared to control which provides insight that sleep extension has an impact on dietary intakes. The previous experimental studies extended sleep duration to the recommended hours however, current evidence suggests that long sleep duration have similar effects on diet as lack of sleep (Frank et al. 2017; Tan et al. 2018) which was observed in the results of this study. It seems a public health message to increase sleep may not have the desired effect if adults sleeping the recommended hours move towards long sleep duration (Tan et al. 2018). Long-intervention studies comparing SS and LS with RS are required for a deeper understanding of the interactions between sleep and fruit and vegetable intakes. On the other hand, sleep is promoted by foods that have an impact on the availability of tryptophan and the synthesis of serotonin and melatonin (Peuhkuri et al. 2012). Some studies indicated that tart cherries (Pigeon et al. 2010) and kiwifruits (Lin et al. 2011) promote sleep due to their high content of antioxidants and serotonin providing insight to the relationship between sleep and diet being potentially bi-directional (Frank et al. 2017) .

According to The Sleep council, sleep duration have been declining with 70% of UK adults sleeping less than 7 h per night (The Great British bedtime report n.d.) and only 30% of UK adults met the 5-a-day recommendation according to Public Health England (National Diet and

Nutrition Survey Results from years 1, 2, 3 and 4 (combined) of the Rolling Programme (2008/2009–2011/2012) n.d.; National Diet and Nutrition Survey Results from years 7 and 8 (combined) of the Rolling Programme (2014/2015 to 2015/2016) n.d.). These trends highlight the importance of translating the scientific evidence focusing on the relationship between sleep and diet into practical messages that can help the public to prevent chronic diseases. More information on the integral relationship between sleep and diet may be included in national dietary guidelines for different populations to enhance healthy lifestyle recommendations. If our results are confirmed by interventional studies, the relationship between sleep and fruit and vegetable consumption can be incorporated in weight-loss programs and those that target improvement in overall health (Frank et al. 2017).

## Strengths and limitations

This study has several limitations that need to be considered when interpreting the results. Diet was assessed using 4-day food diaries starting on a particular day (Friday, Saturday or Sunday) to obtain a range of days of the week however, these days are not representative of a typical week. The self-report of sleep duration was based on memory which could lead to over-reporting (Lauderdale et al. 2008) and no questions regarding sleep disorders or parameters were included. Further limitations include lack of consideration of other factors of sleep that may have an impact on the relationship between sleep and fruit and vegetable intakes such as sleep quality (Katagiri et al. 2014; Hoefelmann et al. 2012), sleep timing (Golley et al. 2013) and chronotype (Bei et al. 2016; Patterson et al. 2016). Other factors include daytime and night time light exposure (Potter et al. 2016), shift work (Potter et al. 2016), daytime napping was also not considered in this study and seasonal variation (Allebrandt et al. 2014) that may affect sleep duration. The smaller number of participants in the prospective analyses was a further limitation. On the other hand, our analyses has several strengths. The UKWCS is a large prospective cohort which includes health-conscious women with a wide diversity in dietary intakes and a large number of participants were included in the cross-sectional analyses which facilitates in clarifying the associations between sleep duration and fruit and vegetable intakes. Furthermore, to our knowledge this is the first study that had investigated the prospective associations between sleep duration and fruit and vegetable intakes.

## Conclusion

Evidence from this study suggest that a sub-group of UK women sleeping the recommended 7–9 h/d had the highest intakes of fruit and vegetable compared with SS and LS indicating that sleep duration may predict the intake of fruits and vegetables. Our findings support the accumulating evidence showing an important contribution of sleep duration to dietary intake.

## Additional file

**Additional file 1:** Sensitivity analyses. (DOCX 712 kb)

### Abbreviations

d: Day; DANTE: Diet and Nutrition Tool for Evaluation; FV: Fruits and vegetables; g: Grams; h: Hours; LS: Long sleepers; NSP: Non-starch polysaccharide; RS: Recommended sleepers; SES: Socio-economic status; SS: Short sleepers; UKWCS: United Kingdom Women's Cohort study

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### Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

### Authors' contributions

EAN conceptualized and designed the study, curated data, analyzed the data, interpreted the results and wrote the manuscript. LJH had a role in the study design, interpretation of results and manuscript editing and revision. JEC had a role in the study design, interpretation of results and manuscript editing and revision. All authors read and approved the final manuscript.

### Ethics approval and consent to participate

Ethical approval was granted at its initiation in 1993 (Research Ethics Committee reference number is 15/YH/0027). The National Research Ethics Committee for Yorkshire and the Humber, Leeds East has now taken on responsibility for the ongoing cohort.

### Consent for publication

Not applicable.

### Competing interests

J.E.C. is a director of the University of Leeds spin out company Dietary Assessment.

## Publisher's Note



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