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Associations of dietary patterns with objective and subjective sleep duration and sleep quality in a population-based cohort study

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ABSTRACT

Objective: To examine cross-sectional and longitudinal associations of various types of dietary patterns with self-reported sleep quality and with actigraphy-estimated sleep parameters in the prospective, population-based Rotterdam Study.

Methods: For each participant, scores for five different dietary patterns were derived based on food frequency questionnaires; two pre-defined scores developed to estimate adherence to the Dutch dietary guidelines and to the Mediterranean diet; and three data-driven scores indicating a prudent, unhealthy and typical Dutch diet. In 2589 participants (median age 56.9 years; 58 % female), self-rated sleep quality was assessed with the Pittsburgh Sleep Quality Index. In 533 participants, actigraphs were worn for an average of 6.8 days (SD: 0.7) to estimate total sleep time, sleep onset latency, wake after sleep onset, and sleep efficiency. Sleep parameters were measured at baseline and 3–6 years later. Multiple linear regression was used to assess cross-sectional and longitudinal associations.

Results: No statistically significant associations between dietary patterns and total sleep time, sleep onset latency, wake after sleep onset, sleep efficiency and subjective sleep quality were observed in cross-sectional or longitudinal analyses. To illustrate, the effect estimate for sleep duration was 2.7 min per night (95 % CI -2.1, 7.5) per 5 point increase in Mediterranean diet score in the cross-sectional analyses. Furthermore, in longitudinal analyses, the effect estimate for sleep duration was −1.0 min per night (95 % CI -5.2, 3.1) per SD increase in the prudent diet.

Conclusions: Our results suggest that dietary patterns are not associated with sleep in this population-based cohort study.

Trial registration: Netherlands National Trial Register and WHO International Clinical Trials Registry Platform (ICTRP; https://apps.who.int/trialsearch/) shared catalogue number NL6645/NTR6831. Registered November 13th, 2017.

1. Introduction

Insufficient sleep duration and quality are both associated with poor mental health, an increased risk of obesity, cardiovascular diseases, diabetes, neurocognitive dysfunction, and premature mortality [1]. Adult people are recommended to sleep 7–9 h a night [2], yet approximately a quarter of the adult population generally sleeps less [3]. Besides sleep duration, it is important to consider other aspects of sleep such as sleep onset latency, wake after sleep onset, sleep efficiency, and sleep quality. This because sleep quality contributes to a better quality of life [4] and a poor sleep quality is also highly prevalent [3].

Several components of dietary intake are hypothesized to have beneficial effects on sleep. For example, literature shows that higher intake of fruit and vegetables could improve sleep due to their high polyphenols content [5]. These polyphenols are hypothesized to improve sleep through the gut-brain axis and clock gene expression [5]. Also foods with a high tryptophan content, such as dairy products, legumes, nuts and seeds are hypothesized to improve sleep, as tryptophan

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can be synthesized into melatonin [6]. Although the effects of specific dietary components may be small, these separate components combined in healthy dietary patterns could potentially be beneficial for sleep. This raises the question of how overall dietary patterns are associated with sleep outcomes.

Previous research indicated that dietary patterns are associated with sleep duration and/or quality. To illustrate, fifteen of the sixteen observational studies of a recent literature review indicated that better adherence to a Mediterranean diet was associated with better subjective sleep duration and/or quality [7]. Some of these studies suggested that this association was only present in participants younger than 75 years old [8] or only in women [9]. Furthermore, as most of these studies only used one single score to measure dietary patterns, no dietary patterns could be compared within studies.

It should be noted that most studies examining the association between dietary patterns and sleep relied on self-reported subjective sleep measurements. However, objective and subjective sleep measurements can differ [10,11]. In general, people tend to overestimate their sleep duration compared to actigraphy-estimated sleep duration [12,13]. This over-estimation was found to be more extreme for people without obesity compared to people with obesity [12]. As obesity is related to unhealthy dietary patterns, this differential measurement error can lead to bias in the association between dietary patterns and sleep. Therefore, more research is needed to examine the association between dietary patterns and sleep outcomes using objective sleep measurements.

So far, only four observational studies examined the association between dietary patterns and sleep using objective sleep measurements. All four studies were cross-sectional and could therefore not assess the temporal relationship between diet and sleep. Two of these studies found an association between a healthier dietary pattern with sleep onset latency [14] or sleep duration [15] while the two other studies found no association [16,17]. Moreover, these studies included a selective population (i.e. only men or patients with obstructive sleep apnoea) [14,16] or only examined sleep duration while neglecting sleep quality [15,17]. Therefore, we comprehensively examined if different types of dietary patterns are associated with both actigraphy-estimated and self-reported sleep duration and quality in a population-based sample of middle-aged and elderly persons in cross-sectional and longitudinal analyses.

2. Materials and methods

2.1. Study design and study population

This study was conducted and reported according to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [18]. For this study, we used data from the Rotterdam Study (RS), an ongoing prospective population-based cohort in Rotterdam, the Netherlands. The design of the Rotterdam study is extensively described elsewhere [19]. For the cross-sectional analyses, we included data of participants recruited between 2006 and 2008 (RS–III–1) when dietary intake and sleep were assessed at the same time point. For the longitudinal analyses, we used sleep data of the first follow-up measurement (RS–III–2) collected between 2012 and 2014. All participants were interviewed at home and came to the research facility for an extensive examination at baseline and during follow-up measurements every 3–6 years.

2.2. Ethical approval

The Rotterdam Study has been approved by the Medical Ethics Committee of Erasmus MC (registration number MEC 02.1015) and by the Dutch Ministry of Health, Welfare and Sport (Population Screening Act WBO, license number 1071272-159521-PG). The Rotterdam Study Personal Registration Data collection is filed with the Erasmus MC Data Protection Officer under registration number EMC1712001. The Rotterdam Study has been entered into the Netherlands National Trial Register (NTR; www.trialregister.nl) and into the WHO International Clinical Trials Registry Platform (ICTRP; https://apps.who.int/trialsearch/) under shared catalogue number NL6645/NTR6831. All participants provided written informed consent to participate in the study and to have their information obtained from treating physicians.

2.3. Dietary assessment and dietary patterns

Baseline dietary intake was examined with a validated self-administrated semi-quantitative food frequency questionnaire (FFQ) containing 389 food items. For all items, the frequency of intake per week or month, the number of servings, and preparation method was assessed [20]. Participants were excluded when having unreliable reported dietary data, defined as <500 or >5000 kcal/day. Data from the FFQ were used to estimate adherence to two pre-defined dietary scores and to three data-driven dietary patterns for each participant.

Adherence to the Dutch dietary guidelines was estimated using a predefined score which is described in detail elsewhere [20]. In short, the predefined score includes scores for adherence (1 point for yes or 0 points for no) to recommendations for 14 components: high consumption of fruit, vegetables, brown bread, wholemeal bread, or other whole grain products, legumes, nuts, fish, and tea; replacement of refined cereal products by whole-grain products, butter and hard fats by soft fats, and vegetables oils; and limited intake of red meat and processed meat, beverages containing sugar, alcohol, and salt (Supplementary Table 1). The final sum score can range from 0 to a maximum of 14 points, with a higher score indicating better adherence to the Dutch dietary guidelines.

A Mediterranean diet score was calculated as proposed by Panagiotakos et al. [21]. In short, the following eleven components were included in the score: non-refined cereals, fruit, vegetables, legumes, potatoes, fish, meat and meat products, poultry, full fat dairy products, olive oil, and alcohol intake. For each component scores ranged from 0 to 5, based on the frequency of consumption. This results in a maximum score of 55, with a higher score indicating better adherence to the Mediterranean diet [21].

Data-driven dietary patterns were previously derived in this cohort with principal component analysis (PCA) and are described elsewhere [22]. In short, the food items of the FFQ were combined into 23 food groups. The first three dietary patterns were selected. Based on the factor loadings for food groups in each of the patterns (Supplementary Table 1), these patterns were named: prudent, unhealthy, and traditional Dutch. The Traditional Dutch diet in this dataset is characterized by a high intake of potatoes (cooked, fried, and baked), whole grain products, cheese, vegetable oils and spreads, and sweet snacks (Supplementary Table 1). Each participant has a standardized adherence score for each of the dietary patterns [22]. A higher standardized adherence score indicates a higher intake of that specific dietary pattern. All dietary patterns used in the current study are summarized in Supplementary Table 1.

The Pearson's correlations between the different dietary scores ranged from −0.61 for the correlation between the Dutch dietary guidelines score with the unhealthy dietary pattern to 0.63 for the correlation between the Dutch dietary guidelines score with the Mediterranean diet score (Supplementary Table 2).

2.4. Assessment of sleep outcomes

Objective sleep outcomes were estimated with accelerometers. At baseline (RS–III–1), the Actiwatch (Actiwatch model AW4; Cambridge Technology, Cambridge, UK) was used and at follow-up (RS–III–2), a Actiwatch or GENEActiv (Activinsight Ltd, Kimbolton, Cambridgeshire, UK) was used. Participants wore the accelerometers for seven consecutive days and nights (except during water-based activities) around their non-dominant wrist. During the actigraphy measurement, participants

were asked to fill in a sleep diary and to press a marker button on the actigraphy when they were planning to go to sleep and when they got out of bed. The accelerometers measured movements with 30s epochs considering the weighted scores of previous and following epochs. To categorize being awake or asleep, a threshold of 20 was used of each 30-s epoch [23]. Recordings were sampled at 32 Hz (Actiwatch) or 50 Hz (GENEActiv). To make records from GENEActiv comparable with the Actiwatch used at baseline, the z-axis data of the tri-axial GENEactiv data were pre-analyzed [24]. Participants with more than 3 h of missing data within a 24-h span and participants with less than 4 full days of data were excluded.

From the actigraphy data, total sleep time in minutes, sleep onset latency in minutes, wake after sleep onset in minutes, and sleep efficiency in percentages were estimated [25]. Total sleep time was estimated by the total duration of all epochs scored as sleep. Sleep onset latency is the estimated time that it took for participants to fall as sleep from time to bed. Time to bed was self-reported by the participant in the sleep diary. If the time to bed was missing in the sleep diary, the information of the marker button on the actigraphy was used. Wake after sleep onset was estimated by the sum of epochs scored as awake since falling asleep and waking up. Last, sleep efficiency was the proportion of time spent sleeping relative to time spent in bed. Time in bed was estimated by the difference in self-reported time to bed and getting up time. As of for time in bed, when data for getting up time in the sleep diary were missing, the information of the actigraphy button was used. For all actigraphy-estimated sleep parameters, extreme outliers (mean ± 4 SD) were winsorized to the maximum value of mean ± 4 times SD.

Subjective sleep quality was assessed with the Pittsburgh Sleep Quality Index (PSQI) which was administered during home interviews, also at both baseline (RS–III–1) and follow-up (RS–III–2) [26]. The PSQI, a 19-item validated questionnaire, consists of seven components: sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbances, use of sleep medication, and daytime functioning. The total score ranges from 0 to 21 with a higher score indicating worse sleep quality [26].

2.5. Assessment of co-variates

Based on previous literature and a Directed Acyclic Graph Effect using DAGitty (www.dagitty.net) (Supplementary Fig. 1) the following covariates were identified: age, sex, living with a partner, educational level, employment status, smoking, physical activity, depression score, prevalence of chronic disease, having sleep apnea, using sleep medication, BMI, alcohol and coffee consumption in week of actigraphy, and energy intake. All covariates were measured at baseline.

Weight and height were measured at the research centre to calculate BMI. Age (years), sex (m/f), living with a partner (yes/no), educational level (primary, low, middle, high), employment status (employed/unemployed), and smoking status (current, former, never smoker) were self-reported based on single questions. Furthermore, a proxy for having sleep apnea (yes/no) was calculated based on two items of the PSQI. Having sleep apnea was considered probable when participants reported breathing pauses during a least one or two nights per week, or when the participant reported loud snoring for at least 2 nights per week in combination with occasional breathing pauses [27]. Having depressive symptoms was assessed with the Center of Epidemiology Scale-Depression (CES-D) [28,29]. When <25 % of the CES-D was missing, a weighted average was calculated. When more than 25 % was missing, no score was calculated. Use of sleep medication in the week of the actigraphy measurement (yes/no), evening alcohol use in the week of the actigraphy measurement (glasses per week after 18:00), evening coffee consumption in the week of the actigraphy measurement (cups per week after 18:00) were derived from sleep diaries that participants filled in while wearing the actigraphy. Last, total energy intake (kcal/-day) was calculated based on the FFQ. Information about disease status was derived from medical records to assess if participants had one or more chronic disease (yes/no). Chronic diseases included: having cancer (including all cancers with exception of non-melanoma skin cancers), diabetes, and/or cardiovascular diseases (including coronary heart disease and stroke). For all analyses, data of covariates at baseline were used.

2.6. Data analysis

Baseline characteristics are reported for the total study population and stratified into three groups based on adherence scores to the Dutch dietary guidelines. Characteristics are reported as mean ± standard deviation (SD) for normally distributed data, median [IQR] for data that are not normally distributed, and as n (%) for categorical data. Associations between dietary patterns and sleep parameters were examined using multiple linear regression with the two dietary scores (Dutch dietary guidelines score and Mediterranean diet score) and the three data-driven dietary patterns (prudent, unhealthy and traditional Dutch) as independent variables and sleep parameters (actigraphy-estimated total sleep time, sleep onset latency, wake after sleep onset and sleep efficiency, and subjective sleep quality) as dependent variables. PSQI data were transformed using square root transformation to better approach a normal distribution. Beta coefficients and their 95 % confidence intervals are reported per 1-point increase for adherence to the Dutch dietary recommendations, per 5-point increase for adherence to the Mediterranean diet, and per SD for the data-driven dietary patterns. Estimates are adjusted for age and sex in the basic model (model 1). Model 2 additionally adjusts for having a partner, educational level, employment status, smoking, physical activity, probably having sleep apnea, depressive symptoms, having a chronical condition, and use of sleep medication in the week of the measurement (only for the analyses with objective data). Model 3 additionally adjusts for BMI, evening alcohol and coffee consumption in the week of actigraphy measurement (only in the analyses with objective data), and energy intake. Model 2 was considered the main model. Model 3 was to explore possible mechanisms by including potential mediators (BMI) or variables that may be part of the exposure (alcohol and coffee). Missing values for covariates (for objective sample: 0.2%–16.5 %; for subjective sample: 0.1%–14.9 %) were imputed by using multiple imputation by chained equations with the MICE package for R software (m = 10 imputations, iterations = 10) [30]. After all analyses were performed in each imputed dataset, the effect estimates of the regression models were pooled using Rubin's rules.

Cross-sectional analyses were performed for the whole study population and in predefined subgroups by stratifying for sex or age (<60 and ≥ 60 years). Besides the stratified analyses, we calculated the p-value for the multiplicative interaction of sex (m/f) and age (y) with each of the dietary patterns. Interactions with a p-value <0.05 were considered statistically significant.

Longitudinal analyses were performed using sleep parameters assessed during follow up (actigraphy or subjective sleep quality) in multiple linear regression models while adjusting for the same sleep parameter at baseline and applying the same models as described above.

All analyses were performed in R version 4.1.0.

3. Results

3.1. Study population

For 2629 participants, dietary data were available. Of those, 553 were included in the cross-sectional analyses with objective sleep data and 2589 in the cross-sectional analyses for subjective sleep quality. For the longitudinal analyses, 358 and 2176 participants were included in the analyses for objective sleep and subjective sleep outcomes, respectively (Fig. 1).

The study population with objective sleep measurements had a median age of 56.2 years (*IQR* 51.3, 59.5), a mean BMI of 27.6 kg/m^2 (*SD*

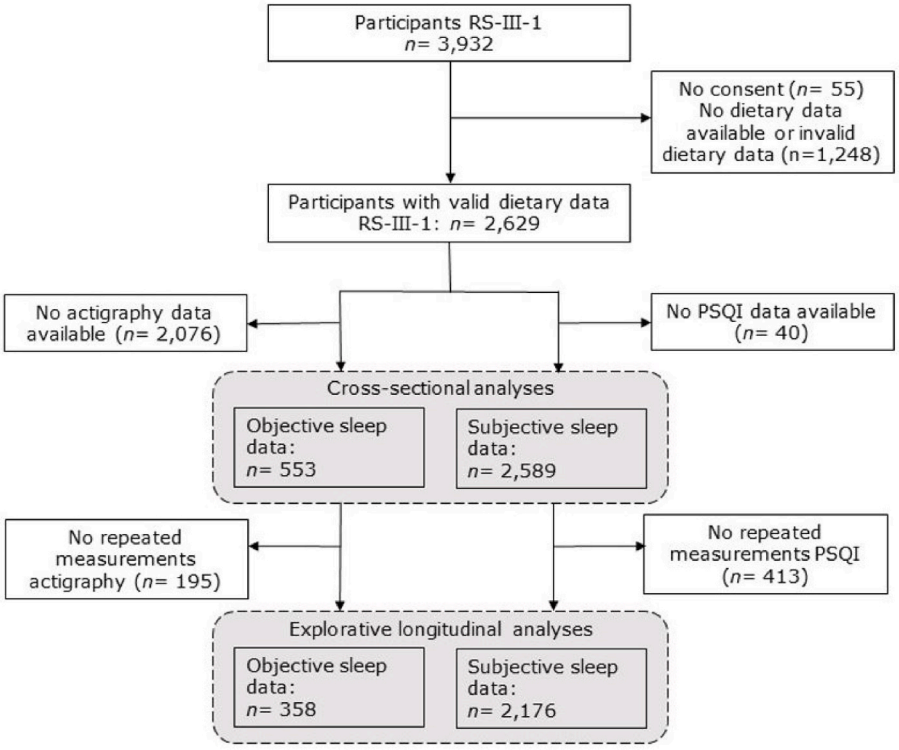

Fig. 1. Flow chart for number of participants in the different sets of analyses.

4.1), and the majority was female (60.9 %, Table 1). Participants with a higher adherence to the Dutch dietary guidelines (score >8) were more often female, were on average more physically active, had a higher level of education, were less often smokers, and drank fewer glasses of alcohol in the week of sleep assessment, compared to subjects with a lower adherence to the Dutch dietary guidelines (Table 1). The study population for the subjective sleep measurements had comparable characteristics to the study population with actigraphy estimated sleep outcomes (Supplementary Table 3). Actigraphy-estimated sleep was measured for on average 6.8 nights (*SD* 0.7). Actigraphy-estimated total sleep times was 365 min (*SD* 52.2) and 44 % did not meet the recommended 7 h of sleep per night (Table 1 and Supplementary Table 4). Furthermore, estimated sleep onset latency was 14.8 min (*IQR* 8.7, 25.0) with 18 % taking longer than 30 min to fall asleep Table 1 and Supplementary Table 4).

3.2. Dietary patterns and sleep

No statistically significant associations were observed between any of the dietary patterns with objective and subjective sleep outcomes in either cross-sectional (Table 2) or longitudinal analyses (Table 3). For example, in adjusted models (model 2), the cross-sectional effect estimate for total sleep time was −1.7 min (*95 % CI* -5.9, 2.5) per SD increase for the unhealthy diet. For sleep onset latency, the effect estimate was 1.1 min (*95 % CI* -0.5, 2.8) per 5 point increase for the Mediterranean diet. Only the interactions between age with the Mediterranean diet and age with the Prudent diet in the association for time awake after sleep onset as outcome were statistically significant. However, the associations in the subgroups stratified by age (<60 vs =>60 years) were not statistically significant (Supplementary Table 7). For sex, none of the interaction terms were statistically significant, but in stratified analyses we observed a few associations in women that were not present in men (Supplementary Tables 5–9). However, the majority of the associations in subgroups was again not statistically significant and effect estimates were small.

In the longitudinal analyses, similar null findings were observed, for example, the effect estimate for total sleep time was −1.0 min (*95 % CI* -5.2, 3.1) per SD increase in prudent diet. For sleep onset latency the effect estimate was 0.3 min (*95 % CI* -1.3, 1.9) per SD increase in traditionally Dutch diet (Table 3).

4. Discussion

In this study, we examined the associations of five dietary patterns with both actigraphy-estimated and self-reported sleep duration and quality in a population-based sample of middle-aged and elderly persons. We observed no statistically significant associations between any of the dietary patterns with total sleep time, sleep onset latency, time awake after sleep onset, sleep efficiency, or subjective sleep quality in either cross-sectional or longitudinal analyses. In addition, we observed no meaningful differences in the associations of dietary patterns and sleep parameters between men and women, or between participants younger or older than 60 years.

Our study does not give indications that there are robust associations of dietary intake with sleep parameters, neither with objective nor with subjective assessments of sleep. We conducted a large number of statistical tests, and none of those in the main analyses were statistically significant. Only a few tests in the stratified analyses were nominally statistically significant. We did not adjust for multiple testing, and it is likely that at least some of these few statistically significant findings in subgroups are chance findings, while the effect sizes of those findings are also small. Some [14,15] but not all [16,17] previous studies reported that dietary patterns are associated with objectively assessed sleep duration [15] and sleep onset latency [14]. Nevertheless, in studies that did find an association, the estimates are small [14] or are not consistent [15]. Furthermore, there are also studies that are in agreement with our results and did not find associations between dietary patterns and objective sleep outcomes [16,17]. This indicates that there might be no, or only a weak, association between dietary patterns and objective sleep outcomes.

Surprisingly, we also did not observe cross-sectional or longitudinal associations between dietary patterns and subjective sleep quality. Most

Table 1
Baseline characteristics for the study population with objective sleep measurements stratified for adherence scores of agreement with the Dutch dietary guideline score (DGS).

	Total study population	DGS <7	DGS 7-8	DGS >8
	n = 553	n = 202	n = 223	n = 128
Age (years)	56.2 [51.3, 59.5]	56.0 [51.1, 59.6]	56.4 [51.1, 59.2]	56.0 [51.9, 59.7]
Female (%)	337 (60.9)	98 (48.5)	150 (67.3)	89 (69.5)
BMI (kg/m^2)[e]	27.6 (4.1)	27.7 (3.9)	27.6 (4.4)	27.3 (3.9)
Physical activity (METh/week)[f]	46.0 [20.0, 86.2]	35.8 [15.3, 67.2]	49.0 [21.6, 90.8]	53.2 [25.4, 98.5]
Energy intake (kcal/day)	2279.4 (688.5)	2112.2 (636.3)	2341.3 (703.4)	2435.4 (692.1)
Education (%)				
- *Lower/intermediate education*[a]	263 (47.6)	106 (52.5)	108 (48.4)	49 (38.3)
- *Higher education*[b]	289 (52.3)	96 (47.5)	115 (51.6)	78 (60.9)
- *Missing*	1 (0.2)	0 (0.0)	0 (0.0)	1 (0.8)
Smoking				
- *Never*	180 (32.5)	54 (26.7)	70 (31.4)	56 (43.8)
- *Former*	246 (44.5)	85 (42.1)	106 (47.5)	55 (43.0)
- *Current*	127 (23.0)	63 (31.2)	47 (21.1)	17 (13.3)
Evening alcohol consumption in week of accelerometer (glasses/week)	3.0 [0.0, 9.0]	5.0 [0.0, 10.0]	3.0 [0.0, 8.0]	2.5 [0.0, 7.0]
Evening coffee consumption in week of accelerometer (cups/week)	7.0 [2.0, 11.0]	7.0 [3.0, 12.0]	5.0 [1.0, 11.0]	7.0 [1.0, 11.0]
Living with partner (%)				
- *No*	90 (16.3)	30 (14.9)	43 (19.3)	17 (13.3)
- *Yes*	462 (83.5)	172 (85.1)	179 (80.3)	111 (86.7)
- *Missing*	1 (0.2)	0 (0.0)	1 (0.4)	0 (0.0)
Employed (%yes)	342 (61.8)	126 (62.4)	133 (59.6)	83 (64.8)
Depression score (CES-D)[g]	3.0 [1.0, 7.0]	3.0 [1.0, 7.0]	3.0 [1.0, 8.0]	3.0 [1.0, 7.1]
Use of sleep medication in week of accelerometer				
- *No*	460 (83.2)	171 (84.7)	179 (80.3)	110 (85.9)
- *Yes*	62 (11.2)	20 (9.9)	28 (12.6)	14 (10.9)
- *Missing*	31 (5.6)	11 (5.4)	16 (7.2)	4 (3.1)
Sleep apnea (%)				
- *No*	413 (74.7)	144 (71.3)	164 (73.5)	105 (82.0)
- *Yes*	49 (8.9)	28 (13.9)	15 (6.7)	6 (4.7)
- *Missing*	91 (16.5)	30 (14.9)	44 (19.7)	17 (13.3)
Prevalence of chronic disease (%yes)[c]	92 (16.6)	44 (21.8)	33 (14.8)	15 (11.7)
PSQI[d,h]	3 [1,5]	3 [1,5]	3 [1,5]	3 [1,4]
Total sleep time (min)	365.0 (52.2)	358.8 (54.3)	370.5 (49.4)	365.5 (52.8)
Sleep onset latency (min)[i]	14.8 [8.7, 25.0]	14.4 [8.2, 24.7]	15.0 [8.7, 25.1]	15.4 [9.3, 25.3]
Sleep efficiency (%)[j]	76.3 [71.4, 80.7]	75.8 [70.3, 80.6]	76.1 [72.0, 80.5]	76.9 [72.3, 81.7]
Time awake after sleep onset (min)[k]	59.0 [45.5, 74.4]	61.2 [46.3, 75.2]	59.6 [46.6, 73.7]	56.5 [44.0, 73.1]
Mediterranean diet score	35.0 (4.6)	32.0 (4.0)	35.4 (3.6)	38.9 (3.7)
Prudent diet (SD-score)	0.8 (1.2)	0.4 (0.9)	0.9 (1.1)	1.4 (1.4)
Unhealthy diet (SD-score)	−0.1 (1.1)	0.6 (0.9)	−0.3 (0.9)	−0.9 (1.0)
Traditional Dutch diet (SD-score)	−0.3 (1.0)	−0.5 (0.9)	−0.2 (1.1)	−0.1 (1.0)

DGS, Dutch dietary guideline score; BMI, body mass index; CES-D, Center of Epidemiology Scale-Depression; PSQI, Pittsburgh Sleep Quality Index; SD, standard deviation. Characteristics for the population for analyses of subjective sleep measures (n = 2589) are presented in Supplementary Table 3.

[a] Lower/intermediate education includes: Primary education, Lower/intermediate general education, and lower vocational education.

[b] Higher education includes: Intermediate vocational education, higher general education, higher vocational education, and university.

[c] Yes if participants has prevalent cardiovascular disease (coronary heart disease or stroke) and/or diabetes mellitus, and/or cancer (except non melanoma skin cancer).

[d] Subjective sleep quality with a lower score indicating better sleep quality.

[e] 3 missings.

[f] 68 missings.

[g] 2 missings.

[h] 9 missings.

[i] 5 outliers (>99.2 min) winsorized.

[j] 4 outliers (<42.84 %) winsorized.

[k] 3 outliers (>156.82 min) winsorized.

previous studies, as summarized in a review, found that adherence to the Mediterranean diet was associated with better self-reported sleep quality or duration [7]. However, one study found no association between adherence to the Mediterranean diet and self-reported difficulties of falling asleep or staying asleep in older men [31]. Furthermore, most studies examining the association between dietary patterns and sleep had a cross-sectional design. Two previous longitudinal studies found that better adherence to the Mediterranean diet was associated with better self-reported sleep quality after 1 year [32] and after a median of 2.8 years [33]. One possible explanation for our null findings could be that our study participants were middle-aged or elderly. Several other studies that did find an association examined younger populations such as university students [34], high school students [35], or adolescents [36]. Sleep quality tends to decrease with age, as indicated by a higher prevalence of insomnia symptoms [3] and other sleep complaints [37]. Possible reasons for this increase in sleep problems could be the higher prevalence of comorbidities in elderly populations. Comorbidities can directly contribute to sleep problems through specific symptoms such as pain, or indirectly due to anxiety related to these diseases [37]. Also side effects of medication and psychosocial factors, such as social isolation and loss of physical function, can have an impact on sleep [37]. All these factors might affect sleep, and this could mean that sleep at older age might be less susceptible for potential effects of dietary intake on sleep.

The main strength of our research is the use of objective and subjective sleep measurements. We also studied an extensive set of sleep parameters while some previous studies with objective sleep

Table 2
Cross-sectional associations between dietary patterns with objective and subjective sleep measurements.

	Total sleep time (min)		Sleep onset latency (min)		Wake after sleep onset (min)		Sleep efficiency (%)		PSQI (square root transformed)	
n model 1	553		553		553		553		2589	
	Beta	95 % CI	Beta	95 % CI	Beta	95 % CI	Beta	95 % CI	Beta	95 % CI
Dutch dietary guideline score (per 1 point)										
Model 1	0.4	(-1.8, 2.6)	0.2	(-0.6, 0.9)	−0.7	(-1.8, 0.3)	0.1	(-0.2, 0.5)	0.008	(-0.011, 0.027)
Model 2	0.9	(-1.4, 3.2)	0.4	(-0.4, 1.2)	−0.8	(-1.9, 0.2)	0.2	(-0.2, 0.6)	0.008	(-0.010, 0.027)
Model 3	1.1	(-1.2, 3.5)	0.2	(-0.6, 1.0)	−0.8	(-1.9, 0.3)	0.3	(-0.1, 0.6)	0.006	(-0.013, 0.025)
Mediterranean diet score (per 5 points)										
Model 1	1.9	(-2.7, 6.5)	0.8	(-0.8, 2.3)	−0.1	(-2.2, 2.0)	0.2	(-0.5, 1.0)	−0.019	(-0.058, 0.020)
Model 2	2.7	(-2.1, 7.5)	1.1	(-0.5, 2.8)	−0.6	(-2.8, 1.6)	0.4	(-0.4, 1.1)	0.010	(-0.028, 0.048)
Model 3	3.5	(-1.6, 8.7)	0.7	(-1.1, 2.5)	−0.8	(-3.2, 1.6)	0.6	(-0.2, 1.4)	0.001	(-0.040, 0.042)
Prudent diet (per SD)										
Model 1	−1.2	(-4.8, 2.3)	1.1	(-0.1, 2.3)	0.4	(-1.2, 2.0)	−0.2	(-0.8, 0.4)	0.017	(-0.014, 0.048)
Model 2	−0.0	(-3.8, 3.7)	1.3	(-0.0, 2.5)	−0.3	(-2.0, 1.4)	0.0	(-0.5, 0.6)	0.022	(-0.007, 0.051)
Model 3	0.8	(-3.9, 5.5)	0.5	(-1.1, 2.1)	−1.1	(-3.2, 1.1)	0.4	(-0.3, 1.1)	0.018	(-0.018, 0.055)
Unhealthy diet (per SD)										
Model 1	−1.7	(-5.7, 2.3)	−0.4	(-1.7, 1.0)	0.4	(-1.5, 2.2)	−0.1	(-0.7, 0.6)	0.004	(-0.029, 0.037)
Model 2	−1.7	(-5.9, 2.5)	−0.7	(-2.2, 0.7)	0.4	(-1.5, 2.4)	−0.2	(-0.8, 0.5)	−0.001	(-0.034, 0.031)
Model 3	−1.7	(-6.0, 2.6)	−0.9	(-2.4, 0.5)	0.2	(-1.8, 2.2)	−0.2	(-0.8, 0.5)	0.001	(-0.032, 0.033)
Traditional Dutch diet (per SD)										
Model 1	1.0	(-3.3, 5.3)	0.6	(-0.8, 2.1)	−0.6	(-2.6, 1.4)	−0.1	(-0.7, 0.6)	0.016	(-0.020, 0.052)
Model 2	0.5	(-3.8, 4.9)	0.7	(-0.8, 2.2)	−0.4	(-2.4, 1.6)	−0.1	(-0.8, 0.6)	0.012	(-0.022, 0.046)
Model 3	5.1	(-1.8, 12.0)	−1.7	(-4.1, 0.7)	−1.9	(-5.1, 1.3)	0.4	(-0.7, 1.5)	−0.009	(-0.061, 0.043)

Estimates are regression coefficients with 95 % confidence intervals (CI) from linear regression models. Model 1 is adjusted for age (years) and sex (m/f). Model 2 is additionally adjusted for having a partner (yes/no), educational level (primary, low, middle, high), employment status (employed/not employed), smoking (current/former/no smoker), physical activity (METh/week), depression score, prevalence of chronic disease (yes/no), sleep apnea (yes/no), and using sleep medication (yes/no; only for the objective sleep outcomes). Model 3 is adjusted for all variables in models 1 and 2 and additionally for BMI (kg/m^2), alcohol (glasses/week; only for the objective sleep outcomes) and coffee consumption (cups/week; only for the objective sleep outcomes) in the week of actigraphy measurement, and energy intake (kcal/day).

Table 3
Longitudinal associations between dietary patterns with objective and subjective sleep measurements.

	Total sleep time (min)		Sleep onset latency (min)		Wake after sleep onset (min)		Sleep efficiency (%)		PSQI (square root transformed)	
n	358		358		358		358		2176	
	Beta	95 % CI	Beta	95 % CI	Beta	95 % CI	Beta	95 % CI	Beta	95 % CI
Dutch dietary guideline score (per 1 point)										
Model 1	−1.8	(-4.2, 0.6)	0.4	(-0.5, 1.2)	−0.3	(-1.5, 0.9)	−0.1	(-0.5, 0.3)	−0.008	(-0.027, 0.010)
Model 2	−2.0	(-4.4, 0.4)	0.6	(-0.3, 1.4)	−0.0	(-1.2, 1.2)	−0.2	(-0.6, 0.2)	−0.008	(-0.027, 0.011)
Model 3	−2.3	(-4.8, 0.2)	0.6	(-0.3, 1.5)	0.2	(-1.1, 1.4)	−0.3	(-0.7, 0.1)	−0.007	(-0.027, 0.012)
Mediterranean diet score (per 5 points)										
Model 1	−0.9	(-5.8, 3.9)	0.2	(-1.5, 1.9)	−0.9	(-3.3, 1.5)	0.4	(-0.5, 1.7)	−0.006	(-0.043, 0.032)
Model 2	−1.5	(-6.5, 3.6)	1.0	(-0.8, 2.7)	−0.6	(-3.1, 1.8)	0.2	(-0.6, 1.1)	−0.003	(-0.042, 0.036)
Model 3	−2.9	(-8.4, 2.6)	1.0	(-0.9, 3.0)	−0.1	(-2.9, 2.6)	0.0	(-0.9, 1.0)	0.003	(-0.038, 0.045)
Prudent diet (per SD)										
Model 1	−0.4	(-4.4, 3.5)	0.4	(-1.0, 1.8)	0.1	(-1.8, 2.1)	−0.0	(-0.6, 0.7)	−0.012	(-0.040, 0.017)
Model 2	−1.0	(-5.2, 3.1)	0.9	(-0.6, 2.4)	0.9	(-1.1, 3.0)	−0.1	(-0.8, 0.6)	−0.012	(-0.041, 0.017)
Model 3	−4.8	(-10.1, 0.6)	1.4	(-0.5, 3.3)	1.9	(-0.8, 4.6)	−0.6	(-1.5, 0.3)	−0.005	(-0.042, 0.032)
Unhealthy diet (per SD)										
Model 1	3.8	(-0.4, 8.1)	−0.1	(-1.6, 1.4)	0.6	(-1.4, 2.7)	0.2	(-0.6, 0.9)	0.001	(-0.030, 0.032)
Model 2	4.1	(-0.4, 8.5)	−0.6	(-2.2, 1.0)	0.2	(-2.0, 2.4)	0.2	(-0.5, 1.0)	−0.003	(-0.036, 0.030)
Model 3	3.8	(-0.8, 8.5)	−0.4	(-2.1, 1.2)	−0.4	(-2.7, 1.9)	0.3	(-0.5, 1.1)	−0.004	(-0.037, 0.030)
Traditional Dutch diet (per SD)										
Model 1	1.4	(-3.0, 5.8)	0.2	(-1.4, 1.7)	−1.5	(-3.7, 0.7)	0.6	(-0.1, 1.3)	−0.004	(-0.039, 0.031)
Model 2	1.3	(-3.2, 5.8)	0.3	(-1.3, 1.9)	−1.2	(-3.4, 1.0)	0.5	(-0.3, 1.3)	−0.006	(-0.041, 0.029)
Model 3	−0.1	(-7.3, 7.2)	−0.1	(-2.7, 2.4)	−2.2	(-5.8, 1.4)	0.5	(-0.7, 1.7)	0.016	(-0.037, 0.069)

Estimates are regression coefficients with 95 % confidence intervals (CI) from linear regression models. Model 1 is adjusted for the same sleep outcome at RS–III–1 (e.g. total sleep time at RS–III–1), age (years), and sex (m/f). Model 2 is additionally adjusted for: having a partner (yes/no), educational level (primary, low, middle, high), employment status (employed/not employed), smoking (current/former/no smoker), physical activity (METh/week), depression score, prevalence of chronic disease (yes/no), sleep apnea (yes/no), using sleep medication (yes/no; only for the objective sleep outcomes). Model 3 is additionally adjusted for: BMI (kg/m^2), alcohol (glasses/week; only for the objective sleep outcomes) and coffee consumption (cups/week; only for the objective sleep outcomes) in the week of actigraphy measurement, and energy intake (kcal/day).

measurements only examined sleep duration [15,17]. Furthermore, few studies examined the association between dietary patterns and sleep using a longitudinal design, which is important to identify temporal relationships. Also, we studied a variety of dietary scores to increase comparability with other studies. Our null findings are consistent over the different dietary patterns, which contributes to the robustness of the conclusion that dietary patterns might not be associated with objective sleep outcomes. Last, we performed stratified analyses to see if the association would differ for sex and age groups. Our study was performed among a middle-aged and elderly population in the Netherlands and results may not be directly generalizable to other populations. However, the absence of meaningful differences in subgroup analyses by age and

sex suggests no major differences in effects of diet on sleep by these population characteristics. This indicates that results might be generalizable to other comparable Western middle-aged or elderly populations.

This study also has several limitations that should be taken into account. First, for the follow-up measurement used in the longitudinal analyses no dietary information was collected. Second, only in a subsample of the Rotterdam study objective measurements of sleep were available which limited our power. Last, although we adjusted for an elaborate set of confounders, the association between dietary patterns and sleep might be complex, and residual confounding can never be completely eliminated in observational studies.

In the current study, we investigated the associations between habitual dietary intake and sleep patterns. Possible directions for future research are to focus on potential acute effects of dietary intake during a specific day with sleep in the following night, or to examine if the timing of dietary intake is important in the association between diet and sleep. For example, a study found that the time between eating or drinking before bedtime is associated with subjective sleep duration and time awake after sleep onset [38]. For such studies, information about timing of dietary intake, preferably during the days of actigraphy measurements would be required, estimated with for example 24-h recalls or food diary.

5. Conclusions

To conclude, in this population-based prospective cohort study of middle-aged and elderly persons, we found no evidence that dietary patterns are associated with actigraphy-estimated and self-reported sleep. The effect of more specific aspects of diet, such as timing of dietary intake, on sleep, should be further studied.

Availability of data and materials

The datasets used and/or analyzed in the current study are available from the corresponding author on reasonable request. All requests will be directed towards the management team of the Rotterdam Study (secretariat.epi@erasmusmc.nl), which has a protocol for approving data requests. Because of restrictions based on privacy regulations and informed consent of the participants, the data underlying this article cannot be made freely available in a public repository.

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CRediT authorship contribution statement

Auke J.C.F. Verkaar: Writing – original draft, Formal analysis, Conceptualization. **Renate M. Winkels:** Writing – review & editing, Conceptualization. **Ellen Kampman:** Writing – review & editing, Conceptualization. **Annemarie I. Luik:** Writing – review & editing, Conceptualization. **Trudy Voortman:** Writing – review & editing, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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