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Emotional eating and cognitive restraint mediate the association between sleep quality and BMI in young adults

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Abstract

This cross-sectional study was designed to investigate whether diet quality and eating behaviors could mediate the association between sleep quality and body mass index (BMI) in young adults. For all participants (n=925; aged 21.4±2.5 77.8% women) we evaluated: BMI, sleep quality, diet quality, and eating behavior dimensions (emotional eating, cognitive restraint, and uncontrolled eating). Linear regression models were used to test associations between exposure and outcome variables. Path analysis was conducted with all potential mediators and covariates entered at the same time. Results showed that emotional eating (β= 0.04 [95% CI: 0.03;0.06]), cognitive restraint (β= 0.03 [95% CI: 0.01;0.04]), uncontrolled eating (β= 0.02 [95% CI: 0.01;0.04]) and diet quality (β= -0.14 [95% CI: -0.19;-0.08]) were significantly associated with sleep quality. Additionally, BMI was significantly associated with PSQI score (β= 0.09 [95% CI: 0.01;0.17]), emotional eating (β= 0.89 [95% CI: 0.60;1.18]), and cognitive restraint (β= 1.37 [95% CI: 1.02;1.71]). After testing for mediation, results revealed that emotional eating and cognitive restraint evidenced a significant mediating effect on the association between sleep quality and BMI. Additionally, diet quality was significantly associated with emotional eating (β= -0.35 [95% CI: -0.56;-0.13]), cognitive restraint (β= 0.53 [95% CI: 0.27;0.79]), and uncontrolled eating (β= -0.49 [95% CI: -0.74;-0.25]). In conclusion, young adults with poor sleep quality are more likely to deal with negative emotions with food, which, in turn, could be associated with higher cognitive restraint, becoming a vicious cycle that has a negative impact on body weight. Our results also emphasize the role of eating behaviors as determinants of diet quality, highlighting the importance of considering sleep quality and eating behaviors when designing obesity prevention strategies in this population.

Keywords: sleep quality, body mass index, emotional eating, cognitive restraint, eating behavior, diet quality.

1. Introduction

College is a period of transition in which many young adults learn to make independent decisions that, among other things, include choosing *what* and *when* to eat, whether or not to exercise, and how much to sleep (Richards & Specker, 2021). Unfortunately, this period usually coincides with academic and social demands, as well as life situations that can disrupt their daily habits (Dinis & Bragança, 2018; Wickham, Amarasekara, Bartonicek, & Conner, 2020). In fact, research has shown that young adults who attend college have late sleep schedules and irregular sleep/wake patterns (Izydorczyk, Sitnik-Warchulska, Lizińczyk, & Lipiarz, 2019; Richards & Specker, 2021; Silva et al., 2016; Zerón-Rugerio, Cambras, & Izquierdo-Pulido, 2019), which in turn lead to poor sleep quality (Pilz, Keller, Lenssen, & Roenneberg, 2018). Noteworthy, poor sleep quality affects around 50 – 60% of college students (Chen & Chen, 2019; Dinis & Bragança, 2018; Memon et al., 2021) and has been highlighted as a significant predictor of poor mental health and low well-being (Wickham et al., 2020), obesity (Krističević, Štefan, & Sporiš, 2018), and unhealthy dietary habits (Yamamoto et al., 2018).

Poor sleep quality can influence 'what' and 'how much' people eat through several mechanisms including alterations in hormones related to appetite (mainly ghrelin and leptin) and increased neuronal activity in response to food intake (Burrows, Fenton, & Duncan, 2020; M.-P. St-Onge, 2017). Not surprisingly, evidence has shown that when people have not slept well, they tend to eat more calories the next day (~350 kcal more) (Al Khatib, Harding, Darzi, & Pot, 2017; M.-P. St-Onge, 2017). In addition, these hormonal and neuronal alterations are accompanied by a greater preference for high-calorie foods, which is mainly driven by hedonic mechanisms (Al Khatib et al., 2017; Goldstein & Walker, 2014). Consequently, poor sleep quality has been highlighted as a modifiable risk factor for obesity (Chaput & Dutil, 2016; Krističević et al., 2018; M.-P. St-Onge, 2017). In fact, Kristicevic et al (Krističević et al., 2018) reported that young adults with poor sleep quality have ~1.40 more odds of being overweight or obese.

Along these lines, emerging evidence has revealed that the link between poor sleep quality and obesity could also be driven by eating behaviors (Blumfield, Bei, Zimberg, & Cain, 2018; Lundahl & Nelson, 2015; Saleh-ghadimi, Dehghan, Farhangi, & Asghari-jafarabadi, 2019). Blumfield et al (Blumfield et al., 2018) demonstrated that disinhibited eating behavior, understood as the need to overeat in the presence of palatable foods or other disinhibiting stimuli like emotional stress, mediated the association between poor sleep quality and obesity among adults. The authors postulated that in the context of sleep impairment, an increased drive for exciting rewards in combination with disinhibited eating behavior may exacerbate the food seeking behavior, especially for palatable foods (Blumfield et al., 2018), which are those that are known to increase the feelings of calmness and satisfaction (Gibson, 2006). What is equally interesting is that lack of sleep could also act as a stressor and increase food consumption in people prone to emotional eating (Dweck, Jenkins, & Nolan, 2014).

Furthermore, a recent study noted that greater dietary restraint is also associated with poor sleep quality (given by higher sleep fragmentation) (Barragán et al., 2021). However, the potential role of dietary restraint as a mediator of the association between sleep quality and obesity remains scarcely studied. Noteworthy, greater dietary restraint has been associated with overweight and obesity among adolescents and young adults (Racine, 2018; Ramírez-Contreras, Farrán-Codina, Izquierdo-Pulido, & Zerón-Rugerio, 2021). Although this fact might seem paradoxical, it has been suggested that greater dietary restraint is associated with increased bottom-up reward reactivity to food stimuli, which may explain why people who attempt to diet are vulnerable to binge eating and weight gain (Bryant, Rehman, Pepper, & Walters, 2019; Martin-Garcia et al., 2016; Racine, 2018). It should be noted that young adulthood is a period of increased risk for excessive weight gain (Deliens, Deforche, Chapelle, & Clarys, 2019; Fedewa, Das, Evans, & Dishman, 2014; Nelson, Story, Larson, Neumark-Sztainer, & Lytle, 2008), at the same time that it is a crucial stage of life for establishing long-term health behaviors (Fedewa et al., 2014; Nelson et al., 2008; Wickham et al., 2020).

Taking into account the aforementioned, it is relevant to study the role that dietary intake and eating behaviors can have in the association between sleep quality and obesity among young adults. Our objective was to investigate whether diet quality and eating behaviors could mediate the association between sleep quality and BMI. We hypothesized that poor diet quality and eating behaviors that promote an overconsumption of energy will mediate the association between poor sleep quality and higher BMI. In addition, we aimed to study which were the dietary habits and eating behavior traits that were significantly associated with sleep quality.

2. Methodology

2.1 Study design, settings, participants and protocol

Young adults (aged 18–30 years) were recruited among undergraduate and postgraduate students at the University of Barcelona (Spain). Participants were invited to take part in this cross-sectional study during the school year, between 2017 and 2019. Exclusion criteria consisted of inability to provide the information required for the development of the study or having previously been diagnosed with chronic diseases such as type 2 diabetes, hypertension and/or cardiovascular disease. Based on these criteria, a total of 938 young adults were eligible and provided written informed consent before joining this study. We further excluded participants who were out of the age range, resulting in a final analytical cohort of 925 participants. All study procedures were conducted according to the Declaration of Helsinki and were approved by the Ethics Committee the University of Barcelona (IRB00003099).

2.2 Outcome variables

2.2.1 Anthropometric parameters

Body mass index was estimated through self-reported height and weight. Participants were asked in a questionnaire 'What is your current weight? (kg)' and 'What is your current height? (cm)', and subsequently BMI was calculated as weight (kg) divided by squared height (m). Note that self-reported BMI had a very high agreement with BMI values among a similar population (Zerón-Rugerio et al., 2019).

2.2.2 Diet quality

Diet quality was evaluated through the Mediterranean Diet Quality Index (KIDMED) (Serra-Majem et al., 2004). This test is based on the principles that sustain Mediterranean dietary patterns and those that undermine them. This questionnaire consists of 16 items which are answered as “Yes” or “No” questions. Subsequently, items denoting a lower adherence are assigned a value of –1, while those related to higher adherence are scored +1. The total score ranges from 0 to 12, where higher scores indicate greater adherence to the Mediterranean Diet. In addition, according to the score, adherence to the Mediterranean diet was classified as “poor” (≤3 points), “average” (4-7 points), or “good” (≥8 points).

2.2.3 Eating behavior

The validated Spanish version of the Three Factor Eating Questionnaire (TFEQ-R21) (Martin-Garcia et al., 2016) was used to assess the following dimensions of eating behavior:

i. Emotional eating: understood as the need to overeat when people are unable to cope with emotionally negative situations. This dimension was evaluated through six items.
ii. Cognitive restraint: understood as the conscious effort of the individual to control what he/she eats to maintain or lose weight. This dimension was evaluated through six items.

iii. Uncontrolled eating: understood as the tendency to overeat in response to the loss of control over food intake. This dimension was evaluated through nine items.

The TFEQ-R21 consists of 21 items which are rated on a four-point Likert scale ranging from 1 ("Definitely true") to 4 ("Definitely false"). Scores are calculated separately for each dimension as a mean of all items, where the higher the score the greater the emotional eating, the cognitive restraint, and/or the uncontrolled eating (Cappelleri et al., 2009; Martin-Garcia et al., 2016). Note that the main strength of the TFEQ is the existence of vast evidence suggesting an important and robust role for the TFEQ traits in obesity, eating styles, eating disorders and associated factors (Bryant et al., 2019).

2.3 Exposure variable

Sleep quality was assessed with the Spanish validated version of the Pittsburgh Sleep Quality Index (PSQI) (Royuela & Macías, 1997). It consists of 19 items, which are grouped to into seven components of sleep quality: subjective sleep quality, sleep latency, sleep duration, habitual sleep efficiency, sleep disturbance, use of sleeping medications, and daytime dysfunction. Total PSQI scores were calculated as the sum of the seven components. Scores range from 0 to 21, where higher scores indicate poor sleep quality. Additionally, according to the score, sleep quality was classified as "good" (PSQI<5 points) and "poor" (PSQI ≥5 points).

2.4 Covariates

The level of physical activity was measured in Metabolic Equivalents of Task (METs) using the short version of the International Physical Activity Questionnaire (IPAQ), which is validated for Spanish population (Román-Viñas, Ribas-Barba, Ngoa, & Serra-Majem, 2013). In this case, the higher the score, the more intense the level of physical activity. Additionally, the chronotype was evaluated through the midpoint of sleep on free-days (MSF) (Roenneberg, Wirz-Justice, & Merrow, 2003).

2.5 Statistical analyses

Normality was confirmed in all variables by histograms and Q-Q plots. Variables are described by means and standard deviations for continuous variables and proportions for categorical data. First, we tested the association between sleep quality and BMI with the outcome variables (diet quality, emotional eating, cognitive restraint and uncontrolled eating) using linear regression analyses. Then, we tested whether those variables (emotional eating and cognitive restraint) that were significantly associated with the BMI were significant mediators of the association between sleep quality and BMI (**Figure 1**). All potential mediators were entered at the same time, using the PROCESS macro (Hayes, 2018) version 3.3 for SPSS.

In addition, we tested the association of the 16 dietary habits evaluated in the KIDMED questionnaire with sleep quality (PSQI score) and the scores of the eating behavior dimensions (emotional eating, cognitive restraint, and uncontrolled eating). To do this, we used general linear models (GLMs) to calculate adjusted differences in PSQI, emotional eating, cognitive restraint, and uncontrolled eating scores based on KIDMED items (reference category “yes”). Finally, we corrected P-values using the Benjamini–Hochberg method, assuming a False Discovery Rate (FDR) of 5%.

All analyses were adjusted for age, gender, BMI, diet quality, physical activity, and chronotype (except when the covariate was the dependent variable of the model). All analyses were carried out in R Software, version 3.4.1. (R Core Team, 2019), except for the mediation models which were performed with SPSS version 25 (IBM SPSS Statistics). A statistical significant test was considered when $p<0.05$.

3. Results

Nine hundred and twenty-five participants (aged 21.4±2.5 years) were included in this cross-sectional study, of whom 77.8% were women (**Table 1**). Overall, 59.2% of the participants showed a poor sleep quality. Regarding BMI, most of the participants were classified as normal-weight (78.7%), while 12.0% were overweight/obese and 9.1% were underweight. Furthermore, half of the participants (53.5%) showed poor or average adherence to the Mediterranean diet, while the other half (46.5%) had high adherence to this dietary pattern. **Table 1** also summarizes the average standardized scores for emotional eating, cognitive restraint, and uncontrolled eating behaviors. Our results also showed that the majority of the participants (57.3%) performed a moderate level of physical activity, while 16.6% reported a low level of physical activity and 26.1% a high level of physical activity.

As shown in **Table 2**, PSQI score was significantly associated with diet quality and eating behaviors. Accordingly, a 1-point increment in the PSQI score was significantly associated with less points in the Mediterranean Diet Quality index (-0.14 [95% CI: -0.19; -0.08]). Conversely, a 1-point increment in the PSQI score was associated with higher emotional eating (0.04 [95% CI: 0.03; 0.06]), cognitive restraint (0.03 [95% CI: 0.01; 0.04]), and uncontrolled eating (0.02 [95% CI: 0.01; 0.04]) behaviors.

Regarding BMI, we observed that it was associated with cognitive restraint and emotional eating (**Table 2**). In which case, the results revealed that a 1-point increment in the emotional eating score was associated with 0.89 kg/m^2 [95% CI: 0.06; 1.18] more BMI, while a 1-point increment in the cognitive restraint score was associated with 1.37 kg/m^2 [95% CI: 1.02; 1.17] more BMI. Furthermore, we observed that BMI was significantly associated with PSQI score (β= 0.09 [95% CI: 0.01; 0.17], p=0.021) (**Figure 2**).

3.1 Emotional eating and cognitive restraint mediate the association between sleep quality and BMI

The mediation model that highlights the effect of sleep quality on BMI via emotional eating and cognitive restraint is shown in **Figure 2**. As observed, paths a_1 and a_2 of the structural model were statistically significant (β= 0.05 [95% CI: 0.03; 0.06], p<0.001 and β= 0.03 [95% CI: 0.02; 0.04], p<0.001, respectively). Consequently, poor sleep quality (higher PSQI score) was significantly associated with both mediators (emotional eating and cognitive restraint). Likewise, our results revealed that paths b_1 and b_2 of the structural model were statistically significant. As such, greater emotional eating and greater cognitive restraint were significantly associated with higher BMI (β= 0.71 [95% CI: 0.42; 1.00], p<0.001 and β= 1.22 [95% CI: 0.87; 1.57], p<0.001, respectively).

Regarding c'-path, we observed that it was not statistically significant (**Figure 2**). Accordingly, our results revealed that there was a significant indirect association between poor sleep quality and higher BMI via emotional eating and cognitive restraint. The summary of indirect effects are shown in **Table 3**. Note that approximately 14.8% of the variance in BMI was accounted by emotional eating and cognitive restraint (R= 0.385; R^2= 0.148; p<0.0001). Additionally, when examining unstandardized beta weights, we observed that cognitive restraint was the strongest predictor of BMI (β= 1.22, p<0.001) (**Figure 2**).

3.2 Dietary habits are significantly associated with sleep quality.

Regarding the association between sleep and dietary habits, our results revealed that higher PSQI score was associated with three of the sixteen habits that characterize the Mediterranean diet (**Figure 3**). Specifically, we observed that attending fast-food restaurants more than once a week was associated with higher the PSQI score (p=0.034). In contrast, regular consumption of fish and nuts was associated with lower PSQI score (p=0.041 and p=0.045, respectively).

3.3 Dietary habits are associated with emotional eating, cognitive restraint, and uncontrolled eating behaviors

Our results also revealed a significant association between eating behavior dimensions and diet quality. In particular, we showed that emotional eating (β= -

0.35 [95% CI: -0.56; -0.13], p=0.002) and uncontrolled eating (β= -0.49 [95% CI: -0.74; -0.25], $p<0.001$) were negatively associated with KIDMED score. It should be noted that consuming fast-food more than once a week ($p<0.001$) and/or eating sweets or candy every day ($p<0.001$ and p=0.043) were associated with higher emotional and uncontrolled eating scores (**Table 4**). In addition, we showed that eating commercially baked goods or pastries for breakfast was significantly associated with emotional eating (p=0.034).

On the other hand, we observed that cognitive restraint was positively associated with KIDMED score (β= 0.53 [95% CI: 0.27; 0.79], $p<0.001$). In this regard, our results showed that the consumption of a second serving of fruit (p=0.016), a daily serving of fresh/cooked vegetables ($p<0.001$), and/or a second serving of vegetables ($p<0.001$) was significantly associated with higher cognitive restraint. Conversely, lower cognitive restraint was found among those who consumed commercially baked goods or pastries for breakfast ($p<0.001$).

4. Discussion

The main contribution of our research work is that emotional eating and cognitive restraint are significant mediators of the association between sleep quality and BMI, among young adults. Blumfield et al (Blumfield et al., 2018) demonstrated that disinhibited eating behavior mediated the association between poor sleep quality and obesity. This is consistent with our finding on the role of emotional eating as a mediator of the association between sleep quality and BMI. Our results suggest that when sleep is neglected and participants are unable to cope with emotionally negative situations (sadness, anger, anxiety, nervousness, etc.), they turn to food for comfort. This is also in line with another study that showed that greater emotional eating scores were associated with poor sleep quality among young women (Dweck et al., 2014). Importantly, the authors also demonstrated that short sleep duration *per se* could act as a stressor, increasing food consumption in those participants who were prone to emotional eating (Dweck et al., 2014). Note that eating sweet and fatty foods is known to alleviate behavioral signs of distress (Gibson, 2006; Penaforte, Minelli, Rezende, & Japur, 2019). Interestingly, our results showed that the consumption of fast-food, commercially baked goods or pastries, and sweets or candy is associated with a higher emotional eating score. Therefore, it is plausible that participants with poor sleep quality are using food as a coping mechanism (Dinis & Bragança, 2018).

Furthermore, our results revealed that cognitive restraint was the strongest predictor of BMI. According to the literature, this is possible since chronic food restriction could alternate with episodes of overeating, which could lead to weight gain (Herman & Mack, 1975; Martin-Garcia et al., 2016; Polivy & Herman, 1985). This weight gain could also lead to greater restriction, becoming a vicious circle (Herman & Mack, 1975; Martin-Garcia et al., 2016; Polivy & Herman, 1985). Therefore, it is plausible that poor sleep quality increases the risk for overeating in response to emotional stress, leading young adults to make a conscious effort to control food intake to manage their body weight. Interestingly, we observed that young adults with poor sleep quality reported taking small portions of food to control their weight, limited food intake to avoid gaining weight, and/or avoided some foods because they made them fat.

In line with the aforementioned, we demonstrated that participants with the highest cognitive restraint score were those who did not consume commercially baked goods or pastries for breakfast. In parallel, healthy eating habits, such as consuming two servings of fruits and vegetables per day were associated with greater cognitive restraint. These findings are consistent with other studies which demonstrated that perceptions about the healthiness of foods may be highly relevant to food intake among participants with greater cognitive restraint (Provencher, Polivy, & Herman, 2009; Racine, 2018). Note that perceptions about the healthiness or ‘‘fatteningness’’ of foods may bias the estimates of the caloric content of foods and, unsurprisingly, this could be counterproductive as a weight management strategy (Provencher et al., 2009). In fact, experimental studies have shown that young adults who usually choose low-calorie or “healthy” foods for weight control are more likely to underestimate the caloric content of food and end up consuming more calories (Provencher et al., 2009; Racine, 2018). Consequently, evidence has shown that young adults with greater dietary restraint are more likely to be overweight (Racine, 2018; Ramírez-Contreras et al., 2021). Likewise, in our study, a 1-point increment in the cognitive restraint score was associated with ~1.22 kg/m^2 more BMI. Although, the role of cognitive restraint in the relationship between sleep quality and BMI may differ based on age. In this regard, Barragan et al (Barragán et al., 2021) showed that among subjects aged 20–73 years the association between poor sleep quality and BMI was moderated by cognitive restraint.

Among other relevant findings, we observed that greater uncontrolled eating was significantly associated with poor sleep quality. It is worth noticing that the impact of sleep loss extends to primary reward-motivated behaviors, including a desire for appetizing food, a greater preference for higher caloric foods, and a higher tendency to overeat (Goldstein & Walker, 2014; Greer, Goldstein, & Walker, 2013; M. P. St-Onge et al., 2012). This, according to a recent meta-analysis (Al Khatib et al., 2017), implies that lack of sleep increases motivation to search for food to obtain a reward. This could explain why, in our study, participants with poor sleep quality felt that they could not stop eating once they had started and also that it was difficult to stop eating before finishing all the food on their plate. It is also worth noting that higher uncontrolled eating was associated with unhealthy eating habits, such as eating sweets and candy daily, and consuming fast-food more than once a week.

Our results also revealed that poor sleep quality was significantly associated with lower adherence to the Mediterranean diet, which is consistent with other studies (Ferranti et al., 2016; Godos et al., 2019). However, a novel finding of our study is that, a regular consumption of nuts, important food staple in the Mediterranean diet (at least 2-3 times/week) was associated with higher sleep quality. It should be noted that nuts are high in folate, magnesium, fiber, and tryptophan (Burrows et al., 2020; Mossavar-Rahmani et al., 2017). The latter is converted by the body into serotonin and melatonin. Note that melatonin is essential for sleep regulation (Burrows et al., 2020). Thus, it is plausible that the combination of several nutrients present in nuts is related to a higher sleep quality (Burrows et al., 2020; Marie-Pierre St-Onge, Mikic, & Pietrolungo, 2016; Yamamoto et al., 2018; Zuraikat, Wood, Barragán, & St-Onge, 2021). Therefore, future intervention studies should focus on studying the potential role of nuts as a sleep-promoting foods.

Regarding other characteristics of the Mediterranean diet and its association with sleep quality, we observed that regular fish consumption (at least 2-3 times/week) was also associated with higher sleep quality, which is in line with other studies (Del Brutto et al., 2016; Hansen et al., 2014). It is worth noting that consumption of oily fish is an important dietary source of long-chain omega-3 polyunsaturated fatty acids, including eicosapentaenoic and docosahexaenoic acids, which play a role in serotonin secretion (Del Brutto et al., 2016). The latter is involved in sleep regulation, especially since serotonin is converted in the body to melatonin, as mentioned above (Burrows et al., 2020).

In contrast, our results showed that attending a fast-food restaurant more than once a week was associated with poor sleep quality. Keep in mind that fast-food restaurants offer energy-dense foods that are known to be high in fat and sugar, but low in fiber. Therefore, this result would be in line with St-Onge et al (M. St-Onge et al., 2011; Marie-Pierre St-Onge et al., 2016; Zuraikat et al., 2021) findings, which revealed that a higher saturated fat intake and a lower consumption of fiber were associated with more nighttime awakenings and reduced overall sleep quality. However, we cannot ignore that the association between diet and sleep quality is bidirectional (Burrows et al., 2020). Therefore, it is also plausible that poor sleep quality can exacerbate the food-seeking behavior, especially for palatable foods (Blumfield et al., 2018; Greer et al., 2013).

Our study has certain limitations, starting with the observational nature of the study that prevents us from claiming causation and the use of use of self-reported data weight and height. In addition, we acknowledge the use of self-reported data to evaluate diet quality and eating behaviors as a limitation of the study. To help avoid underreporting in future studies, we suggest the use of objective data, including actigraphy to assess sleep quality, as well as the measurement of body composition to assess nutritional status. However, our sample size is large enough to provide sufficient strength for the associations of sleep quality with diet quality, eating behaviors, and BMI.

In summary, our findings indicate that emotional eating and cognitive restraint could underlie the association between poor sleep quality and higher BMI among young adults. In this context, it is likely that young adults with poor sleep quality are more likely to cope with negative emotions with food, which, in turn, could be associated with higher cognitive restraint, becoming a vicious cycle that has a negative impact on body weight. It is also worth noting that eating habits differed as a function of eating behaviors, being emotional and uncontrolled eating associated with a higher consumption of fast-food and sweets (only in the case of emotional eating). Meanwhile, cognitive restraint was related to the consumption of fruits and vegetables, and a lower consumption of commercially baked goods. Although, the latter was not associated with a lower BMI. These findings could open a new framework when designing strategies for obesity prevention in young adults, which according to our results, should consider both sleep and eating behaviors. Finally, our data also revealed that sleep quality has a significant association with the adherence to the Mediterranean diet, suggesting the potential role of nuts and fish as sleep promoting foods in this population.

Author Contributions

MFZR, TC and MIP designed the study; MFZR, TC and MIP acquired the data; MFZR and AH analyzed the data; MFZR wrote the first draft; AH, TC, and MIP revised the manuscript. All authors read and approved the final manuscript.

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Ethical Statement

All study procedures were conducted according to the Declaration of Helsinki and were approved by the Ethics Committee the University of Barcelona (IRB00003099).

Conflict of Interests

The authors declare no conflict of interest.

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Figure Captions

Figure 1. Path diagram for the total effect of sleep quality on the body mass index (BMI) and the indirect effects of sleep quality on the BMI through the potential mediation of emotional eating and cognitive restraint. In the top diagram "c" is the total effect of exposure (X) on outcome (Y) ignoring the mediator (M). In the bottom diagram, the mediation of the effect of sleep quality on the BMI through diet quality and eating behaviors (emotional eating and cognitive restraint) is shown, where "a" is the effect of exposure on mediator and "b" is the effect of mediator on outcome. Effect c' is the direct effect of exposure on outcome while adjusting for the mediator.

Figure 2. Mediation model highlighting the effect of sleep quality on BMI via emotional eating and cognitive restraint. Unstandardized coefficients [95% confidence interval] are shown. The model was adjusted for age, gender, chronotype, diet quality, and physical activity. Solid lines indicate statistically significant paths, while dotted lines indicate non-significant paths; ***p<0.001.

Figure 3. Associations between Pittsburg Sleep Quality Index and the 16 items of the Mediterranean Diet Quality Index. General linear model adjusted for age, gender, BMI, physical activity, and chronotype were conducted to test these associations. P-values were corrected using the Benjamini–Hochberg method, assuming a False Discovery Rate (FDR) of 5%. *p<0.05

Table 1. General characteristics of the population studied.

Total sample, n	925
Age, years	21.4 (2.5)
Gender, %women	77.8
Sleep variables	
Sleep quality, score	5.4 (2.5)
Good sleep quality, %	40.8
Chronotype (MSF), hh:mm	04:47 (1.11)
BMI, kg/m^2	21.8 (3.1)
Diet quality, score	7.0 (2.2)
Poor (≤3 points), %	5.9
Average (4–7 points), %	47.6
Good (8–12 points), %	46.5
Eating behavior	
Emotional eating, score	1.7 (0.6)
Cognitive restraint, score	2.1 (0.5)
Uncontrolled eating,score	2.0 (0.6)
Physical activity, METs	2 161.1(1 722.6)

BMI, Body mass index; METs, Metabolic Equivalents of Task; MSF, Midpoint of sleep in free-days. Data are expressed as mean and standard deviation for continous data, and percentages for categorical data.

Table 2. Associations between the Pittsburgh Sleep Quality Index (PSQI) and the body mass index (BMI) with diet quality and eating behaviors (emotional eating, cognitive restraint and uncontrolled eating).

	PSQI, score		**BMI**, kg/m^2	
	β [95%CI]	*p-value*	*β [95%CI]*	*p-value*
Diet quality, score	-0.14 [-0.19; -0.08]	**<0.00001**	0.04 [-0.05; 0.13]	0.339
Eating behaviors				
Emotional eating, score	0.04 [0.03; 0.06]	**<0.00001**	0.89 [0.60; 1.18]	**<0.00001**
Cognitive restraint, score	0.03 [0.01; 0.04]	**<0.001**	1.37 [1.02; 1.71]	**<0.00001**
Uncontrolled eating, score	0.02 [0.01; 0.04]	**0.001**	0.10 [-0.24; 0.44]	0.556

CI, confidence interval. Associations between sleep quality and BMI were tested using linear regression analyses. All analyses were adjusted for age, gender, BMI, diet quality, physical activity, and chronotype (except when the covariate was the dependent variable of the model). The table shows the unstandardized coefficient (β), CI, and p-value associated with each predictor variable. Significant p-values are shown in bold.

Table 3. Summary of indirect effects from sleep quality[1] to BMI.

	Coefficient	S.E.	95% CI
Direct effect	0.01	0.04	-0.06; 0.09
Total indirect effect	0.07	0.02	0.04; 0.10*
Indirect effect (via mediators)			
Emotional eating	0.03	0.01	0.02; 0.06*
Cognitive restraint	0.04	0.01	0.02; 0.06*

BMI, Body mass index. [1]Sleep quality was measured with the Pittsburg Sleep Quality Index. Pathway analyses were conducted using the PROCESS tool. Analyses were adjusted for age, gender, chronotype, diet quality, and physical activity. *p<0.05

Table 4. Associations between eating behaviors (cognitive restraint, emotional eating and uncontrolled eating) and the 16 items of the Mediterranean Diet Quality Index. General linear model adjusted for age, gender, BMI, physical activity, and chronotype were used to calculate adjusted differences between categories, the reference category was 'Yes'. P-values were corrected using the Benjamini–Hochberg method, assuming a False Discovery Rate (FDR) of 5%. *p<0.05, ***p<0.001.

	Emotional eating, score β [95% CI]	**Cognitive restraint**, score β [95% CI]	**Uncontrolled eating**, score β [95% CI]
First serving of fruit, daily	0.01 [-0.09; 0.11]	0.06 [-0.02; 0.14]	-0.06 [-0.15; 0.03]
Second serving of fruit, daily	-0.06 [-0.14; 0.02]	0.11 [0.04; 0.18]*	-0.09 [-0.16; -0.01]
Fresh or cooked vegetables, daily	-0.05 [-0.16; 0.06]	0.19 [0.10; 0.28]***	-0.12 [-0.21; -0.02]
Fresh or cooked vegetables, >1 time/day	-0.02 [-0.10; 0.07]	0.13 [0.06; 0.20]***	-0.08 [-0.16; -0.01]
Regular fish consumption, 2-3 times/week	-0.01 [-0.10; 0.07]	0.05 [-0.02; 0.11]	-0.09 [-0.17; -0.02]
Fast-food, >1 time/week	0.30 [0.18; 0.42]***	-0.05 [-0.15; 0.05]	0.26 [0.15; 0.37]***
Legumes, >1 time/week	-0.04 [-0.14; 0.06]	0.02 [-0.06; 0.10]	-0.07 [-0.15; 0.02]
Pasta or rice, ≥ 5 times/week	-0.01 [-0.09; 0.07]	-0.06 [-0.13; 0.01]	0.05 [-0.03; 0.12]
Cerales/grains for breakfast	0.00 [-0.12; 0.13]	0.07 [-0.03; 0.17]	0.06 [-0.05; 0.17]
Regular nut consumption, 2-3 times/week	-0.01 [-0.09; 0.08]	0.08 [0.01; 0.15]	-0.07 [-0.15; 0.00]
Use of olive oil at home	-0.22 [-0.54; 0.10]	-0.19 [-0.45; 0.07]	-0.18 [-0.46; 0.11]
Skipping breakfast	0.01 [0.16; -0.14]	0.11 [-0.01; 0.24]	0.08 [-0.05; 0.21]
Dairy product for breakfast	-0.08 [-0.17; 0.01]	-0.06 [-0.13; 0.02]	0.01 [-0.07; 0.10]
Commercially baked goods or pastries for breakfast	0.15 [0.04; 0.25]***	-0.16 [-0.25; -0.08]***	0.11 [0.01; 0.20]
Yogurts or cheese, daily	-0.08 [-0.16; 0.00]	-0.01 [-0.78; 0.06]	-0.03 [-0.10; 0.04]
Sweets and candy, every day	0.29 [0.08; 0.49]***	-0.15 [-0.32; 0.02]	0.24 [0.06; 0.42]*