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Does sleep affect weight gain? Assessing subjective sleep and polysomnography measures in a population-based cohort study (CoLaus/HypnoLaus)

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Abstract

Study Objectives: Although several studies have linked short and long sleep duration to weight gain, mixed results exist. Contrarily, few studies associated objectively measured sleep characteristics with weight gain. We investigated the association between several sleep characteristics measured by questionnaire and polysomnography with prospective weight gain in a population-based, middle-aged cohort.

Methods: Three samples were analyzed: sample 1 (n=2551, 47.3% men, 56.9±10.3 years) had data for subjective sleep characteristics, sample 2 (n=1422, 49.4% men, 57.6±10.4 years) had objective sleep assessment (polysomnography) and sample 3 consisting of 1259 subjects included in both samples. Multivariable logistic regressions were performed to assess the relationship between sleep characteristics and ≥5 kg weight gain during a median follow-up of 5.3 years.

Results: In both study samples 12% of the subjects gained ≥5 kg during follow-up. Multivariable analyses showed poor subjective sleep quality [as assessed by Pittsburgh sleep quality index: odds ratio (95% confidence interval): 1.54 (1.19-1.99)]; percentage of sleep spent in stage 2 [1.32 (1.10-1.58)] and under 90% oxygen saturation (SpO_2<90) [1.23 (1.07-1.41)]; moderate/severe oxygen desaturation index [1.70 (1.01-2.85)] and autonomic arousal duration [1.22 (1.02-1.45)] were related to ≥5 kg weight gain. Only poor subjective sleep quality was robustly associated with weight gain in all sensitivity analyses, except in female subsamples.

Conclusions: Poor subjective sleep quality, and to some extent moderate to severe oxygen desaturation, but no other sleep characteristics, were robustly associated with weight gain. Future studies should confirm the relationship between sleep quality and weight gain, assess sex differences and investigate underlying mechanisms.

Keywords: weight gain; obesity; sleep characteristics; polysomnography; population-based cohort study; middle-aged adults

Statement of Significance

Most studies investigating the effect of sleep characteristics on prospective weight gain in adults report clinically insignificant weight gain, rely on non-representative samples, and fail to adjust for important confounders, which results in inconsistent findings. In this large population-based cohort, we prospectively investigated the associations between ≥5 kg weight gain over a median follow-up of 5.3 years and sleep characteristics measured by polysomnography and questionnaire. Only subjective sleep quality, and to some extent oxygen desaturation related variables (ODI and SpO_2<90), were related to weight gain, whereas sleep duration and other sleep characteristics were not. Potential sex differences, as well as mechanisms linking subjective sleep quality and oxygen desaturation variables with weight, should be further investigated.

Introduction

The increasing prevalence of overweight and obesity over the past decades[1] has paralleled the reduction in sleep duration[2] and the increase in sleep complaints.[3,4] Whereas short sleep duration consistently predicts weight gain or obesity in children,[5] this association remains rather unclear in adults.[5,6] Poor sleep quality has been linked to obesity and overweight independently of sleep duration in women,[7] and good sleep quality has been associated with weight loss in overweight adults[8] respectively women.[9] To our knowledge, no study so far has linked sleep quality with prospective weight gain in non-pregnant middle-aged to elderly healthy adults. Associations between other sleep characteristics including long sleep duration,[10] obstructive sleep apnea[11] or sleep fragmentation[12] and weight gain and/or incident obesity have been reported, and are possibly mediated by reduced quality and in case of sleep disturbances by quantity of sleep. However, most longitudinal studies investigating the effect of sleep on weight gain relied either on self-reported[5] or objective measures,[11,12] or were carried out in non-population based samples,[7,13] or failed to adjust for important confounders such as dietary intake.[12,13] Indeed, to our knowledge, no study ever assessed the associations between a large range of subjectively and polysomnographically-assessed sleep characteristics and weight gain in a population-based sample. Hence, we conducted an exploratory study to assess which subjective and objective sleep characteristics are associated with weight gain.

Although evidence is inconclusive regarding the relationship between sleep duration and weight gain, and scarce regarding the association between other sleep characteristics and weight gain, previous studies suggest that unfavorable sleep characteristics are related to weight gain.[6,10–12] Hence, we aimed to associate a range of sleep characteristics measured by questionnaire and polysomnography with weight gain over a median follow-up of 5.3 years in a middle—aged to elderly population-based sample. We hypothesized that short sleep duration, poor sleep quality and sleep disturbances would be associated with weight gain.

Methods

Population sampling

HypnoLaus is a population-based sleep cohort study conducted in Lausanne, Switzerland. The HypnoLaus study was performed between September 1, 2009 and June 30, 2013 and participants were recruited among the CoLaus study.[14] Participants of the CoLaus study were identified from a random sample of adults aged 35-75 years living in the city of Lausanne, Switzerland (117,161 habitants),[15] and the initial cohort included 6,733 participants (52.5% women). The CoLaus study was conducted to assess the prevalence and determinants of cardiovascular risk factors and cardiovascular disease, and to identify new determinants of these risk factors.

For the HypnoLaus study, the first consecutive 3,043 participants of the first follow-up of the CoLaus study (hereafter referred to as baseline) were invited to undergo one full night polysomnography (PSG) at home. Out of these, 2,168 (71%) accepted the invitation, but 60 (3%) had technical problems and were invited to undergo a second PSG; six participants declined and 54 participants agreed.[16] Therefore, 2,162 complete PSG recordings were obtained in the HypnoLaus cohort and included in this study.

All participants were contacted again to participate in the follow-up (median follow-up time 5.3, average 5.3 (SD 0.6), interquartile range 5.1-5.5 years), which was performed between May 2014 and April 2017.

Clinical data collection

Participants from CoLaus/HypnoLaus study were invited to attend the outpatient clinic at the University Hospital of Lausanne (CHUV, Lausanne, Switzerland) in the morning after an overnight fasting for clinical assessment and questionnaires completion. Body weight and height were measured using a calibrated scale and a vertical stadiometer, respectively (Seca®, Hamburg, Germany). BMI was calculated as body mass in kg divided by the square of the participant's height in meters. Abdominal girth was measured mid-way between the lowest rib and the iliac crest using a non-stretchable tape and the average of two measurements was taken. Weight gain and increase in abdominal girth during follow-up time were dichotomized (<5 kg and ≥5 kg resp. <5 cm and ≥5 cm) in order to assess only clinically important changes and reduce measurement error. Thresholds were chosen based on a WHO recommendation to not exceed 5 kg weight gain in adult life.[17]

Subjective sleep characteristics

Self-reported sleep duration stemmed from the Pittsburgh Sleep Quality Index (PSQI) and was categorized as short (<6 h), normal (6-8 h) and long (>8 h). Data on subjective sleep duration was available at baseline and follow-up. Sleep quality was measured by PSQI and dichotomized into good/poor sleep quality (≤5/>5),[18] and excessive daytime sleepiness (EDS) was assessed using the Epworth sleepiness scale (ESS >10).[19]

Polysomnography

PSG was performed at baseline. A detailed description of the PSG procedure is described in **supplementary file 1**. The following PSG measures were used in the analyses: total sleep time (TST): time spent asleep in minutes from sleep onset to morning awakening categorized as <6 h, 6-8 h & >8 h; stage 1 and 2, slow wave sleep and rapid eye movement (REM): measured as percentage of total sleep time; sleep efficiency: percentage of total time in bed spent asleep; sleep apnea (OSA) severity: number of apneas/hypopneas per hour of sleep (AHI) categorized as follows: no (AHI<5 events/h of sleep), mild (5≤AHI<15 events/h of sleep), moderate/severe (AHI≥15 events/h of sleep). Severity of oxygen desaturation index (ODI) was defined as the number of ≥ 3% oxygen saturation drops per hour of sleep and categorized as follows: normal (ODI<5 drops/h of sleep), mild (5≤ODI<15 drops/h of sleep), moderate/severe (ODI≥15 drops/h of sleep); mean SpO2: mean oxygen saturation; SpO2 <90: percentage of total sleep time spent under a 90% oxygen saturation threshold; arousal index (ArI): number of arousals measured by EEG per hour of TST; autonomic arousal index (AArI): number of autonomic arousals measured by pulse oxymetry and defined as pulse wave amplitude drops >30%, per hour of TST; autonomic arousal duration (AArD): duration of autonomic arousal in seconds; periodic limb movement index during sleep (PLMSI): number of periodic limb movements divided per hours of sleep. In order to be consistent with the literature,[5,6,8,9,11] we categorized sleep duration, PSQI, and AHI, which subsequently led to the categorization of EDS and ODI.

Covariates

Age, sex, educational attainment (mandatory, apprenticeship, high school, university), marital (living alone or in couple) and smoking (current, former, never) status were collected using questionnaires.

Dietary intake was assessed using a validated food frequency questionnaire querying the consumption of 97 different food items including portion size over the previous four weeks.[20] The alternative healthy eating index (AHEI) was adapted from McCullough et al.[21] In our study, the amount of trans fat could not be assessed, and we considered all participants taking multivitamins as taking them for a duration of ≥5 years. Thus, the modified AHEI score ranged between 2.5 and 77.5 instead of 2.5 and 87.5 for the original AHEI score.[21] Higher values represented a healthier diet.

Physical activity was assessed by the physical activity frequency questionnaire, which has been validated in the population of Geneva.[22] This self-reported questionnaire assesses the type and duration of 70 kinds of (non-)professional activities and sports during the previous week. Sedentary behaviour was defined as spending more than 90% of the daily energy in activities below moderate- and high-intensity (defined as requiring at least 4 times the basal metabolic rate, BMR).[23] BMR multiples are close to Metabolic Equivalent of Task (MET) multiples, although MET multiples do not take into account participant sex, age or height. Change in sleep duration was defined as change in self-reported sleep duration category (from PSQI) between baseline and follow-up (i.e. from <6 h to 6-8 h). In order to be consistent with previous literature,[24] we categorized change in sleep duration as increasing, maintaining and decreasing.

Statistical analyses

All statistical analyses were performed using STATA 15.1 (Stata-Corp, College Station, TX, USA). As only a subsample of the cohort underwent full PSG, we constructed two study samples to analyze the relationship between 1) subjective sleep characteristics and 2) PSG sleep characteristics and weight gain (the two study samples partly overlap; **supplementary figure 1)**. The study samples were characterized by descriptive statistics, and the prevalence of sleep characteristics was reported according to <5kg / ≥5kg weight gain over a median follow-up time of 5.3 years. Categorical variables were summarized as the number of subjects with column percentages, and continuous variables as means with standard deviation. Pearson chi-square (for categorical variables) or ANOVA (for continuous variables) were used to evaluate differences in sleep characteristics between weight gain groups. Multivariable logistic regressions were performed to assess the association between subjective and objective sleep characteristics and weight gain over the follow-up period for each variable separately. Continuous variables were standardized and odds ratios with 95% confidence intervals (CIs) were obtained. We adjusted for age, sex, education, living alone status, AHEI, sedentary behavior, smoking status (never, former, current) and BMI at baseline. We also performed all analyses on the overlapping sample (i.e. participants having both subjective and objective sleep data, see **supplementary figure 1**).

We performed several sensitivity analyses to check for the robustness of our results; Firstly, as data was not missing at random, we used inverse probability weighting to adjust for a potential bias resulting of the exclusion criteria and thus specified a missingness model. Secondly, we performed sex-stratified analyses. Thirdly, we adjusted all analyses for change in subjective sleep duration as experimental studies indicate that sleep curtailment is associated with weight gain.[25] Fourthly, we performed linear regression analyses with weight change as a continuous variable. Fifthly, we performed the same analyses for abdominal girth increase (≥5 cm) over a median follow-up time of 5.3 years for the full sample and additionally stratified for sex, as part of the female sample was likely to become postmenopausal during follow-up time. Sixthly, we excluded subjects that were obese at baseline. Seventhly, we adjusted all analyses for follow-up time. Lastly, whereas most analyses were exploratory, we hypothesized that short sleep duration, poor sleep quality and high sleep fragmentation (measured by sleep efficiency and total arousal index) were related to weight gain. Thus, we adjusted the significance threshold for these four variables using the Bonferroni correction, and lowered the p-value to 0.0125 (i.e. 0.05/4).

All sensitivity analyses were performed on the subjective and PSG sample separately, not on the common sample.

Exclusion criteria

Participants were excluded from the analyses when they 1) were lost to follow-up, 2) had missing data on BMI at baseline or follow-up, 3) were on a slimming diet at baseline or follow-up, 4) had missing covariates, and missing data either 5a) on subjective sleep characteristics or 5b) on PSG sleep characteristics.

Ethical statement

The institutional Ethics Committee of the University of Lausanne, which afterwards became the Ethics Commission of Canton Vaud (www.cer-vd.ch) approved the CoLaus and HypnoLaus study and the approval was renewed for the follow-ups. All participants gave their signed informed consent before entering the study.

Results

Study population and characteristics

Of the initial 5064 subjects participating, 2551 (50.4%) were retained for subjective sleep characteristics and of the 2162 subjects undergoing full PSG, 1422 (65.8%) were retained for objective sleep characteristics. The reasons for exclusion are summarized in **figure 1** and the comparison between included and excluded participants is summarized in **supplementary table 1**. In both samples, excluded subjects lived more frequently alone, had lower AHEI, were more often current smokers, and had higher BMI at baseline compared to included subjects. Excluded subjects from the sample analyzing subjective sleep characteristics were older and with higher educational level compared to included subjects (**supplementary table 1**). Excluded subjects from the sample investigating PSG sleep characteristics were more frequently women and with lower educational level compared to included subjects (**supplementary table 1**).

Figure 1 Exclusion procedure, HypnoLaus study, Lausanne, 2009-2017

Table 1 summarizes the characteristics of the study sample according to weight gain over a median follow-up time of 5.3 years. In both study samples, 12% of the subjects gained ≥5 kg during follow-up time. Subjects gaining ≥5 kg were younger, more often living alone, had a lower AHEI and a higher BMI at baseline compared to subjects gaining less than 5 kg. Subjects increasing their sleep duration between baseline and follow-up were more likely to gain weight in the subjective sample.

Association between sleep characteristics and weight gain

Table 2 displays bivariate relationships between subjective and PSG sleep characteristics with ≥5 kg weight gain. Subjects gaining ≥5 kg reported lower sleep quality and more frequently EDS. In the study sample undergoing PSG, subjects with ≥5 kg weight gain had higher sleep efficiency, spent a higher percentage of time under 90% SpO_2 and had a lower PLMSI.

In multivariable analyses, poor sleep quality (PSQI) was associated with ≥5 kg weight gain over a median follow-up time of 5.3 years in the subjective [OR 1.54; 95% CI (1.19-1.99)] (**table 3**) as well as in the common sample [1.66 (1.16-2.37)] (**table 4**). Subjective sleep duration and EDS were not related to ≥5 kg weight gain (**tables 3 and 4**).

Higher percentage of total sleep time spent in stage 2 [1.32 (1.10-1.58) resp. 1.32 (1.08-1.60)] and under 90% oxygen saturation (SpO_2<90%) [1.23 (1.07-1.41) resp. 1.27 (1.10-1.47)] was related to gaining ≥5 kg over follow-up time. Moderate/severe ODI [1.70 (1.01-2.85) resp. 1.92 (1.11-3.32)] was associated with ≥5 kg weight gain compared to normal ODI. Increased autonomic arousal duration [1.22 (1.02-1.45) resp. 1.26 (1.05-1.52)] was related to ≥5 kg weight gain. Whereas all these sleep characteristics were associated with weight gain in both the PSG (**table 3**) and the common sample (**table 4**), higher percentage of total sleep time spent in slow wave sleep [0.82 (0.68-1.00)] was associated with ≥5 kg weight gain only in the common sample (**table 4**). No association was found for all other PSG sleep characteristics and ≥5 kg weight gain (**tables 3 and 4**).

Sensitivity analyses

In the first sensitivity analysis, in which the main analyses were inverse probability weighted for exclusion, the associations remained stable, whereas moderate/severe ODI was borderline significant (**supplementary table 2**). Additionally, a lower percentage spent in slow wave sleep was associated with weight gain.

In the second, sex-stratified sensitivity analysis, associations between SpO_2<90% and weight gain remained stable in both sexes, whereas the relationship between autonomic arousal duration and weight gain was no longer significant. The association between poor sleep quality and weight gain remained for male but not for female subjects. Contrarily, the associations between stage 2 and moderate/severe ODI with weight gain remained for female but not for male subjects. Male subjects reporting short sleep duration had higher odds for ≥5 kg weight gain; however, when further adjusting for change in sleep duration, these associations disappeared (data not shown). Male subjects with higher autonomic arousal index were less likely to gain ≥5 kg weight (**supplementary table 3**).

In the third sensitivity analysis additionally adjusting for change in subjective sleep duration, the association with weight gain remained for stage 2 and $SpO_{2,}$ but was no longer significant for sleep quality, moderate/severe ODI and autonomic arousal duration (**supplementary table 4**).

In the fourth sensitivity analysis investigating the association between sleep characteristics and continuous weight change between baseline and follow-up, poor sleep quality, moderate ODI and PLMSI were related to gaining weight (**supplementary table 5**).

In the fifth sensitivity analysis, short subjective sleep duration, poor sleep quality and autonomic arousal index were associated with ≥5 cm increase in abdominal girth in full sample. Men reporting short sleep duration and poor sleep quality had higher odds of ≥5 cm increase in abdominal girth compared to men without these sleep complaints (**supplementary table 6**). However, the associations with short sleep duration were no longer significant when adjusting for change in sleep duration (data not shown). In women, only percentage spent in REM was associated with ≥5 cm abdominal girth increase (**supplementary table 6**).

In the sixth sensitivity analyses, in which we excluded subjects that were obese at baseline, associations between poor sleep quality, stage 2, and SpO_2<90% with weight gain remained stable (**supplementary table 7**). Additionally, low SWS was associated with weight gain.

In the seventh sensitivity analyses with further adjustment for follow-up time, all associations remained stable (**supplementary table 8**).

Lastly, after applying the Bonferroni correction, poor sleep quality remained associated with weight gain.

Discussion

This is the first study to evaluate the association between both subjective and PSG measured sleep characteristics and weight gain in a middle-aged, population-based sample. We found that subjective sleep quality, and to some extent oxygen desaturation related variables, were related to weight gain, whereas other sleep characteristics such as sleep duration were not.

Sleep duration and weight gain

As both reported and PSG-measured short or long sleep duration were not robustly associated with weight gain, we reject our hypothesis that short sleep duration is associated with weight gain.

Those findings are in line with a review reporting mixed results regarding this association in middle-aged populations,[5] and with a review reporting no longitudinal association between objectively measured sleep duration and weight gain.[26] Nevertheless, our results contradict a meta-analyses reporting an effect of short[6] and long[10] sleep duration on incident obesity. It should be noted that, in studies reporting an effect of short and long sleep duration on weight gain, the weight gains over time were clinically non-relevant (0.15kg/m^2 over 4 years, respectively 1.14 kg over 16 years),[13,27] and that the meta-analyses on incident obesity[6,10] included studies that failed to adjust for important confounders such as dietary intake.[12,13] Also, laboratory studies reporting an effect of sleep restriction on weight gain in adults[25] do not reflect real-life conditions, as their results mirror the effect of a transition into short sleep rather than the effect of chronic short sleep status. The results from the sensitivity analyses support this hypothesis, as the association between self-reported short sleep duration, weight gain as well as abdominal girth increase in men, was cancelled with the inclusion of change in subjective sleep duration between baseline and follow-up. A possible explanation for the lack of association is that subjects with short sleep are used to higher calorie intake.[5] Overall, our results suggest that both subjective and objective short and long sleep duration are not associated with weight gain.

Sleep quality and weight gain

Subjective poor sleep quality was associated with weight gain. This finding is in line with previous studies reporting that poor sleep quality was associated with incident obesity[28] and good sleep quality [measured by PSQI] was associated with weight loss in obese[8] and increased the likelihood of weight loss success.[9] A recent review suggested that psychological stress plays an important role in this association, as stress negatively impacts subjective sleep quality and vice-versa, leading to weight gain.[29] The relationship between sleep quality and weight gain remained stable in our sensitivity analyses except for women. We assume that we did not find an association between sleep quality and increase in weight or abdominal girth in women because a large share of women turned menopausal during the follow-up time. Overall, our results support our hypothesis that poor subjective sleep quality is associated with weight gain. However, further studies are needed to confirm those findings and assess whether the association differs by sex.

Sleep architecture and weight gain

Whereas stage 2 was associated with weight gain, other sleep stages were either unrelated (stage 1 and REM) or inconsistently related (SWS) with weight gain. The association between increased stage 2 (and lower SWS in some sensitivity analysis) and weight gain suggests that "lighter sleep", which may be due to sleep fragmentation, is associated with weight gain. This finding is in line with a previous study showing an association between greater sleep fragmentation and higher BMI[12] as well as with a study reporting that higher sleep fragmentation was associated with lower magnitude of weight reduction in a weight-loss program.[30] However, the association between stage 2 and weight gain was not found in men nor when continuous weight change or abdominal girth increase were considered. Furthermore, the (inconsistent) association between lower percentage of sleep time spent in SWS and weight gain is in line with a previous study reporting an inverse relationship between SWS and BMI,[31] and postulate that decreased SWS induces insulin resistance.[32] Higher PLMSI was only spuriously related to weight gain. Interestingly, subjects gaining ≥5 kg had lower PLMSI than subjects gaining less than 5kg. As higher PLMSI is associated with increasing age and male gender,[33] we assume an interaction between PLMSI and these variables in multivariable models.

Sleep apnea, oxygen saturation and weight gain

Few studies assessed the effect of OSA on weight gain. A previous study linked OSA measured by PSG to weight gain after 5 years; still, the increase in BMI (0.53 kg/m^2) was small and clinically irrelevant.[11] In this study, no association was found between OSA measured by the apnea-hypopnea index and weight gain.

However, our results suggest an association between nocturnal oxygen level and weight gain. Of the three variables related to nocturnal oxygen saturation (ODI, mean SpO_2, SpO_2<90), moderate/severe ODI and percentage of sleep spent under 90% oxygen saturation were associated with weight gain. A possible explanation for these associations is that severe chronic intermittent hypoxia affects weight gain by inducing insulin resistance,[34] and decreasing leptin secretion.[35] The lower leptin secretion would then increase food intake, leading to weight gain. Indeed, when adjusting for change in sleep duration, the association between SpO_2<90 and weight gain remained. A possible explanation would be an increased oxidative stress, resulting from chronic intermittent hypoxia[36] that has been linked to weight gain.[37] Contrarily, mean SpO_2 was not related to weight gain. Although SpO_2 and ODI were not related to weight gain in all sensitivity analyses, it is plausible that severe oxygen desaturation is associated with weight gain. Future studies should confirm these associations.

Autonomic arousals and weight gain

Arousals from sleep measured by EEG (ArI) have been linked to central sympathetic activations and peripheral vasoconstrictions that can be detected by PWA drops (autonomic arousals).[38,39] Whereas both arousal indexes were either unrelated or inconsistently related to weight gain, the duration of autonomic arousals – measuring the duration of vasoconstriction – was positively associated with weight gain. This suggests that vessel contractility impairment (i.e. slowly reversible vasoconstrictions) is related to weight gain, but the possible underlying mechanisms are not clear. However, the inclusion of change in subjective sleep duration cancelled this association and the results were unstable in other sensitivity analyses. Overall, our data does not support an association between autonomic arousals and weight gain.

Limitations

We acknowledge several limitations. The possible selection bias due to loss to follow-up could distort our findings and lead to an underestimation of the results, as excluded subjects more often had unfavorable sleep characteristics (**supplementary table 9**). However, when the analyses were inverse probability weighted, the results remained stable, suggesting that the selection bias is marginal. Next, we examined the relationship between a wide range of sleep characteristics and weight gain. Although the problem of multiple testing arises, adjustment for multiple testing is not strictly required in exploratory studies.[40] Still, as we had three initial hypotheses involving four sleep parameters, we lowered the significance threshold according to the Bonferroni method when testing them; importantly, the association between poor sleep quality and weight gain remained significant even after correcting for multiple testing. Next, some of the statistically significant associations might not be of clinical importance. Further, PSG results relied on one single night, and although PSG is considered as the gold standard in sleep studies, it cannot capture night-to-night variability. In order to assess the possible impact of this so-called "first-night effect", PSG was performed at home and 20 randomly selected participants underwent a second PSG at home to determine short-term variability. Only the percentage of TST spent in REM differed between the two nights (21.4±6.7 versus 24.0±5.0%, P = 0.04). Also, PSG sleep characteristics were measured during one night and retrospective self-reported sleep characteristics were based on a longer time frame, limiting the direct comparison between the two. Further, subjective sleep duration is one component of the PSQI questionnaire and analysis of sleep duration and PSQI may be slightly redundant. Lastly, residual confounding of unmeasured covariates such as cardiometabolic risk factors or insomnia cannot be excluded.

Conclusion

Subjective sleep quality, and to some extent moderate to severe oxygen desaturation (ODI and SpO_2<90%), were associated with weight gain. No association was found between weight gain and sleep duration nor with any other sleep characteristics.

List of abbreviations

OR, odds ratio; CI, confidence interval; SpO_2<90, percentage of sleep spent under 90% oxygen saturation; BMI, body mass index; PSG, polysomnography; PSQI, Pittsburgh Sleep Quality Index; EDS, excessive daytime sleepiness; ESS, Epworth sleepiness scale; TST, total sleep time; OSA, obstructive sleep apnea; AHI, apnea/hypopnea index; ODI, oxygen desaturation index; SpO_2, oxygen saturation; ArI, arousal index; AArI, autonomic arousal index; AArD, duration of autonomic arousal;

PLMSI, periodic limb movement index during sleep; AHEI, alternative healthy eating index; BMR, basal metabolic rate; MET, metabolic equivalent of task

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Figure Captions

Figure 1 Exclusion procedure, HypnoLaus study, Lausanne, 2009-2017

Captions for supplementary materials

Supplementary file 1: Description of polysomnography procedure

Supplementary figure 1: Overlapping of subjective and PSG study samples

Supplementary table 1: Characteristics of included and excluded subjects

Supplementary table 2: Results inverse probability weighted

Supplementary table 3: Sex-stratified results

Supplementary table 4: Results adjusted for change in sleep duration

Supplementary table 5: Results for continuous weight change

Supplementary table 6: Results for abdominal girth increase

Supplementary table 7: Results for non-obese subjects at baseline

Supplementary table 8: Results for subjects included in subjective and PSG sample

Supplementary table 9: Sleep characteristics of included and excluded subjects

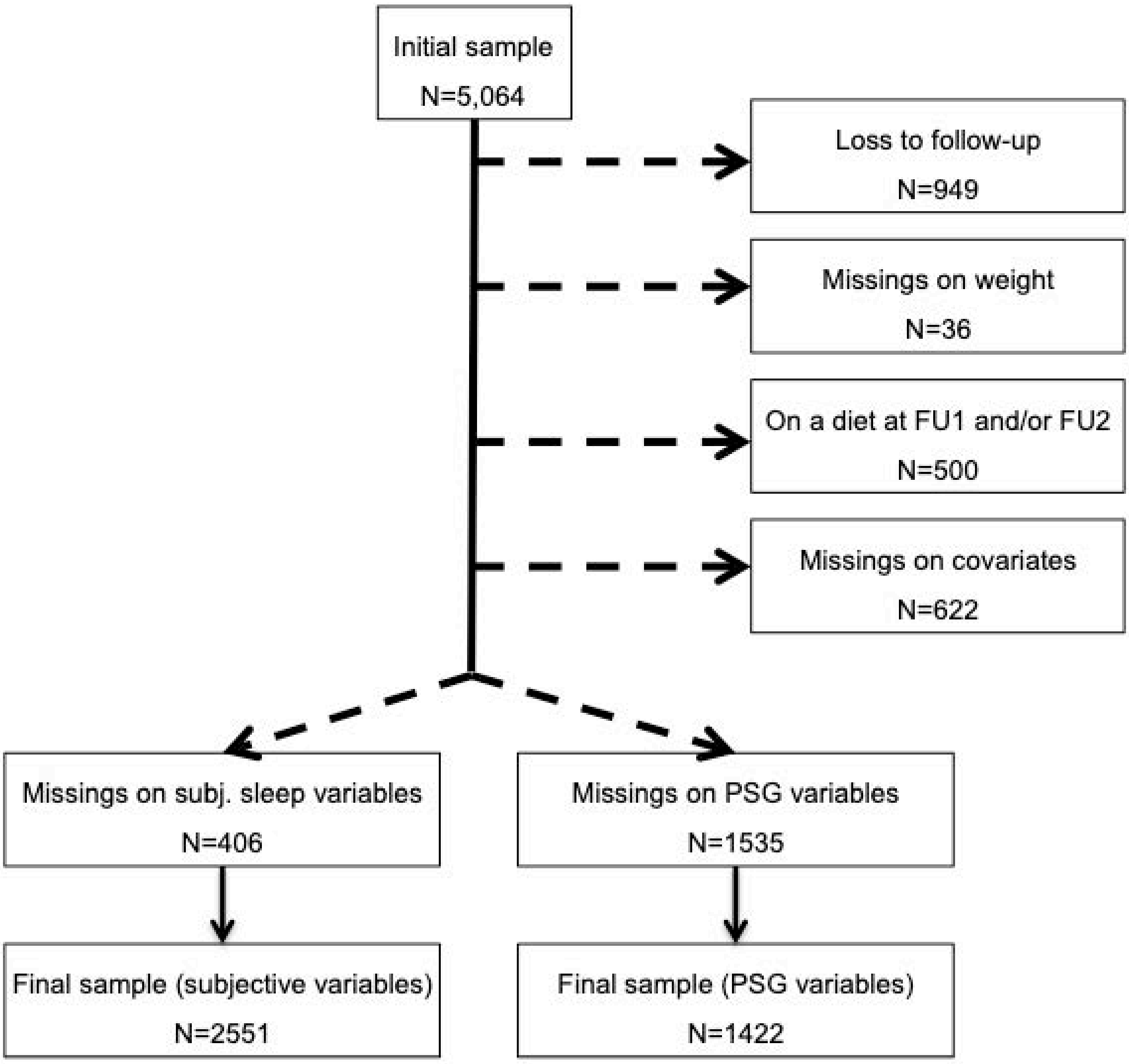

Figure 1 Exclusion procedure, HypnoLaus study, Lausanne, 2009-2017

Supplementary file 1: Polysomnography

An in-home overnight full PSG was performed using a digital portable sleep-wake recording system (EMBLA Titanium®, Embla systems, Inc, Broomfield, USA). A trained technician hooked-up the subject in the CIRS facility (Center for Investigation and Research in Sleep, CHUV, Lausanne, Switzerland). The electrodes and recorder were installed at the laboratory and recordings were done in the normal home environment. PSG measurements included: electroencephalograms (EEG) from frontal, central and occipital areas (F3-M2, C3-M2, O1-M2, F4-M1, C4-M1, O2-M1) according to the international 10/20 electrode configuration system, right and left electrooculograms (EOG), mental-submental electromyogram (EMG), right and left leg EMG, thoracic and abdominal breathing movements by respiratory inductance plethysmography, respiratory airflow by a nasal-cannula connected to a pressure transducer, oxygen saturation (SpO_2) by pulse oxymetry, heart rate by electrocardiogram (ECG), and body position.

PSGs were scored using Somnologica software (Embla systems, Inc, Broomfield, USA) by two experienced scorers, with an inter-agreement concordance greater than 90%. Sleep, arousal and movements during sleep were scored based on the 2007 American Association for Sleep Medicine (AASM) manual for the scoring of sleep and associated events[1]. Concerning respiratory events, apneas and hypopneas were defined according to the 2012 AASM criteria[2]. Each recording was reviewed for validation of the respiratory scoring by a single investigator.

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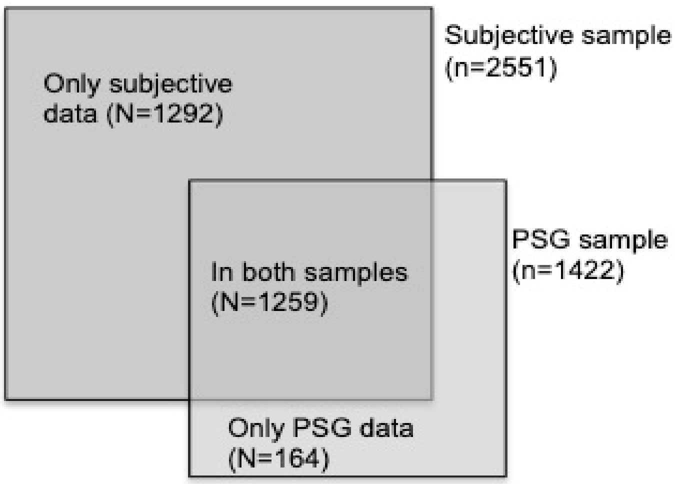
Supplementary figure 1 Distribution of subjective and PSG study samples



Supplementary table 1: Characteristics of the included and excluded subjects in 1) sample analyzing subjective sleep characteristics and 2) sample analyzing objective sleep characteristics.

	Sample analyzing subjective sleep characteristics			**Sample analyzing objective sleep characteristics**		
	Included (N=2551)	Excluded (N=2513)	p-value	Included (N=1422)	Excluded (N=3642)	p-value
Male gender	1208 (47.4)	1149 (45.7)	0.257	703 (49.4)	1654 (45.4)	0.010
Age (years) ±	56.9±10.3	58.7±10.7	<0.001	57.6±10.4	57.8±10.6	0.440
Education level			<0.001			<0.001
Mandatory educ.	329 (12.9)	549 (21.9)		175 (12.3)	703 (19.3)	
Apprenticeship	913 (35.8)	883 (35.2)		519 (36.5)	1277 (35.1)	
High school	706 (27.7)	600 (23.9)		395 (27.8)	911 (25.1)	
University	603 (23.7)	476 (19.0)		333 (23.4)	746 (20.5)	
Living alone status	1004 (39.4)	1151 (46.7)	<0.001	544 (38.3)	1611 (44.8)	<0.001
Alternative Healthy Eating Index	32.1±9.8	31.5±10.6	0.033	32.3±9.7	31.6±10.3	0.027
Sedentary behavior	1432 (56.1)	973 (59.7)	0.023	776 (54.6)	1629 (59)	0.006
Smoking			0.001			<0.001
Never	1098 (43.1)	937 (38.2)		609 (42.8)	1426 (39.8)	
Former	932 (36.5)	951 (38.7)		557 (39.2)	1326 (37)	
Current	521 (20.4)	568 (23.1)		256 (18)	833 (23.2)	
BMI at baseline ±	25.4±4.1	27.0±5.0	<0.001	25.6±4.1	26.4±4.8	<0.001

BMI, body mass index. Results are expressed as N (%) for categorical variables or mean±standard deviation for continuous variables. P-values from Pearson chi2 or ANOVA when appropriate.

Supplementary table 2: Effect of subjective sleep characteristics (N=2551) and 2) PSG sleep characteristics (N=1422) on weight gain (≥5 kg) over 5 years for each variable separately, adjusted for sex, age, education, marital status, alternative healthy eating index, sedentary behavior, smoking status and body mass index at baseline, inverse probability weighted CoLaus/HypnoLaus 2009-2017

	OR (95% CI)	**p-value**
Subjective sleep characteristics		
Sleep duration		
<6 h	1.35 (0.88 - 2.06)	0.165
6-8 h (ref.)	1	
>8 h	1.01 (0.57 - 1.77)	0.985
Poor sleep quality (PSQI>5)	1.55 (1.19 - 2.01)	0.001
Excessive daytime sleepiness (ESS>10)	1.29 (0.89 - 1.86)	0.175
PSG Sleep characteristics		
Sleep duration		
<6 h	1.30 (0.88 - 1.94)	0.190
6-8 h (ref.)	1	
>8 h	0.63 (0.33 - 1.18)	0.147
Stage 1 (% of total sleep time)	0.93 (0.75 - 1.17)	0.544
Stage 2 (% of total sleep time)	1.36 (1.11 - 1.66)	0.003
Slow wave sleep (% of total sleep time)	0.83 (0.69 – 1.00)	0.044
REM (% of total sleep time)	0.86 (0.70 - 1.05)	0.134
Sleep efficiency	1.02 (0.83 - 1.25)	0.868
Severity of obstructive sleep apnea		
Normal (ref.)	1	
Mild	0.94 (0.59 - 1.48)	0.775
Moderate/severe	1.29 (0.75 - 2.20)	0.353
Oxygen desaturation index		
Normal (ref.)	1	
Mild	1.35 (0.87 - 2.10)	0.175
Moderate/severe	1.71 (1.00 - 2.93)	0.051
Mean oxygen saturation	1.02 (0.83 - 1.25)	0.868
SpO_2<90%	1.25 (1.10 - 1.42)	0.001

Arousal index	1.06 (0.86 - 1.31)	0.571
Autonomic arousal index	0.96 (0.77 - 1.18)	0.688
Autonomic arousal duration	1.22 (1.00 - 1.48)	0.049
Periodic limb movement index	0.88 (0.70 - 1.10)	0.262

PSQI, Pittsburgh sleep quality index; ESS, Epworth sleepiness scale; PSG, polysomnography; SpO_2<90%, percentage of sleep spent under 90% oxygen saturation. Statistical analysis conducted using logistic regression. Results are expressed as odds ratio (OR) and (95% confidence interval - CI).

The entire study population was considered, and the probability of being included was estimated depending on age, sex, educational level, marital status, AHEI, sedentary behavior, smoking and body mass index using logistic regression separately for the two samples. Subjects were given the inverse weight of being included, and the analysis was then performed only on the included subjects for the two samples separately. The sum of weight for the subjective sample was n=4037, and n=4039 for the PSG sample.

Supplementary table 3: Sex-stratified effect of subjective sleep characteristics (N=2551) and 2) PSG sleep characteristics (N=1422) on weight (≥5 kg) over 5 years for each variable separately, adjusted for age, education, marital status, alternative healthy eating index, sedentary behavior, smoking status and body mass index at baseline, CoLaus/HypnoLaus 2009-2017.

	Men		**Women**	
	OR (95% CI)	**p-value**	**OR (95% CI)**	**p-value**
Subjective sleep characteristics				
Sleep duration				
<6 h	1.86 (1.05 - 3.29)	0.032	0.98 (0.52 - 1.85)	0.958
6-8 h (ref.)	1		1	
>8 h	1.16 (0.47 - 2.86)	0.745	0.94 (0.45 - 1.95)	0.873
Poor sleep quality (PSQI>5)	1.81 (1.24 - 2.64)	0.002	1.34 (0.94 - 1.90)	0.105
Excessive daytime sleepiness (ESS>10)	0.77 (0.43 - 1.37)	0.368	1.57 (0.97 - 2.54)	0.068
PSG Sleep characteristics				
Sleep duration				
<6 h	1.64 (0.97 - 2.76)	0.063	1.00 (0.53 - 1.89)	0.991
6-8 h (ref.)	1		1	
>8 h	0.84 (0.31 - 2.29)	0.731	0.55 (0.26 - 1.16)	0.118
Stage 1 (% of total sleep time)	0.94 (0.73 - 1.22)	0.661	0.86 (0.61 - 1.20)	0.373
Stage 2 (% of total sleep time)	1.12 (0.86 - 1.47)	0.395	1.57 (1.21 - 2.04)	0.001
Slow wave sleep (% of total sleep time)	0.95 (0.72 - 1.24)	0.685	0.75 (0.58 - 0.97)	0.031

REM (% of total sleep time)	0.96 (0.74 - 1.25)	0.767	0.81 (0.62 - 1.04)	0.098
Sleep efficiency	0.95 (0.73 - 1.22)	0.672	1.12 (0.80 - 1.57)	0.494
Severity of obstructive sleep apnea				
Normal (ref.)	1		1	
Mild	0.55 (0.27 - 1.10)	0.091	1.33 (0.75 - 2.36)	0.336
Moderate/severe	1.00 (0.51 - 1.96)	0.993	1.64 (0.80 - 3.36)	0.180
Oxygen desaturation index				
Normal (ref.)	1		1	
Mild	1.07 (0.52 - 2.19)	0.853	1.54 (0.86 - 2.76)	0.150
Moderate/severe	1.35 (0.64 - 2.87)	0.427	2.38 (1.13 - 5.02)	0.023
Mean oxygen saturation	0.85 (0.65 - 1.10)	0.216	1.11 (0.87 - 1.42)	0.384
SpO_2<90%	1.21 (1.01 - 1.46)	0.038	1.28 (1.03 - 1.60)	0.028
Arousal index	1.05 (0.81 - 1.35)	0.723	1.07 (0.82 - 1.40)	0.620
Autonomic arousal index	0.69 (0.51 - 0.92)	0.011	1.16 (0.90 - 1.50)	0.261
Autonomic arousal duration	1.22 (0.95 - 1.55)	0.116	1.27 (0.96 - 1.67)	0.094
Periodic limb movement index	0.73 (0.52 - 1.03)	0.072	1.05 (0.76 - 1.47)	0.753

PSQI, Pittsburgh sleep quality index; ESS, Epworth sleepiness scale; PSG, polysomnography; SpO_2<90%, percentage of sleep spent under 90% oxygen saturation. Statistical analysis conducted using logistic regression. Statistical analysis conducted using logistic regression. Results are expressed as odds ratio (OR) and (95% confidence interval - CI).

Supplementary table 4: Effect of subjective sleep characteristics (N=1923) and 2) PSG sleep characteristics (N=1062) on weight gain (≥5 kg) over 5 years for each variable separately, adjusted for sex, age, education, marital status, alternative healthy eating index, sedentary behavior, smoking status, body mass index at baseline and <u>change in subjective sleep duration</u>, CoLaus/HypnoLaus 2009-2017

	OR (95% CI)	**p-value**
Subjective sleep characteristics		
Sleep duration		
<6 h	0.93 (0.48 - 1.78)	0.827
6-8 h (ref.)	1	
>8 h	1.35 (0.65 - 2.81)	0.421
Poor sleep quality (PSQI>5)	1.32 (0.96 - 1.82)	0.089
Excessive daytime sleepiness (ESS>10)	1.02 (0.66 - 1.59)	0.923
PSG Sleep characteristics		
Sleep duration		
<6 h	1.21 (0.75 - 1.96)	0.428
6-8 h (ref.)	1	
>8 h	0.54 (0.25 - 1.15)	0.112
Stage 1 (% of total sleep time)	0.81 (0.62 - 1.07)	0.141
Stage 2 (% of total sleep time)	1.25 (1.00 - 1.57)	0.050
Slow wave sleep (% of total sleep time)	0.89 (0.72 - 1.11)	0.298
REM (% of total sleep time)	0.98 (0.79 - 1.22)	0.858
Sleep efficiency	1.05 (0.81 - 1.36)	0.712
Severity of obstructive sleep apnea		
Normal (ref.)	1	
Mild	0.82 (0.49 - 1.37)	0.448
Moderate/severe	1.03 (0.57 - 1.88)	0.911
Oxygen desaturation index		
Normal (ref.)	1	
Mild	1.14 (0.69 - 1.91)	0.604
Moderate/severe	1.31 (0.70 - 2.46)	0.404
Mean oxygen saturation	1.01 (0.80 - 1.28)	0.950
SpO_2<90%	1.32 (1.07 - 1.62)	0.010

Arousal index	0.98 (0.77 - 1.24)	0.846
Autonomic arousal index	0.96 (0.76 - 1.22)	0.753
Autonomic arousal duration	1.02 (0.81 - 1.28)	0.845
Periodic limb movement index	0.73 (0.53 - 1.01)	0.057

PSQI, Pittsburgh sleep quality index; ESS, Epworth sleepiness scale; PSG, polysomnography; SpO_2<90%, percentage of sleep spent under 90% oxygen saturation. Statistical analysis conducted using logistic regression. Results are expressed as odds ratio (OR) and (95% confidence interval - CI).

Supplementary table 5: Effect of subjective sleep characteristics (N=2551) and 2) PSG sleep characteristics (N=1422) on weight change over 5 years for each variable separately, adjusted for sex, age, education, marital status, alternative healthy eating index, sedentary behavior, smoking status, and body mass index at baseline, CoLaus/HypnoLaus 2009-2017.

	Standardized beta coefficient	**p-value**
Subjective sleep characteristics		
Sleep duration		
<6 h	-0.015	0.438
6-8 h (ref.)	0	
>8 h	-0.028	0.161
Poor sleep quality (PSQI>5)	0.051	0.009
Excessive daytime sleepiness (ESS >10)	0.026	0.183
PSG Sleep characteristics		
Sleep duration		
<6 h	0.015	0.580
6-8 h (ref.)	0	
>8 h	-0.021	0.437
Stage 1 (% of total sleep time)	-0.004	0.877
Stage 2 (% of total sleep time)	0.039	0.145
Slow wave sleep (% of total sleep time)	-0.019	0.470
REM (% of total sleep time)	-0.034	0.208
Sleep efficiency	0.007	0.814
Severity of obstructive sleep apnea		
Normal (ref.)	0	
Mild	0.027	0.408
Moderate/severe	0.059	0.088
Oxygen desaturation index		
Normal (ref.)		
Mild	0.022	0.524
Moderate/severe	0.069	0.050
Mean oxygen saturation	0.028	0.348
SpO_2<90%	0.018	0.505
Arousal index	0.029	0.298

Autonomic arousal index	0.015	0.587
Autonomic arousal duration	0.035	0.187
Periodic limb movement index	-0.058	0.038

PSQI, Pittsburgh sleep quality index; ESS, Epworth sleepiness scale; PSG, polysomnography; SpO_2<90%, percentage of sleep spent under 90% oxygen saturation. Statistical analysis conducted using linear regression. Results are expressed as standardized beta coefficients with p-values.

Supplementary table 6: Effect of subjective sleep characteristics (N=2544) and 2) PSG sleep characteristics (N=1419) on abdominal girth increase (≥5 cm) over 5 years for each variable separately in full sample and stratified by sex, adjusted for (sex), age, education, marital status, alternative healthy eating index, sedentary behavior, smoking status and body mass index at baseline, CoLaus/HypnoLaus 2009-2017.

	Full sample		**Men**		**Women**	
	OR (95% CI)	**p-value**	**OR (95% CI)**	**p-value**	**OR (95% CI)**	**p-value**
Subjective sleep characteristics	(N=2544)		(N=1203)		(N=1341)	
Sleep duration						
<6 h	1.50 (1.08 - 2.08)	0.015	1.79 (1.14 - 2.82)	0.011	1.29 (0.80 - 2.09)	0.299
6-8 h (ref.)	1		1		1	
>8 h	1.28 (0.88 - 1.85)	0.202	1.73 (0.97 - 3.07)	0.064	1.10 (0.67 - 1.82)	0.704
Poor sleep quality (PSQI>5)	1.09 (0.89 - 1.34)	0.386	1.48 (1.10 - 1.97)	0.009	0.82 (0.62 - 1.09)	0.167
Excessive daytime sleepiness (ESS>10)	1.10 (0.82 - 1.48)	0.522	1.04 (0.69 - 1.57)	0.836	1.12 (0.73 - 1.71)	0.619
PSG Sleep characteristics	(N=1419)		(N=701)		(N=718)	
Sleep duration						
<6 h	1.25 (0.93 - 1.68)	0.133	1.27 (0.86 - 1.87)	0.228	1.18 (0.74 - 1.89)	0.491
6-8 h (ref.)	1		1		1	
>8 h	0.88 (0.57 - 1.35)	0.553	1.35 (0.69 - 2.63)	0.375	0.69 (0.39 - 1.22)	0.204
Stage 1 (% of total sleep time)	1.09 (0.96 - 1.25)	0.184	1.04 (0.88 - 1.22)	0.677	1.18 (0.94 - 1.50)	0.159
Stage 2 (% of total sleep time)	1.02 (0.90 - 1.16)	0.765	1.01 (0.84 - 1.22)	0.908	1.06 (0.88 - 1.28)	0.540
Slow wave sleep (% of total sleep time)	0.95 (0.84 - 1.09)	0.481	0.87 (0.72 - 1.07)	0.183	1.01 (0.84 - 1.22)	0.903

REM (% of total sleep time)	0.94 (0.82 - 1.07)	0.326	1.10 (0.92 - 1.33)	0.292	0.78 (0.65 - 0.95)	0.014
Sleep efficiency	0.92 (0.80 - 1.06)	0.230	0.94 (0.78 - 1.13)	0.524	0.88 (0.71 - 1.11)	0.284
Severity of obstructive sleep apnea						
Normal (ref.)	1		1		1	
Mild	1.02 (0.74 - 1.42)	0.892	0.73 (0.44 - 1.21)	0.222	1.24 (0.79 - 1.93)	0.350
Moderate/severe	1.07 (0.74 - 1.54)	0.727	0.95 (0.58 - 1.58)	0.858	1.08 (0.61 - 1.90)	0.793
Oxygen desaturation index						
Normal (ref.)	1		1		1	
Mild	1.13 (0.82 - 1.57)	0.459	1.12 (0.67 - 1.88)	0.655	1.10 (0.71 - 1.71)	0.679
Moderate/severe	1.04 (0.71 - 1.53)	0.828	1.14 (0.66 - 1.95)	0.645	0.89 (0.50 - 1.60)	0.705
Mean oxygen saturation	0.89 (0.78 - 1.03)	0.109	0.94 (0.76 - 1.15)	0.541	0.86 (0.71 - 1.04)	0.110
SpO_2<90%	1.06 (0.94 - 1.20)	0.363	1.00 (0.84 - 1.20)	0.980	1.15 (0.95 - 1.38)	0.156
Arousal index	0.96 (0.84 - 1.11)	0.608	1.00 (0.83 - 1.20)	0.998	0.91 (0.73 - 1.14)	0.426
Autonomic arousal index	0.84 (0.73 - 0.96)	0.014	0.84 (0.68 - 1.02)	0.085	0.83 (0.68 - 1.01)	0.057
Autonomic arousal duration	0.97 (0.86 - 1.11)	0.682	0.95 (0.80 - 1.13)	0.565	1.02 (0.83 - 1.24)	0.875
Periodic limb movement index	0.96 (0.83 - 1.10)	0.542	0.98 (0.83 - 1.17)	0.858	0.91 (0.70 - 1.18)	0.475

PSQI, Pittsburgh sleep quality index; ESS, Epworth sleepiness scale; PSG, polysomnography; SpO_2<90%, percentage of sleep spent under 90% oxygen saturation. Statistical analysis conducted using logistic regression. Results are expressed as odds ratio (OR) and (95% confidence interval).

Supplementary table 7: Effect of 1) subjective sleep characteristics (N=2249) and 2) PSG sleep characteristics (N=1246) on weight change (≥5 kg) over 5 years in non-obese adults at baseline, for each variable separately, adjusted for sex, age, education, marital status, alternative healthy eating index, sedentary behavior, smoking status, and body mass index at baseline, CoLaus/HypnoLaus 2009-2017.

	OR (95% CI)	**p-value**
Subjective sleep characteristics		
Sleep duration		
<6 h	1.27 (0.79 - 2.04)	0.320
6-8 h (ref.)	1	
>8 h	0.92 (0.50 - 1.68)	0.782
Poor sleep quality (PSQI>5)	1.46 (1.10 - 1.93)	0.008
Excessive daytime sleepiness (ESS >10)	1.01 (0.67 - 1.51)	0.973
PSG Sleep characteristics		
Sleep duration		
<6 h	1.40 (0.91 - 2.14)	0.125
6-8 h (ref.)	1	
>8 h	0.77 (0.41 - 1.45)	0.423
Stage 1 (% of total sleep time)	0.94 (0.75 - 1.19)	0.618
Stage 2 (% of total sleep time)	1.27 (1.04 - 1.55)	0.020
Slow wave sleep (% of total sleep time)	0.82 (0.67 – 1.00)	0.048
REM (% of total sleep time)	0.95 (0.79 - 1.16)	0.642
Sleep efficiency	0.97 (0.77 - 1.20)	0.755
Severity of obstructive sleep apnea		
Normal (ref.)	1	
Mild	0.78 (0.48 - 1.25)	0.301
Moderate/severe	1.36 (0.81 - 2.29)	0.247
Oxygen desaturation index		
Normal (ref.)	1	
Mild	1.12 (0.69 - 1.79)	0.650
Moderate/severe	1.68 (0.97 - 2.91)	0.065
Mean oxygen saturation	1.00 (0.81 - 1.23)	0.998
SpO_2<90%	1.29 (1.09 - 1.53)	0.003

Arousal index	1.13 (0.90 - 1.40)	0.296
Autonomic arousal index	0.88 (0.72 - 1.08)	0.215
Autonomic arousal duration	1.19 (0.98 - 1.46)	0.087
Periodic limb movement index	0.80 (0.61 - 1.05)	0.110

PSQI, Pittsburgh sleep quality index; ESS, Epworth sleepiness scale; PSG, polysomnography; SpO_2<90%, percentage of sleep spent under 90% oxygen saturation. Statistical analysis conducted using logistic regression. Results are expressed as odds ratio (OR) and (95% confidence interval - CI).

Supplementary table 8: Effect of subjective sleep characteristics (N=2551) and 2) PSG sleep characteristics (N=1422) on weight gain (≥5 kg) over 5 years for each variable separately, adjusted for sex, age, education, marital status, alternative healthy eating index, sedentary behavior, smoking status, body mass index at baseline and follow-up time, CoLaus/HypnoLaus 2009-2017.

	OR (95% CI)	p-value
Subjective sleep characteristics		
Sleep duration		
<6 h	1.36 (0.89 - 2.07)	0.150
6-8 h (ref.)	1	
>8 h	0.99 (0.56 - 1.74)	0.970
Poor sleep quality (PSQI>5)	1.53 (1.19 - 1.98)	0.001
Excessive daytime sleepiness (ESS >10)	1.36 (0.89 - 2.07)	0.150
PSG Sleep characteristics		
Sleep duration		
<6 h	1.38 (0.93 - 2.05)	0.107
6-8 h (ref.)	1	
>8 h	0.65 (0.36 - 1.19)	0.163
Stage 1 (% of total sleep time)	0.92 (0.75 - 1.12)	0.389
Stage 2 (% of total sleep time)	1.33 (1.11 - 1.60)	0.003
Slow wave sleep (% of total sleep time)	0.84 (0.70 - 1.01)	0.069
REM (% of total sleep time)	0.88 (0.73 - 1.05)	0.153
Sleep efficiency	0.99 (0.81 - 1.21)	0.922
Severity of obstructive sleep apnea		
Normal (ref.)	1	
Mild	0.94 (0.61 - 1.46)	0.785
Moderate/severe	1.30 (0.80 - 2.13)	0.293
Oxygen desaturation index		
Normal (ref.)	1	
Mild	1.31 (0.84 - 2.04)	0.236
Moderate/severe	1.71 (1.02 - 2.88)	0.043
Mean oxygen saturation	1.00 (0.84 - 1.20)	0.963
SpO_2<90%	1.23 (1.07 - 1.41)	0.004

Arousal index	1.06 (0.88 - 1.27)	0.541
Autonomic arousal index	0.93 (0.77 - 1.13)	0.476
Autonomic arousal duration	1.21 (1.01 - 1.45)	0.034
Periodic limb movement index	0.86 (0.69 - 1.09)	0.211

PSQI, Pittsburgh sleep quality index; ESS, Epworth sleepiness scale; PSG, polysomnography; SpO_2<90%, percentage of sleep spent under 90% oxygen saturation. Statistical analysis conducted using logistic regression. Results are expressed as odds ratio (OR) and (95% confidence interval - CI).

Supplementary table 9: Sleep characteristics of the included and excluded subjects in 1) sample analyzing subjective sleep characteristics and 2) sample analyzing objective sleep characteristics.

	Included	**Excluded**	**p-value**
Subjective sleep characteristics	(N=2551)	(N=2513)	
Sleep duration			<0.001
<6 h	199 (7.8)	209 (9.9)	
6-8 h (ref.)	2185 (85.7)	1665 (79.0)	
>8 h	167 (6.6)	234 (11.1)	
Poor sleep quality (PSQI>5)	826 (32.4)	603 (39.5)	<0.001
Excessive daytime sleepiness (ESS >10)	274 (10.7)	198 (10.7)	0.885
PSG Sleep characteristics	(N=1422)	(N=740)*	
Sleep duration			0.001
<6 h	359 (25.3)	203 (27.4)	
6-8 h (ref.)	911 (64.1)	421 (56.9)	
>8 h	152 (10.7)	116 (15.7)	
Stage 1 (% of total sleep time)	11.8 (6.7)	12.1 (8.2)	0.367
Stage 2 (% of total sleep time)	46.1 (9.8)	47.3 (11.2)	0.013
Slow wave sleep (% of total sleep time)	19.9 (8.2)	19.3 (9.0)	0.101
REM (% of total sleep time)	22.1 (5.9)	21.3 (6.7)	0.003
Sleep efficiency	85.0 (10.4)	83.9 (11.8)	0.039
Severity of obstructive sleep apnea			<0.001
Normal (ref.)	435 (30.6)	167 (22.6)	
Mild	508 (35.7)	261 (35.3)	
Moderate/severe	479 (33.7)	312 (42.2)	
Severity of oxygen desaturation			<0.001
Normal (ref.)	435 (30.6)	176 (23.8)	
Mild	529 (37.2)	265 (35.8)	
Moderate/severe	458 (32.2)	299 (40.4)	
Mean oxygen saturation	94.2 (1.7)	93.7 (4.0)	<0.001
SpO_2<90%	3.4 (10.7)	6.3 (16.0)	<0.001
Arousal index	21.0 (10.5)	21.9 (12.0)	0.102
Autonomic arousal index	65.0 (23.5)	60.4 (25.5)	<0.001

Autonomic arousal duration	14.3 (3.2)	14.3 (3.3)	0.684
Periodic limb movement index	13.5 (23.1)	14.3 (24.2)	0.483

* of the subjects with full polysomnography (N=2162)

PSQI, Pittsburgh sleep quality index; ESS, Epworth sleepiness scale; PSG, polysomnography; SpO_2<90%, percentage of sleep spent under 90% oxygen saturation. Results are expressed as N (%) for categorical variables or mean ±standard deviation for continuous variables. P-values from Pearson chi2 or ANOVA when appropriate.