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ORIGINAL ARTICLE

Association Between Weekend Catch-up Sleep and Lower Body Mass: Population-Based Study

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Study Objectives: To determine if weekend catch-up sleep (CUS) impacts body mass index (BMI) in the general population.
Methods: A stratified random sample (2156 subjects; age 19–82 years old, 43.0 ± 14.5; 1183 male) from the general population was evaluated, in 2010, using face-to-face interviews about sociodemographic characteristics, height, weight, habitual sleep duration, and time-in-bed at night on weekdays and weekend, sleep-related profiles, mood and anxiety scales, and comorbid-medical conditions. Weekend CUS was identified when nocturnal sleep extension occurred over the weekend, and this was quantified. Average sleep duration, BMI, and chronotype were determined. The association of BMI with the presence and the amount of weekend CUS was analyzed, independent of average sleep duration, chronotype, and sociodemographic factors.
Results: BMI and average sleep duration was 23.0 ± 3.0 kg/m^2 and 7.3 ± 1.2 hours, respectively. The weekend CUS group consisted of 932 subjects (43.2%) who slept longer on weekend than weekdays by 1.8 ± 1.1 hours. Weekend CUS subjects had a significantly lower BMI (22.8 ± 0.19 kg/m^2) than the non-CUS (23.1 ± 0.19 kg/m^2) group, after adjustment for age, sex, average sleep duration, chronotype, other sociodemographic factors, and anxiety/mood status (p = .01) The relationship between weekend CUS and BMI was dose-dependent (p = 0.02): Every additional hour of weekend CUS was associated with a decrease of 0.12 kg/m^2 in BMI (95% confidence interval, −0.23 to −0.02).
Conclusions: Weekend sleep extension may have biological protective effects in preventing sleep-restriction induced or related obesity. The results suggest a simple population-level strategy to minimize effects of sleep loss.

Statement of Significance
Short sleep is increasingly regarded as a risk for obesity. This study demonstrates a significant dose-dependent relationship between lower body mass index (BMI) and weekend sleep extension in an adult general population, independent of average sleep duration across the week and chronotype. Chronotype was also associated with BMI: the later the chronotype, the higher the BMI, an association attenuated by weekend sleep extension. The results imply that weekend sleep extension provides protection against weight gain related to sleep restriction as well as late chronotype.

Keywords: Sleep deprivation, obesity, chronobiology, sleep duration, body weight, chronotype.

INTRODUCTION

The rise in obesity is a major public health concern.[1] Increased body weight is related to altered blood pressure regulation and glucose metabolism, which then leads to hypertension, diabetes/metabolic syndrome, and eventually results in increased cardiovascular mortality risk.[2,3] The increasing longevity of humans allows relatively small effects to have substantial long-term consequences: sleep state (quality, duration, timing) is one such factor. Excessive calorie intake and sedentary life style are regarded as the 2 main factors in the development of obesity,[4,5] but abnormal sleep is now considered to contribute to the obesity epidemics.[4] Sleep curtailment, disrupted sleep, or circadian misalignment is all related to increased body weight.[6–15]

In a modern society, habitual sleep restriction seems to be inevitable due to social obligations or work schedules, with a tendency to reduced sleep duration.[16] The importance of insufficient sleep in the development of obesity is highlighted in that it is a substantially common and potentially modifiable condition.[4,16] Insufficient sleep has undesirable effects on metabolism, by inducing obesity, glucose intolerance, and dyslipidemia, which contribute to the development of metabolic syndrome and cardiovascular disease.[10,17–22] Sleep curtailment increases ghrelin and reduces leptin levels along with a sympathetic tilt to sympathovagal imbalance, leading in aggregate to a rise of stress hormones, increased appetite and caloric intake, especially fat nutrients, eventually leading to obesity and metabolic derangement.[8,23–27] There is some preliminary evidence supporting the concept that sleep extension improves glucose metabolism and cognitive function in healthy subjects with chronic sleep insufficiency.[28,29]

To cope with sleep loss, people usually engage in daytime napping or extend nighttime sleep during weekends or other time periods free from social or work obligation. Such measures might counteract the deleterious effects of sleep debt. Midday napping reduces coronary mortality and improves cognitive performance, and weekend sleep extension is associated with a lowered risk of hypertension.[30–32] However, the role of napping remains controversial. A few population-based studies report associations of napping with increased obesity, diabetes, and mortality.[33–36] It is difficult to dissociate the effects of sleep pathology, for example, sleep apnea, causing napping versus inadequate sleep, and the likely the impact of these conditions could be different. However, weekend CUS is somewhat more "physiological," similar to drinking after a period thirst to restore homeostasis. The association between weekend sleep extension and cardiometabolic disorders, especially obesity, in adult population is largely unknown. Only 2 studies in children demonstrating a relationship between longer weekend sleep and lower risk of obesity have been reported.[37,38]

Weekend sleep extension is not solely explained by sleep debt built-up over weekdays. Circadian preference also contributes to the differences in nocturnal sleep duration between the weekdays (conforming to a social clock) and weekend (conforming to an endogenous clock). The evening type sleeps are longer in the weekends than during the weekdays[39] and is associated with obesity and metabolic derangement.[15,40] Therefore, circadian preferences need to be considered to interpret the relationship between weekend sleep extension and metabolic health including body weight.

In this study, we aimed to investigate the association between weekend sleep extension and body mass index (BMI) in the general adult population. The hypothesis tested is that weekend sleep extension is related to lower body weight in adults, independent of habitual sleep duration and circadian preference.

METHODS

Study Population and Survey Methods

We included subjects (aged 19 years or older) who participated in a nationwide cross-sectional survey of sleep and headache, in the Republic of Korea.[32] The sampling of subjects and survey was conducted by Gallup Korea in 2010 using a 2-stage random sampling method proportional to the distribution of the population from 15 administrative districts. According to the population distribution of age and sex, Gallup Korea approached 7616 subjects and a total of 2836 subjects (age 43.0 ± 14.5 years old; 1183 male) completed the survey through a face-to-face interview. The interview was performed by trained personnel using structured questionnaires about sociodemographic characteristics, height, weight, habitual sleep duration and time-in-bed at night during weekdays and weekends, sleep-related profiles including sleep quality, insomnia, habitual snoring, and daytime sleepiness, a mood and anxiety scale, and comorbid medical conditions. For this study, we excluded 151 subjects working as shift workers and 529 subjects with missing of any relevant information. A total of 2156 subjects (age 19–82, 43.0 ± 14.5 years old; 1183 male) was included in the final analysis.

The study design was approved by the institutional review board of Seoul National University Bundang Hospital and Hallym University Sacred Heart Hospital. All participants provided written informed consent.

Sleep Duration, Weekend Catch-up Sleep, and BMI

Sleep duration was defined based on the responses to the question: "How many hours of sleep did you usually get a night for the past month? Please respond separately for weekday and weekend." Average sleep duration was a weighted mean of sleep durations on weekday and weekend, calculated as (5 × weekday-sleep + 2 × weekend-sleep)/7. The difference in sleep durations between on weekday and weekend was assessed. The presence of weekend catch-up sleep (CUS) was defined when sleep duration in the weekend was longer than during weekdays. Average sleep duration and weekend CUS was examined as both continuous and categorical measures (sleep duration in hours, <6, ≥6 to <7, ≥7 to <8, ≥8; weekend CUS in hours, 0, >0 to <1, ≥1 to 2, ≥2). The BMI (kg/m^2) was calculated from self-reported height (cm) and body weight (kg). Obesity was defined as BMI ≥25.0 kg/m^2.[41]

Chronotype, Sleep Efficiency, and Sleep-Related Variables

Information on the time-in-bed onset and offset on weekdays (workdays) and weekend (free days) was collected. We adopted the "midpoint of sleep on free days corrected for sleep extension on free days (MSFsc)" as an indicator of chronotype.[15,42] MSFsc was calculated as follows: MSFsc = midpoint of sleep on free days − 0.5 × (sleep duration on free days − [5 × sleep duration on workdays + 2 × sleep duration on free days]/7). Sleep efficiency (%) was defined by (reported sleep duration/time in bed) × 100, and calculated on weekdays and weekend, separately.

Subjective daytime sleepiness was measured with the Epworth Sleepiness Scale, and excessive daytime sleepiness was defined as a score >10.[43] Overall, sleep quality was evaluated using the Pittsburgh Sleep Quality Index: poor sleep quality was a score >5. Insomnia was evaluated with the Insomnia Severity Index and a score >14 was the diagnostic criteria of moderate-to-severe clinical insomnia.[44] Habitual snoring was defined when participants reported snoring with a frequency of at least 4 nights a week. Perceived insufficient sleep was defined when there was an unmet need for sleep, based on the response (yes or no) to the question, "Do you think your sleep amount is sufficient for your sleep need?".[45]

Anxiety, Depression, and Other Measures

The Goldberg anxiety scale and the Patient Health Questionnaire-9 depression scale were applied.[46,47] The Korean version of each scale was validated in Korean adults.[48,49] Anxiety was defined when the anxiety scale score was ≥5. With this threshold, sensitivity and specificity was 82.0% and 94.4%, respectively.[48] Subjects with the depression scale score ≥10 were considered to have depression, with sensitivity and specificity of 81.1% and 89.9%.[49]

Alcohol drinking and smoking status were categorized into 2 groups (current vs. never or former). Regular physical exercise was defined when subjects reported participating in sweat-inducing exercise at least 3 times a week for more than 30 minutes for each activity. Self-reported years of education were documented and education level was classified into 2 groups (<12 education-year vs. ≥12 education-year). Income level was divided into 2 groups, higher versus lower than the minimum monthly cost of living per person in Korea. Current job status was also documented (yes or no).

Statistical Analysis

The primary aim was to test the association of BMI with the presence and the amount of weekend CUS, independent of average sleep duration, chronotype, and sociodemographic factors. For group comparisons between subjects with and without weekend CUS, a 2-tailed Student's *t*-test or chi-square test was used for continuous or categorical variables, respectively. We performed multiple linear regression, logistic regression, and general linear model analysis to test the relationship between

BMI and weekend CUS, adjusted for age, sex, average sleep duration, chronotype (MSFsc), regular physical exercise, alcohol drinking, smoking, education, anxiety, depression, and income. Adjusted odds ratio (OR) and predicted BMI were primary parameters of interests. The data analysis were performed using SPSS version 22.0 (SPSS, Chicago, IL), and p <.05 indicated statistical significance.

RESULTS

Characteristics of Weekend CUS and Non-CUS Group

In 2156 subjects, the BMI was 23.0 ± 3.0 kg/m^2, obesity was present in 23.7%, and average sleep duration was 7.3 ± 1.2 hours. The weekend CUS group comprised of 932 subjects (43.2%, Table 1) who slept longer on weekend than weekdays by 1.8 ± 1.1 hours. The CUS group had shorter sleep duration

Table 1—Participant Characteristics in the Weekend Catch-up Sleep (CUS) Group and Non-CUS Group (*N* = 2156).

Characteristics	Weekend CUS group (*N* = 932)	Non-CUS group (*N* = 1224)	*p*
Age (year)	38.4 ± 12.6	46.6 ± 14.8	<.0001*
Male sex	498 (53.4)	685 (56.0)	.251
Education (≥12 education-year)	447 (48.0)	810 (66.2)	<.0001*
Job (yes)	815 (87.5)	956 (78.1)	<.0001*
Income (>the minimum cost of living)	846 (90.8)	981 (80.1)	<.0001*
BMI (kg/m^2)	22.6 ± 2.9	23.3 ± 3.0	<.0001*
Obesity	173 (18.5)	337 (27.5)	<.0001*
Regular physical exercise	219 (23.5)	338 (27.6)	.029*
Alcohol use	668 (71.7)	798 (65.2)	.051
Current smoking	295 (31.7)	341 (27.9)	.211
Goldberg anxiety scale score	1.7 ± 2.0	1.8 ± 2.1	.406
Anxiety	97 (10.4)	150 (12.3)	.179
PHQ-9 depression scale score	2.4 ± 3.4	2.2 ± 3.4	.241
Depressive mood	46 (4.9)	45 (3.7)	.150
SD weekday (hour)	6.9 ± 1.1	7.2 ± 1.3	<.0001*
SD weekend (hour)	8.6 ± 1.4	7.1 ± 1.3	<.0001*
SD average (hour)	7.4 ± 1.1	7.2 ± 1.3	<.001*
MSFsc	3:58 AM ± 96 min	3:25 AM ± 108 min	<.0001*
Perceived insufficient sleep	328 (35.2)	351 (28.7)	.001*
PSQI score	3.7 ± 2.3	3.6 ± 2.4	.190
Poor sleep quality	167 (18.0)	218 (17.8)	.937
Habitual snoring	145 (15.6)	251 (20.5)	.003*
ESS	5.8 ± 3.9	5.5 ± 4.0	.093
Excessive daytime sleepiness	113 (12.1)	143 (11.7)	.760
ISI score	3.7 ± 4.5	3.8 ± 4.8	.610
Moderate-to-severe insomnia	35 (3.8)	57 (4.7)	.302
Sleep efficiency, weekday (%)	98.2 ± 9.9	98.9 ± 8.6	.082
Sleep efficiency, weekend (%)	98.4 ± 12.9	98.4 ± 10.4	.976

Data presented as mean ± standard deviation or number (%). *P* values from Student *t*-test or chi-square test; **p* < .05. Each parameter defined as follows: obesity was defined as BMI ≥25.0 kg/m^2; regular physical exercise defined when subjects did sweat-inducing exercise at least three times a week with each episode lasting at least 30 minutes; anxiety as a Goldberg anxiety scale score ≥5; depressive mood as a PHQ-9 depression score ≥10; *SD* average calculated as (5 × weekday-sleep + 2 × weekend-sleep)/7; MSFsc calculated as midpoint of sleep on free days – 0.5 × (sleep duration on free days − [(5 × sleep duration on work days + 2 × sleep duration on free days)/7]); perceived sleep insufficiency when subjects reported the presence of unmet need for sleep; poor sleep quality as the PSQI score >5; habitual snoring as the snoring frequency ≥4 nights/week; excessive daytime sleepiness as the ESS score >10; moderate-to-severe insomnia as the ISI score >14; sleep efficiency (%) calculated as (reported sleep duration/time in bed) × 100. BMI = body mass index; CUS = weekend catch-up sleep; ESS = Epworth Sleepiness Scale; ISI = Insomnia Severity Index; MSFsc = midpoint of sleep on free days corrected for sleep extension on free days; PHQ-9 = Patient Health Questionnaire-9; PSQI = Pittsburgh Sleep Quality Index; *SD* = sleep duration.

on weekdays (6.9 ± 1.1 hours vs. 7.2 ± 1.3 hours) but had longer average sleep duration (7.4 ± 1.1 vs. 7.2 ± 1.3) than the non-CUS group. The estimated circadian phase was delayed in the CUS group, reflected in the difference of MSFsc between 2 groups (3:58 am ± 96 min vs. 3:25 am ± 108 min). The BMI was significantly lower in the CUS group than the non-CUS (22.6 ± 2.9 kg/m^2 vs. 23.3 ± 3.0 kg/m^2). Sleep efficiency as well as the presence of daytime sleepiness, insomnia, poor sleep quality, anxiety, and depressive mood were similar between the 2 groups, although the CUS group more frequently reported perceived sleep insufficiency (Table 1).

Association of BMI With Average Sleep Duration, Weekend CUS, and Chronotype

The unadjusted BMI tended to be inversely related to the average sleep duration (23.2 ± 0.2 kg/m^2, sleep duration <6 hour; 23.3 ± 0.1 kg/m^2, 6 to <7 hour; 22.9 ± 0.1 kg/m^2, 7 to <8 hour; 23.0 ± 0.1 kg/m^2, ≥8 hour; p = .05). However, when adjusted for weekend CUS, chronotype, sociodemographic factors, and other covariates, the association between sleep duration and BMI was neither U-shaped nor linear (Table 2).

Weekend CUS was significantly associated with lower BMI, independent of age, sex, average sleep duration, and chronotype (Table 2). The predicted BMI was 22.8 ± 0.19 kg/m^2 in the CUS group and 23.1 ± 0.19 kg/m^2 in the non-CUS (p = 0.02). The decrease in BMI was proportional to the amount of weekend CUS (Figure 1)—the more weekend CUS, the lower the BMI. Every additional hour of weekend CUS was associated with a decrease of 0.12 kg/m^2 in BMI (95% confidence interval [CI], −0.23 to −0.02).

Weekend CUS tended to modify the association between sleep duration and BMI. In the non-CUS group, the subjects with a sleep duration shorter than 7 hours had a higher BMI than the subjects sleeping more than 7 hours (Figure 2), although the interaction between average sleep duration and weekend CUS was not significant (p = .59). The presence of weekend CUS was significantly associated with lower BMI across the whole range of sleep duration (p = .01; Figure 2).

A later chronotype was related to higher BMI, independent of age, sex, the presence of weekend CUS, and average sleep duration (Table 2). MSFsc positively correlated with BMI (β = .11; 95% CI, 0.01–0.21; p = .040). The interaction between chronotype and weekend CUS was not significant (p = .40), although later MSFsc tended to associate with higher BMI in the non-CUS group, but not in the CUS group (Table 3).

Among sociodemographic variables, age, male sex, and lower education were associated with higher BMI (Table 2).

DISCUSSION

In this study, we demonstrate an association between weekend sleep extension and BMI in a representative largely nonobese adult population sample. The predicted BMI in the CUS group was significantly lower than the non-CUS group, independent of average sleep duration, chronotype, sociodemographic factors, and other confounders. The weekend CUS group slept less on weekdays and reported unmet sleep needs, a perceived sleep insufficiency, more frequently than the non-CUS group, but achieved more sleep across the week through weekend sleep extension, indicated by the longer average sleep duration. The relative lack of baseline obesity in our population more readily differentiates sleep effects.

Compensatory sleep extension on weekends may have a protective role against weight gain due to chronic partial sleep loss. The Hordaland Health Study measured sleep duration separately during workweek and free times in middle aged adults,

Table 2—Multiple Linear Regression Models for Predictors of Body Mass Index (N = 2156).

Variables	Model 1		Model 2		Model 3	
	β (95% CI)	p	β (95% CI)	p	β (95% CI)	p
Presence of weekend CUS	−0.31 (−0.57, −0.06)	.015*	−0.32 (−0.58, −0.07)	.016*	−0.31 (−0.57, −0.06)	.015*
Age (year)	0.04 (0.03, 0.05)	<.0001*	0.05 (0.04, 0.06)	<.0001*	0.04 (0.03, 0.05)	<.0001*
Male sex	1.48 (1.24, 1.72)	<.0001*	1.46 (1.22, 1.70)	<.0001*	1.35 (1.04, 1.66)	<.0001*
SD average (hour)			−0.07 (−0.17, 0.04)	.201	−0.07 (−0.17, 0.03)	.173
MSFsc			0.11 (0.01, 0.21)	.034*	0.11 (0.01, 0.21)	.040*
Regular physical exercise					0.11 (−0.16, 0.39)	.423
Alcohol consumption					0.11 (−0.17, 0.40)	.431
Current smoking					0.31 (−0.02, 0.62)	.062
Education (≥12 education-year)					0.35 (0.07, 0.63)	.014*
Income (>the minimum cost of living)					0.31 (−0.05, 0.67)	.121
Job					−0.23 (−0.59, 0.12)	.199
Anxiety					−0.21 (−0.62, 0.19)	.303
Depressive mood					0.09 (−0.56, 0.72)	.793

Data presented as correlation coefficient (β, 95% CI) from multiple linear regression analysis; *p < .05. CI = confidence interval; CUS = catch-up sleep; MSFsc = midpoint of sleep on free days corrected for sleep extension on free days; *SD* = sleep duration.

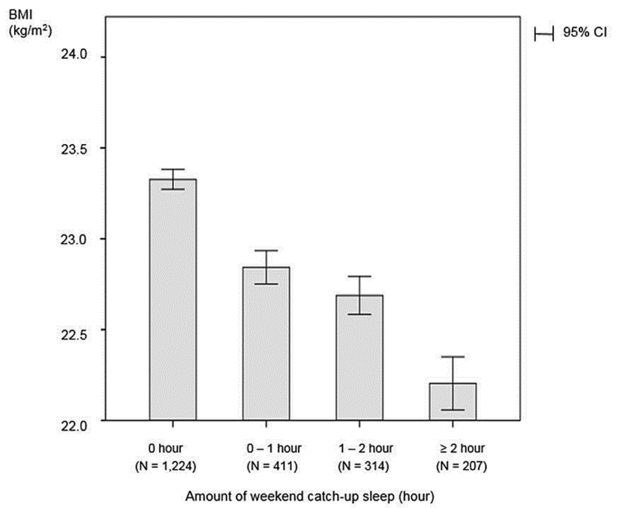

Figure 1—Correlation between body mass index and the amount of weekend catch-up sleep (N = 2156). Data from general linear model analysis, adjusted for age, sex, average sleep duration, chronotype, physical activity, anxiety, depressive mood, alcohol drinking, smoking, education, income, and job (p = .02). BMI = body mass index; CI = confidence interval.

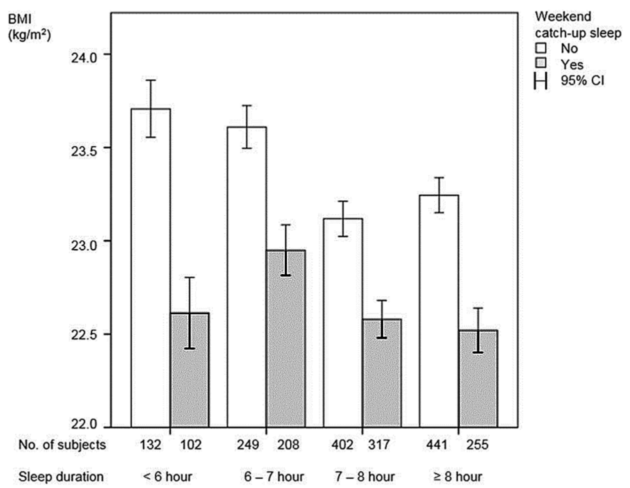

Figure 2—Predicted body mass index in the weekend catch-up sleep (CUS) and the non-CUS group stratified by average sleep duration (N = 2156). Data from general linear model analysis, adjusted for age, sex, chronotype, physical activity, anxiety, depressive mood, alcohol drinking, smoking, education, income, and job. BMI = body mass index; CI = confidence interval; CUS = catch-up sleep.

demonstrating that a high BMI correlated with short average and free time sleep duration.[50] Two previous studies on elementary school children in Asian countries, Hong Kong and South Korea, demonstrated that weekend or holiday sleep extension was associated with a lower risk of being overweight in a dose-dependent manner, especially in children who sleep less over school days.[37,38] Our results are largely concordant, but in adult population.

Protective biologic effects of weekend CUS may extend beyond obesity. As reported previously,[32] in our study population, an additional hour of weekend CUS was related to a decrease in the prevalence of hypertension (OR, .83; 95% CI, 0.72–0.95), more strongly among subjects reporting perceived sleep insufficiency (OR, .61; 95% CI, 0.42–0.82) than those without sleep insufficiency (OR, .95; 95% CI, 0.80–1.12). Interindividual differences in sleep need and in vulnerability to sleep loss is widely acknowledged.[51,52] Among subjects having similar amounts of sleep, those who complain of unmet sleep need are likely to require more sleep or be more vulnerable to sleep loss than those who do not, and eventually get more benefit from weekend sleep extension. In this study population, the predicted BMI was 22.7 ± 0.3 kg/m^2 and 23.0 ± 0.3 kg/m^2 in those with and without weekend CUS, respectively, among subjects (N = 679) who reported perceived sleep insufficiency (p = .18; data not shown in the results). Perceived insufficient sleep was related to shorter average sleep duration (6.7 ± 1.2 hour), and to sleep curtailment even with weekend sleep extension (6.9 ± 1.1 hours).

Weekend CUS should reasonably be considered an independent factor in epidemiological investigations. In most studies concerning the effect of sleep on body weight or obesity, sleep duration was determined by participants' reports on the average or usual amount of sleep a night or 24-hour.[6,7,9–12] In this setting, participants may have reported sleep duration as the amount of sleep on a weekday, rather than an average value across a week or sleep on a weekend. A few studies considered only workday sleep duration.[7,53] Consequently, sleep duration might have been systematically underestimated, considering the high prevalence of weekend CUS in this study and others.[15,50] This problem might have been overcome in other studies that used a weighted average of reported sleep duration on weekday and weekend.[8,50,54–56] Studies which perform actigraphy for epidemiological investigations could evaluate objective versus subjective dimensions of weekend CUS, to determine if they are biologically equivalent.[14,56,57]

The unadjusted difference in BMI between the weekend CUS and non-CUS group was relatively small (0.6 kg/m^2) compared with the association of habitual sleep duration and BMI. In studies of western populations, BMI in the group of short sleep duration (<5–6 hours/night) was usually higher than the reference group (7–8 hours/night) by more than 1.0 kg/m^2.[8–10,13,14] Achieving sufficient amount of nocturnal sleep is still important to maintain cardiometabolic health. Weekend CUS could be a quick fix to compensate sleep loss over the week but is not an ultimate solution for chronic sleep loss, reflected in the finding that the CUS group had longer average sleep duration than the non-CUS. If average sleep duration over the week is far below the optimal amount even with weekend sleep extension, the benefits from the weekend CUS would likely dissipate.

Chronotype, especially the evening type, is related to metabolic disturbances including obesity.[15,40,58] Mechanisms include circadian misalignment, partial sleep deprivation (at least during workdays), light exposure at night per se, and nocturnal eating.[15,58,59] A late chronotype leads to weekend sleep extension.[15,39] Therefore, it is mandatory to adjust circadian preference in the analysis of relationship between sleep duration and body weight and the effect of weekend CUS. In this study, a

Table 3—Association Between Later Chronotype and Higher Body Mass Index Stratified by the Presence of Weekend Catch-up Sleep.

	Chronotype (MSFsc)		
	β	95% CI	*p*
Weekend CUS group (*N* = 932)	.06	−0.10 to 0.21	.460
Non-CUS group (*N* = 1224)	.13	−0.01 to 0.27	.059

Data from linear regression model adjusted for age, sex, sleep duration, regular physical exercise, depression, anxiety, alcohol drinking, smoking, education, monthly income, and job. Chronotype is estimated by "midpoint of sleep on free days corrected for sleep extension on free days (MSFsc)". As later is the MSFsc, subject is regarded to have more delayed chronotype, and vice versa. CI = confidence interval; CUS = catch-up sleep; MSFsc = midpoint of sleep on free days corrected for sleep extension on free days.

later chronotype via the MSFsc positively correlated with BMI and obesity (Table 2). However, the association was attenuated in the weekend CUS group (Table 3), which implies that the weekend sleep extension may alleviate the undesirable effects of at least modest degrees of a late chronotype. There is probably a trade-off between relieving homeostatic sleep pressure and worsening circadian misalignment with long sleep duration weekend sleeping in, as extreme late chronotype individual can and often do.

Another strategy to pay off sleep debt incurred in daily life is to take a nap. Unlike the favorable results of weekend CUS in the current study, several studies demonstrated a negative influence of daytime napping on individual health including increased all-cause or cardiovascular mortality, obesity, diabetes, impaired cognition, and depression.[33–36] The incongruous influences of weekend sleep extension and napping can be explained by several mechanisms: (1) circadian misalignment effects; (2) daytime napping is usually short and fragmented sleep, but night sleep extension is a part of natural sleep aligned with circadian rhythm and likely to be considerably longer and more consolidated; (3) type of sleep (REM rich during extension, NREM during napping); (4) driving mechanisms—more likely to be pathological sleep inducing daytime napping, while restriction of normal sleep for sleep extension.[60] In epidemiologic studies, napping is usually defined by the subjects' reports on the presence and frequency of habitual napping. The driving mechanism, a nap by choice to satiate sleep needs versus a nap due to an inability to maintain wakefulness, is often not well characterized.[33–36] Considering the plausible cognitive benefits of napping by choice,[31,61] future epidemiologic investigations may usefully attempt to delineate underlying driving mechanisms for napping, to define the type of nap, and to identify napping as a compensation for sleep debt.

Despite the novelty and strength of design and finding, our study has several limitations. The BMI was calculated from reported, not measured, height and weight. In previous epidemiologic studies, self-reported BMI was highly correlated with measured BMI but generally underestimated compared with a measured one, and systematic errors were greater in certain groups (older subjects, shorter men, and heavier women).[62–64] Therefore, the use of reported BMI is likely to underestimate obesity or overweight prevalence, but will produce minimal bias to explore the association of BMI and other conditions.[63,64] Furthermore, in this study the non-CUS group was older and had a higher BMI than the CUS, which suggests that the reported BMI would have been underestimated more in the non-CUS group. The association between weekend CUS and BMI was undeterred by the possibility that the measurement errors of BMI contributed to the attenuation of BMI difference between the 2 groups. Other limitations are as follows. Information on calorie intake and detailed quantitative parameters of physical activity are unavailable, which are important contributors to body weight. No objective measure of sleep duration and quality was available. Weekend CUS could be proposed as a simple population-level strategy to counteract cardiometabolic derangements induced by every day sleep loss, but our data cannot determine the optimal "dose" of CUS, or the optimal amount of social jetlag to balance biological and social needs.[15] Any role of gene–environment interactions also needs to be assessed-if specific obesity or circadian genetic polymorphisms modify the effect of weekend CUS on obesity.

CONCLUSION

We demonstrate a positive dose-dependent association between weekend CUS and body weight in an adult general population. This association was independent of average sleep duration across a week and chronotype. The association of a later chronotype with higher BMI was attenuated by weekend CUS, a desirable effect of social jetlag. Sleep extension is an applicable population-level strategy. A deeper understanding of biological mechanisms is desirable.

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DISCLOSURE STATEMENT

Thomas is co-inventor and patent holder of the ECG-derived sleep spectrogram, which may be used to phenotype sleep quality and central/complex sleep apnea. The technology is licensed by Beth Israel Deaconess Medical Center to MyCardio, LLC. He is also co-inventor and patent holder of the Positive Airway Pressure Gas Modulator, being developed for treatment of central/complex sleep apnea. He is a consultant in software development for DeVilbiss. The other authors have no financial conflicts of interest.