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Association of morning and evening physical exercise with sleep quality and insomnia: differences between chronotypes

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Abstract

Objective: to investigate the association of morning and evening physical exercise with sleep quality (duration, latency, awakenings, and self-perceived sleep quality) and insomnia, depending on the chronotype. Methods: Participants (n=2,050; 18-65y) were part of a population-based research, with virtual data collection. Multiple logistic regression models were conducted to analyze the association of physical exercise (yes/no; frequency; morning/evening) with sleep variables (outcome), among all participants and according to chronotype. Linear regression analysis assessed differences in sleep duration, latency, and nocturnal awakenings (outcomes) associated with physical exercise variables. Multiple analyzes were adjusted for age, sex, diet quality, BMI, smoking, and evening alcohol consumption. Results: Participants who performed physical exercise had better sleep parameters and its practice in the morning was associated with shorter sleep latency among early (OR=-0.49; 95%CI=0.25;0.94; $p<0.05$) and late chronotypes (β=-15.10; 95%CI=-28.39;-1.81; $p<0.05$). There was no effect of exercising in the evening among intermediate and late chronotypes, however, among early types, it was associated with a higher frequency of awakenings (OR=1.78; 95%CI=1.06;2.96; $p<0.05$) and insomnia (OR=1.91; 95%CI=1.04;3.53; $p<0.05$). Conclusions: Such findings suggest the need to consider chronotypes, along with existing recommendations for sleep hygiene and circadian hygiene, in clinical-epidemiological physical activity strategies focused on promoting sleep quality and circadian health.

Keywords: Sleep, Chronotype, Chronobiology, Exercise.

INTRODUCTION

The Sleep Foundation recommends that adults sleep between 7 and 9h each night[1] and, along with duration, sleep latency of up to 30 minutes and up to 1 awakening after sleep onset are also sleep quality indicators[2].

Nevertheless, within contemporary society, issues associated with sleep have emerged as a significant concern for public health, garnering frequent attention in clinical settings. Approximately one-third of the global populace is believed to suffer from inadequate sleep[3]. Chronic insomnia, constituting the prevailing sleep disorder, affects about 10% of the worldwide population[4].

While a multitude of elements are included in sleep hygiene guidelines, the consistent engagement in physical activity is underscored in all recommendations and approaches designed to prevent and/or assist in the adjunctive treatment of sleep disorders[5]. Many aspects associated with physical exercise have been suggested to enhance sleep quality, such as elevating body temperature prior to bedtime, improving vagal modulation, altering cortisol secretion, and boosting mood[6].

However, although exercising at any time during the day may enhance sleep quality when compared to a lack of exercise[7], numerous experts view evening exercise, particularly if performed very close to bedtime, as a possible trigger for sleep disturbances. They hypothesize that morning exercise might yield superior effects on sleep[8].

Recent chronobiological research suggests that besides being an important *zeitgeber* (from the German *zeit*, "time" and *geber*, "giver") of the circadian system, exercising in the early hours of the day could increase the amplitude of biological rhythms, make them less fragmented, improve circadian rhythms of

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body temperature and anticipate the Dim Light Melatonin Onset (DLMO). On the other hand, its evening practice could cause rhythms more fragmented, with less amplitude, and delay the midpoint of sleep from 3:00-4:00 (more restful sleep) to 6:00-7:00, increasing awakenings and leading to less restful sleep[9,10].

This team is still under debate and with controversial results in the literature. Some studies emphasize that exercise, regardless of the timing, results in prolonged non-rapid eye movement (NREM) sleep without affecting overall sleep quality. Such studies recommend that, given the vital role of exercise in promoting good health, sleep hygiene guidelines should encourage physical activity at any time of the day [8,11,12].

In this controversy, new insights have been provided by chronobiological research, which has suggested that the effects of evening exercise may be different according to individual circadian characteristics, determined by the chronotype [13-15].

Chronotypes describe an individual's sleep-wake schedule and can be classified, by the midpoint of sleep, into early/morning, intermediate, or late/evening types[16]. It reflects individual variations in the allocation of their circadian rhythms in relation to the 24-hour environmental cycles, which are expressed in the preferences of sleep schedules and the optimization for the development of different activities, including physical exercises, at certain times of the day[17]. For instance, individuals classified as early-types tend to go to bed and wake up very early, engaging in activities during the morning. In contrast, late-types prefer going to bed and waking up very late, engaging in activities during the evening[16]. These variances could result in distinct effects of morning and evening exercises on each specific type[13-15].

Nonetheless studies on the relationship between exercise time and sleep according to chronotypes are worldwide scarce, and, to our knowledge, there are no previous epidemiological studies, especially population-based ones, in Brazil.

Therefore, using data from the first national survey with a chronobiological focus on sleep, nutrition and health[18-20], our study aimed to: 1. Investigate the association of physical exercise with sleep quality (duration, latency, awakenings, and self-perception of quality) and insomnia and, 2. Verify the association of morning and evening physical exercise with sleep, depending on the chronotype.

Our main hypotheses were that (1) exercise would be positively associated with better sleep quality indicators; (2) evening exercise would be associated with worse indicators of sleep quality and insomnia among early chronotypes, but not among late and intermediate types, and (3) morning exercise would be associated with better sleep quality and lower odds of insomnia, regardless of the chronotype.

METHODS

Study design and population

This study was carried out with data from the first and second stages of the SONAR-Brazil Survey, which aims to investigate chronobiological aspects related to sleep, food, and nutrition in Brazilian adults. This is exploratory, population-based research, with data collection exclusively in a virtual environment. Participants were adults, non-pregnant, aged between 18 and 65 years, born and residing in all regions of Brazil (n=2 140). After excluding participants who declared being shift workers [n=90] the final sample totalized 2 050 non-pregnant Brazilian adults[18].

Considering a large population, to estimate population proportions with a confidence level of 95% and a margin error of 5% we defined, a priori, a minimum sample size of 385 valid questionnaires. However, the sample size remained open, and the efforts were directed to increase as maximum as possible to minimize the error margin. The final sample of 2 050 guarantees proportion estimates with a 95% confidence level and a margin of error lower than 4%. All data collection procedures have been conducted according to the Declaration of Helsinki and approved by the Committee of Research Ethics[18].

Recruitment took place between August 2021 and September 2022 and data were collected using a Google Form. By clicking on the research link, the volunteer respondents were directed to informed consent and, only after indicating their consent to participate in the study, they were directed to the questionnaire, made up of four blocks: characterization, health and lifestyle, sleep characteristics, eating and sleeping schedules. The generated responses were automatically stored in spreadsheets compatible with Microsoft Office Excel and later exported to the statistical software STATA 13 statistical software (Stata Corporation) for statistical analyses. The link to the online questionnaire was disseminated in several ways: referral of health professionals' reports in newspapers/magazines, advertisements on social media platforms, research institutes, health fairs, events scientific journals, and electronic pages addressing the research participants, to increase research visibility and, consequently, data collection[18].

Sleep traits and circadian parameters

In the questionnaire block about 'eating and sleeping schedules', the participants were informed: 'In this section, we want to know your routine on weekdays/work-days and weekends/free days'. The following questions were used to measure usual sleep and wake times: 'Considering your habits during the last month, on a typical weekday [or weekend]' 1. What time do you wake up? 2. What time do you sleep? Responses were in 30-min increments[18-20].

Sleep duration (in hours) was calculated as the difference between bedtime and wake-up timing[18-20]. We also calculated the midpoint of sleep on weekdays and weekends, defined as the middle time point between bedtime and wake-up timing[18-20].

The average weekly sleep duration, wake-up time, bedtime, and the midpoint of sleep were calculated as follows: [(5 × sleep duration/wake-up time/bedtime/midpoint of sleep on weekdays) + (2 × sleep duration/wake-up time/bedtime/midpoint of sleep on weekends)]/7[18-20].

Sleep latency was investigated by asking: 'During the past month, how long (in minutes) has it usually taken you to fall asleep each night?' and nocturnal awakenings by: "How many times do you wake up during the night, after sleep onset?'.

Considering the cutoff points established by the American Sleep Foundation for classifying sleep quality indicators, sleep variables were categorized into sleep duration <7 or ≥7 h/night, sleep latency ≤30 or > 30 min/night and awakening nocturnal ≤1 or >1/night[2,18].

Self-perception of sleep quality was investigated based on the question: "How do you rate the quality of your sleep?", with the possible answers: very good, good, poor, very poor. We considered poor sleep quality for those who answered poor or very poor[18].

Finally, participants were also asked about the diagnosis of insomnia.

Chronotypes

We adopted the "midpoint of sleep on free days corrected for sleep extension on free days (MSFsc)" as an indicator of chronotype, which is proposed to clean the chronotype of the confounder sleep debt[21]. For participants whose sleep duration on free days was longer than workdays, the midpoint was calculated as follows: [bedtime on free days + (sleep duration on free days/2)]. For participants whose sleep duration on free days was shorter than workdays, due to the sleep debt accumulated over the workweek, the corrected midpoint of sleep was applied, and calculated as follows: [bedtime on free days + (weekly average sleep duration/2)][18,21,22].

The 25th and 75th percentiles of MSFsc values were computed. Participants with MSFsc values below the 25th percentile were categorized as early-chronotype, those with values above the 75th percentile were classified as late-chronotype, and individuals with values falling between these percentiles were designated as intermediate-chronotype [23,24].

Physical Exercise

The practice of physical exercise, frequency, and time-of-day were investigated based on the following questions: 1. "Do you practice physical exercise or sport (of moderate or vigorous intensity)?" (e.g.: Walking, treadmill walking, bodybuilding, hydro gymnastics, gymnastics in general, swimming, martial arts and fighting, cycling, volleyball/football, dance, running, treadmill running, aerobics, soccer/futsal, basketball and/or tennis); 2. "On which day(s) of the week do you practice physical exercise or sport?"; 3. What is the duration (minutes) on each day of practice?; and 4. "Which time-of-day of the day do you usually practice it?", and possible answers were: morning (5:00 to 12:00), afternoon (12:00 to 18:00), and/or evening (after 18:00)[18].

From these questions, the weekly frequency (mean of the number of days in the week) and weekly duration (weekly frequency x duration on each day of practice) were calculated.

Lifestyle traits

Screen time per day was evaluated by the questions: "In your free time (not counting work/study), how many hours/day do you spend watching TV, on your computer, tablet, or cell phone?".

Food consumption was investigated using a food frequency questionnaire comprising 19 food/preparation categories, for which participants selected the frequency of weekly consumption: 'never', 'sometimes (1-3 days/week)', 'almost always (4-6 days/week)' or 'always (6-7 days/week)'. We evaluated the diet quality score based on the Food Guide for the Brazilian Population as proposed in a previous study[18-20].

For anthropometric evaluation, the BMI [weight(Kg)/height)m)²] was calculated, based on self-reported weight and height[18-20].

Some other details of the survey questionnaire concerning other covariates including sex, marital status, smoking, and evening alcohol consumption (after 18:00), were also included in our study.

Statistical analyses

To assess the differences between groups of participants categorized according to the chronotype (early/intermediate/late) in their characteristics, the ANOVA test (for continuous variables) and the chi-square test (for categorical variables) were performed.

Independent adjusted logistic regression models were conducted to assess OR and 95%CI differences in sleep duration (≤7h or >7h), sleep latency (>30min or ≤30min), poor sleep quality (poor or good), awakenings (>1 or ≤1/night), and insomnia (yes or no) (as outcomes) with the physical exercise variables (yes or no; days/week; morning or evening).

Linear regression analyses (β and 95%CI) evaluated differences in sleep duration (h), sleep latency (min), and awakenings (n) (as outcomes) associated with the same exercise variables.

To verify associations between physical exercise in the morning (5:00-12:00) and in the evening (after 18:00) with sleep outcomes, analyses were conducted with all participants and, subsequently, with each chronotype (early/intermediate/late).

All multiple analyzes were adjusted for age, sex, diet quality, BMI, smoking, and evening alcohol consumption. A P value ≤0.05 was considered statistically significant.

RESULTS

Of the 2 050 Brazilian adults [34 years old (18 to 65); 73% women] who participated in the study, 22% slept <7h, 35% reported awakenings>1/night, 27% reported latency>30min, 26% had insomnia and 30% poor self-perception of sleep quality. The practice of physical exercise was reported by 67%, with an average weekly duration of 194 (±215) min. Most of the participants reported exercising in the morning (33%), followed by the evening (28%) and afternoon (21%) (Table 1).

Table 1 also presents the characterization of the population according to chronotype. Early-types had a higher prevalence of good diet quality (36%, versus intermediate: 33% and late: 25%), lower evening alcohol consumption (37%, versus intermediate: 50% and late: 58%), and smoking (~3%, versus intermediate: 5% and late: 12%) (all p<0.001).

Except for sleep duration, variables related to sleep quality showed significant differences (p<0.001) when comparing groups. Early-types presented a higher frequency of awakenings, however, presented the shortest sleep latency (a difference of 20 minutes between late-types). Late-types were the ones with the highest prevalence of insomnia and poor sleep quality, about 37% (versus early: 23% and intermediate: 22%) and 39% (versus early: 31% and intermediate: 25%), respectively (Table 1).

Regarding the practice of physical exercise, the late-types were more sedentary. In addition to 38% not exercising (versus early: 34% and intermediate: 31%), screen time duration was also the highest (all with p<0.05), however, there was no difference in duration and frequency of physical exercise between groups (Table 1).

Among exercisers, the prevalence of the practice in the morning was higher among early-types and in the evening, it was higher among late-types. While ~40% of early-types exercised in the morning (versus intermediate: ~34% and late: ~23%), ~34% of late-types exercised in the evening (versus early: ~20% and intermediate: ~29%) (p<0.001) (Table 1).

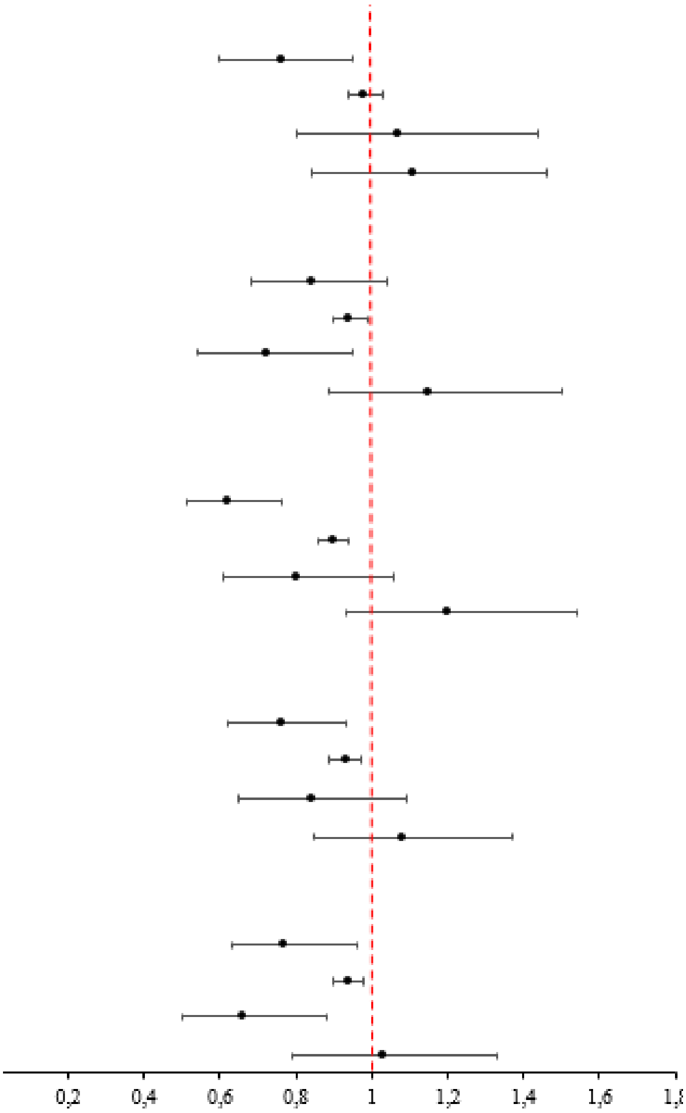
Table 1: Characteristics of the participants according to their chronotypes (n=2050)

		Chronotype			P value*
	Total	**Early**	**Intermediate**	**Late**	
Total	2 050 (100)	490 (23.90)	1.076 (52.49)	484 (23.61)	
Sex, % female	1 498 (73.07)	359 (73.27)	813 (75.56)[c]	326 (67.36)[c]	**0.003**
Age, y	34.32 (11.59)	37.94 (11.72)[ab]	34.48 (11.37)[ac]	30.30 (10.63)[bc]	**<0.001**
Marital Status					
Married/Living with Partner,%	793 (38.68)	257 (52.45)[ab]	433 (40.24)[ac]	103 (21.28)[bc]	**<0.001**
BMI, kg/m2	25.14 (5.03)	25.60 (5.07)[a]	24.94 (4.78)[a]	25.12 (5.50)	0.055
Diet quality (score)	35.32 (4.55)	35.97 (4.58)[b]	35.41 (4.50)[c]	34.44 (4.53)[bc]	**<0.001**
Low (1st tertile),%	699 (34.10)	128 (26.12)[ab]	369 (34.29)[ac]	202 (41.74)[bc]	**<0.001**
Intermediate (2d tertile),%	700 (34.15)	184 (37.55)[ab]	353 (32.81)[ac]	163 (33.68)[bc]	
Good (3d tertile),%	651 (31.76)	178 (36.33)[ab]	354 (32.90)[ac]	119 (24.59)[bc]	
Screen Time, m/day	211.84 (157.37)	172.12 (125.90)[ab]	205.06 (151.57)[ac]	267.12 (181.96)[bc]	**<0.001**
Non-Smokers,%	1 926 (93.95)	473 (96.53)[b]	1027 (95.45)[c]	426 (88.02)[bc]	**<0.001**
Evening alcohol,%	996 (48.59)	181 (36.94)[ab]	534 (49.63)[ac]	281 (58.06)[bc]	**<0.001**
Sleep traits					
Bedtime,hh:mm	23.33 (1.31)	22.16 (0.95)[ab]	23.21 (0.81)[ac]	24.76 (1.19)[bc]	**<0.001**
Waketime,hh:mm	7.12 (1.36)	5.89 (0.83)[ab]	7.02 (0.84)[ac]	8.58 (1.37)[bc]	**<0.001**
Sleep duration, h/night	7.79 (1.17)	7.72 (1.18)	7.81 (1.12)	7.82 (1.25)	0.35
<7h/night,%	445 (21.71)	115 (23.47)	221 (20.54)	109 (22.52)	0.37
Nocturnal awakenings, n/night	1.30 (1.23)	1.56 (1.37)[ab]	1.21 (1.14)[a]	1.21 (1.24)[b]	**<0.001**
>1/night,%	715 (34.88)	221 (45.10)[ab]	343 (31.88)[a]	151 (31.20)[b]	**<0.001**
Sleep Latency, m	33.47 (36.69)	28.08 (34.27)[b]	29.35 (30.62)[c]	48.10 (46.41)[bc]	**<0.001**
>30m,%	549 (26.78)	101 (20.61)[b]	241 (22.40)[c]	207 (42.77)[bc]	**<0.001**
Insomnia, %	532 (25.95)	111 (22.65) [b]	240 (22.30)[c]	181 (37.40)[bc]	**<0.001**
Poor sleep quality, %	613 (29.90)	154 (31.43)[ab]	269 (25.00)[ac]	190 (39.26)[bc]	**<0.001**
Physical Exercise					
Physical exerciser, %	1 365 (66.59)	325 (66.33)	739 (68.68)[c]	301 (62.19)[c]	**0.04**
Duration, min/day	194.37 (215.01)	198.76 (215.77)	193.22 (211.25)	192.47 (222.78)	0.87
Frequency, d/week	2.69 (2.30)	2.71 (2.38)	2.76 (2.26)	2.52 (2.29)	0.15
Timing, %					
Morning (5:00-12:00)	675 (32.93)	195 (39.80)[b]	369 (34.29)[c]	111 (22.93)[bc]	**<0.001**
Afternoon (12:00-18:00)	437 (21.32)	95 (19.39)	232 (21.56)	110 (22.73)	0.42
Evening (after 18:00)	573 (27.95)	96 (19.59)	313 (29.09)	164 (33.88)	**<0.001**

Abbreviation: BMI, body mass index. Values are shown as means ± SDs or percentages. P values are derived from the ANOVA (for continuous variables) and the chi-square test (for categorical variables). a = Morning vs. Intermediary; b = Morning vs. Evening; c = Intermediate vs. Evening (Bonferroni posthoc comparisons between categories. Values with the same superscript on the same line are significantly different). Significant P-values ≤ 0.05 are shown in bold.

The results of the multiple logistic analyses, adjusted for age, sex, diet quality, BMI, smoking, and evening alcohol consumption, are shown in Figures 1 and 2. Among all participants, physical exercisers (compared to non-exercisers) had lower odds of short sleep duration (OR=0.76; 95%CI=0.60;0.95; p=0.019], poor sleep quality (OR=0.62; 95%CI=0.51;0.76; p<0.001), awakenings >1/night (OR = 0.76; 95%CI=0.62;0.93; p=0.009) and sleep latency >30 min (OR=0.77; 95%CI=0.63;0.96; p=0.019). Higher weekly exercise frequency also demonstrated a protective effect for insomnia, poor sleep quality, awakenings, and sleep latency, and the exercise in the morning reduced the odds of insomnia by 28% (95%CI=0.54;0.95; p=0.025) (Figure 1).

Variables	*Adjusted OR* (IC 95%)	P Value*
SLEEP DURATION (<7h/night)		
Physical exerciser	0,76 (0.60; 0.95)	**0.019**
Exercise Frequency, d/week	0.98 (0.94; 1.03)	0.629
Morning exercise (5:00-12:00)	1.07 (0.80; 1.44)	0.628
Evening exercise (>18:00)	1.11 (0.84; 1.46)	0.457
INSOMNIA		
Physical exerciser	0.84 (0.68; 1.04)	0.116
Exercise Frequency, d/week	0.94 (0.90; 0.99)	**0.020**
Morning exercise (5:00-12:00)	0.72 (0.54; 0.95)	**0.025**
Evening exercise (>18:00)	1.15 (0.89; 1.50)	0.260
POOR SLEEP QUALITY		
Physical exerciser	0.62 (0.51; 0.76)	**0.000**
Exercise Frequency, d/week	0.90 (0.86; 0.94)	**0.000**
Morning exercise (5:00-12:00)	0.80 (0.61; 1.06)	0.128
Evening exercise (>18:00)	1.20 (0.93; 1.54)	0.144
AWAKENINGS (>1/night)		
Physical exerciser	0.76 (0.62; 0.93)	**0.009**
Exercise Frequency, d/week	0.93 (0.89; 0.97)	**0.003**
Morning exercise (5:00-12:00)	0.84 (0.65; 1.09)	0.205
Evening exercise (>18:00)	1.08 (0.85; 1.37)	0.501
SLEEP LATENCY (<30min)		
Physical exerciser	0.77 (0.63; 0.96)	**0.019**
Exercise Frequency, d/week	0.94 (0.90; 0.98)	**0.014**
Morning exercise (5:00-12:00)	0.66 (0.50; 0.88)	**0.005**
Evening exercise (>18:00)	1.03 (0.79; 1.33)	0.806



Significant P-values ≤ 0.05 are shown in bold.

Figure 1: Multiple logistic regressions analyzing the association of physical exercise and sleep outcomes. Data are presented as OR (95% CI) and multiple models are adjusted for age, sex, diet quality, BMI, smoking, and evening alcohol consumption (n=2 050).

In the early-type group, morning exercises (compared to early-types that exercised at other time-of-day) had 53% (95%CI=0.25;0.87; p=0.01) lower odds of having insomnia, 51% lower odds of >1 awakening/night (CI95%=0.30;0.80; p=0.005) and of sleep latency> 30min (95%CI 0.25;0.94; p=0.03). On the other hand, early-types who exercised in the evening (compared to early-types that exercised at other time-of-day) had 91% higher odds of having insomnia (95%CI=1.04;3.52; p=0.03) and 78% higher odds of >1 awakening/night (95%CI=1.06;2 .96; p=0.02) (Figure 2).

In the late-type group, those who exercised in the morning (compared to late-types that exercised at other time-of-day) were 48% less likely to report sleep latency>30min (95%CI: 0.27;1.00; p=0.05) (Figure 2).

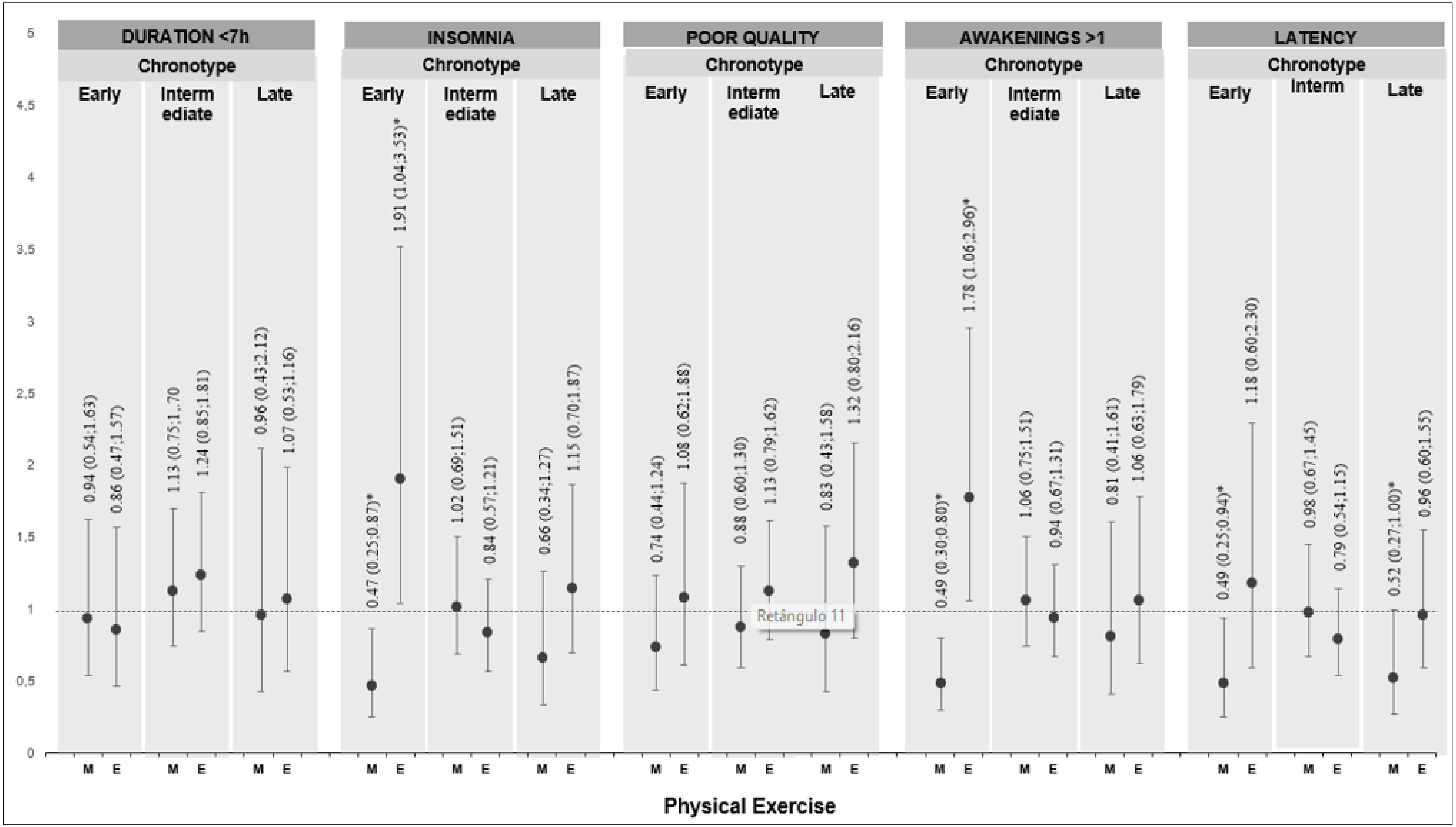
Among the intermediates-types, the time-of-day of physical exercise was not associated with any of the sleep variables, nor was there an association between evening exercise and sleep among the late-types participants (Figure 2).

Linear regression models are shown in Table 2. After adjusting for age, sex, diet quality, BMI, smoking, and evening alcohol consumption, participants who practiced physical exercise (compared to non-exercisers) had an increase in sleep duration (β=0.11; 95%CI=0.00;0.22; p=0.03), and a reduction in awakenings (β=-0.19; CI95%=-0.31;-0.08; p=0.001) and sleep latency (β=-5.58, 95%CI=-9.02;-2.14; p=0.001). For each additional day of weekly exercise, there was a decrease in both awakenings (β=-0.04; 95%CI=-0.06;-0.01; p=0.001) and sleep latency (β=-1 .00; CI95%=-1.71;-0.29; p=0.004).

Among all participants, while the exercise in the morning decreased the sleep latency by 5.97min (CI95%=-9.85;-2.09; p=0.003), the exercise in the evening increased it by 3.73min (95%CI=0.09;7.37; p=0.04) (Table 2).

This effect of morning exercise on sleep latency remained in the analysis conducted among late-types exercisers (compared to late-types that exercised at other time-of-day), with an even greater reduction, about 15.10min (95%CI=-28.39;-1.81; p=0.02). (Table 2).

Among early-types, those who exercised in the morning (compared to early-types that exercised at other time-of-day) had a reduction in the frequency of nocturnal awakenings (β=-0.30; 95%CI=-0.59;-0.22; p=0.03), while those who practiced in the evening (compared to early-types that exercised at other time-of-day) had an increase in their occurrence (β=0.36; CI95%=0.05;0.67; p=0.021) (Table 2).



*Abbreviation: M, Morning; E, evening. * P-values derived from multiple logistic models are significant (≤ 0.05).*

Figure 2: Multiple logistic regressions analyzing the association of morning and evening physical exercise with sleep outcomes according to chronotypes[1]. Data are presented as OR (95% CI) and models are adjusted for age, sex, diet quality, BMI, smoking, and evening alcohol consumption. *[1] Physical exercisers with early chronotype (n=325); Physical exercisers with intermediate chronotype (n=739); Physical exercisers with late chronotype (n=301).*

Table 2: Multiple linear regressions analyzing the association of physical exercise with sleep according to chronotype. Data are presented as the coefficient of β (95% CI), and multiple models are adjusted for age, sex, diet quality, BMI, smoking, and evening alcohol consumption.

	Sleep Duration (h)				**Awakenings (n/night)**				**Sleep Latency (min)**			
	Unadjusted β (95% CI)	**P value***	**Adjusted β (95% CI)**	**P value***	**Unadjusted β (95% CI)**	**P value***	**Adjusted β (95% CI)**	**P value***	**Unadjusted β (95% CI)**	**P value***	**Adjusted β (95% CI)**	**P value***
All Participants												
Pratice, yes[1]	0.10 (-0.00; 0.21)	0.05	0 .11 (0.00; 0.22)	0.03*	-0.27 (-0.39; -0.16)	<0.001	-0.19 (-0.31; -0.08)	0.001*	-7.39 (-10.75; -4.03)	<0.001	-5.58 (-9.02; -2.14)	**0.001***
Frequency, d/week[1]	0 .00 (-0.02; 0.02)	0.99	0.00 (-0.02; 0.02)	0.81	-0.06 (-0.08; -0.03)	<0.001	-0.04 (-0.06; -0.01)	0.001*	-1.34 (-2.03; -0.65)	<0.001	-1.00 (-1.71; -0.29)	**0.006***
Morning (5:00-12:00)[2]	-0.08 (-0.21; 0.04)	0.21	-0.09 (-0.22; 0.03	0.15	0.01 (-0.11; 0.14)	0.82	-0.08 (-0.21; 0.05)	0.22	-5.84 (-9.65; -2.02)	0.003	-5.97 (-9.85; -2.09)	**0.003***
Evening (>18:00)[2]	-0.03 (-0.16; 0.08)	0.53	-0.02 (-0.14; 0.09)	0.66	0.01 (-0.10; 0.14)	0.79	0.07 (-0.05; 0.19)	0.24	4.20 (0.59; 7.81)	0.02	3.73 (0.09; 7.37)	**0.04***
Early Chronotype[3]												
Morning (5:00-12:00)	-0.06 (-0.30; 0.18)	0.61	-0.05 (-0.30; 0.18)	0.63	-0.21 (-0.49; 0.07)	0.14	-0.30 (-0.59; -0.02)	0.03*	-4.31 (-11.21; 2.57)	0.21	-5.38 (-12.37; 1.60)	0.13
Evening (>18:00)	0.02 (-0.23; 0.29)	0.85	0.02 (-0.24; 0.29)	0.86	0.30 (-0.00; 0.61)	0.056	0.36 (0.05; 0.67)	0.02*	3.73 (-3.76; 11.23)	0.32	3.90 (-3.69; 11.49)	0.31
Intermediate Chronotype[4]												
Morning (5:00-12:00)	-0.01 (-0.18; 0.15)	0.89	-0.06 (-0.23; 0.10)	0.47	0.04 (-0.13; 0.21)	0.64	-0.02 (-0.19; 0.15)	0.81	0.95 (-3.13; 5.03)	0.648	-0.02 (-4.16; 4.12)	0.99
Evening (>18:00)	-0.13 (-0.29; 0.02)	0.08	-0.10 (-0.26; 0.05)	0.19	0.01 (-0.14; 0.17)	0.86	0.05 (-0.11; 0.21)	0.52	-1.44 (-5.30; 2.41	0.46	-1.01 (-4.89; 2.86)	0.60
Late Chronotype[5]												
Morning (5:00-12:00)	-0.23 (-0.60; 0.13)	0.21	-0.19 (-0.55; 0.17)	0.31	0.07 (-0.26; 0.41)	0.66	-0.08 (-0.41; 0.23	0.59	-14.23 (-27.34; -1.12)	0.03*	-15.10 (-28.39; -1.81)	**0.02***
Evening (>18:00)	0.04 (-0.24; 0.33)	0.75	0.11 (-0.17; 0.39)	0.43	-0.06 (-0.32; 0.19)	0.61	-0.04 (-0.29; 0.20)	0.73	7.49 (-2.74; 17.72)	0.15	5.81 (-4.49; 16.11)	0.26

**Significant P-values ≤ 0.05 are shown in bold.*

Abbreviations: CI, Confidence Interval. [1]all participants (n=2 050); [2]all physical exercisers (n=1 365); [3] physical exercisers with early chronotype (n=325); [4]physical exercisers with intermediate chronotype (n=739); [5]Physical exercisers with late chronotype (n=301).

DISCUSSION

As far as we are aware, this is the first study to investigate the association between physical exercise and sleep among the general Brazilian adult population, and also the first to consider the chronotype in the analysis of the effects of performing physical exercise in the morning and in the evening.

Late chronotype associated with sleep impairments (later bedtimes, poorer sleep quality, and insomnia) and corroborating our hypotheses, participants who practiced physical exercise were less likely to have short sleep duration, self-perception of poor sleep quality, more than one awakening per night and sleep latency longer than 30 minutes. Among physical exercisers, those who exercised in the morning had 28% lower odds of having insomnia, and a ~6min reduction in sleep latency, and, among those who exercised in the evening, the sleep latency was ~ 4min longer.

Indeed, the protective effect of physical exercise on sleep has already been elucidated in different geographic and socioeconomic scenarios[25,26] and the association of exercising close to bedtime with longer sleep-onset latency was also reported previously[8].

However, the main insight of our findings was the different effects of the period of exercise on sleep according to chronotypes. Morning exercise was the ideal time, both in the early and late chronotypes. For the late-types, the exercise in the morning was associated with shorter sleep latency. Among the early-types, the sleep latency, the frequency of awakenings, and the odds of having insomnia were lower when they exercised in the morning, however, awakenings and insomnia were more frequent when they exercised in the evening. And no effect was observed among intermediate-types.

Despite the effect of physical exercise on the regulation of the circadian system has not yet been sufficiently studied, some have shown that morning or early afternoon exercises advance, while evening exercises significantly delay the phases of internal circadian hormonal rhythms[9,27-30].

Especially in individuals with a late chronotype, an advance in the internal circadian rhythm would better align the internal rhythms with the environment and social schedules, which would reflect on the advance of sleep, substantially mediated by the anticipation of melatonin secretion.

Corroborating our study, a clinical trial with 52 young adults demonstrated that the effect of the time-of-day of exercise was influenced by the chronotype of the participants. The researchers measured the dim light melatonin onset and found that among late chronotypes, exercises both in the morning and evening induced phase advances (0.54±0.29hours and 0.46±0.25 hours, respectively). In contrast, early-types had phase advances with morning exercise (0.49 ± 0.25 hours) but delays with evening exercise (–0.41±0.29 hours)[14].

Another investigation among college students showed that late chronotypes reported later bedtime, longer sleep latencies, and poorer sleep quality, compared to early/intermediate chronotypes, and the chronotype moderated the relationship between exercise timing and sleep impairments[15].

Furthermore, more intense exercise close to bedtime could compromise the feeling of drowsiness by increasing cortisol and adrenaline levels, and body temperature and in turn, increase sleep latency, delay bedtime, and compromise its duration, due to the difficulty of sleep compensating in the morning to attend social and work/study demands[10].

In summary, our results, in line with previous studies, reaffirm that an active lifestyle could be considered a useful tool to improve sleep and reduces sleep problem. Secondarily, the demonstrated positive effect of exercising in the morning, suggests that the exercise schedule seems effective in changing the phase of the internal circadian rhythm and, therefore, has the potential to reduce exposure to circadian misalignment and positively influence sleep indicators[14,15].

Strengths and Weaknesses

Our study possesses several limitations, beginning with the utilization of self-reported questionnaires, which are susceptible to underreporting or misreporting. Additionally, the investigation of sleep domains relied on precise questions, with the questionnaire specifying that responses should reflect recent behaviors (last month). To ensure data closely aligned with typical behavior, the questionnaire differentiated between weekdays (work/study days) and weekends (free days)[31].

Additionally, we recognize as limitations the absence of the specific physical exercise clock time and the subjective self-reported habitual sleep, however, self-reports were considered valid for large-scale studies[32].

At last, even though we adjusted for sociodemographic, diet-related, and lifestyle variables, it is important to acknowledge a fundamental limitation inherent to cross-sectional studies. The direction of the relationship and potential causal pathways can only be hypothesized in such study designs.

CONCLUSION

Our findings point to the need for personalized prescriptions of physical exercise schedules based on circadian phenotypes. Late chronotypes, who experience the most severe circadian misalignment, showed sleep benefits from exercising in the morning and had no impairment from exercising in the evening. On the other hand, evening exercise negatively influenced nocturnal awakenings and insomnia in early chronotypes.s

Given the above, we expect that our findings support evidence indicating the need to consider interindividual variations determined by chronotypes, along with existing recommendations for sleep hygiene and circadian hygiene, in clinical-epidemiological physical activity strategies focused on promoting sleep quality and circadian health, as well as on the prevention and treatment of insomnia.

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Disclosure

The author reports no conflicts of interest in this work.

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REFERENCES

1. Hirshkowitz M, Whiton K, Albert SM, Alessi C, Bruni O, DonCarlos L, et al. National Sleep Foundation's updated sleep duration recommendations: final report. Sleep Health. 2015;1(4):233-43. doi: 10.1016/j.sleh.2015.10.004.
2. Ohayon M, Wickwire EM, Hirshkowitz M, Albert SM, Avidan A, Daly FJ, et al. National Sleep Foundation's sleep quality recommendations: first report. Sleep Health. 2017; 3(1):6-19. doi: 10.1016/j.sleh.2016.11.006.
3. Grandner MA. Sleep, Health, and Society. Sleep Med Clin. 2020;15(2):319-40. doi: 10.1016/j.jsmc.2020.02.017.
4. Morin CM, Jarrin DC. Epidemiology of Insomnia: Prevalence, Course, Risk Factors, and Public Health Burden. Sleep Med Clin. 2022; 17(2):173-91. doi: 10.1016/j.jsmc.2022.03.003.
5. Sejbuk M, Mirończuk-Chodakowska I, Witkowska AM. Sleep Quality: A Narrative Review on Nutrition, Stimulants, and Physical Activity as Important Factors. Nutrients. 2022; 14(9):1912. doi: 10.3390/nu14091912.
6. Uchida S, Shioda K, Morita Y, Kubota C, Ganeko M, Takeda N. Exercise effects on sleep physiology. Front Neurol. 2012; 3:48. doi: 10.3389/fneur.2012.00048.
7. Alley JR, Mazzochi JW, Smith CJ, Morris DM, Collier SR. Effects of resistance exercise timing on sleep architecture and nocturnal blood pressure. J Strength Cond Res. 2015; 29(5):1378-85. doi: 10.1519/JSC.0000000000000750.
8. Stutz J, Eiholzer R, Spengler CM. Effects of Evening Exercise on Sleep in Healthy Participants: A Systematic Review and Meta-Analysis. Sports Med. 2019; 49(2):269-87. doi: 10.1007/s40279-018-1015-0.
9. Youngstedt SD, Elliott JA, Kripke DF. Human circadian phase-response curves for exercise. J Physiol. 2019; 597(8):2253-68. doi: 10.1113/JP276943.
10. Garaulet M. Los relojes de tu vida. Barcelona. España: Paidós; 2017.
11. Goldberg M, Pairot de Fontenay B, Blache Y, Debarnot U. Effects of morning and evening physical exercise on subjective and objective sleep quality: an ecological study. J Sleep Res. 2023; 10:e13996. doi: 10.1111/jsr.13996.
12. Yue T, Liu X, Gao Q, Wang Y. Different Intensities of Evening Exercise on Sleep in Healthy Adults: A Systematic Review and Network Meta-Analysis. Nat Sci Sleep. 2022;14:2157-77. doi: 10.2147/NSS.S388863.
13. Moreno CRC, Raad R, Gusmão WDP, Luz CS, Silva VM, Prestes RM, et al. Are We Ready to Implement Circadian Hygiene Interventions and Programs? Int J Environ Res Public Health. 2022; 19(24):16772. doi: 10.3390/ijerph192416772.
14. Thomas JM, Kern PA, Bush HM, McQuerry KJ, Black WS, Clasey JL, et al. Circadian rhythm phase shifts caused by timed exercise vary with chronotype. JCI Insight. 2020; 5(3):e134270. doi: 10.1172/jci.insight.134270.
15. Glavin EE, Ceneus M, Chanowitz M, Kantilierakis J, Mendelow E, Mosquera J, et al. Relationships between sleep, exercise timing, and chronotype in young adults. J Health Psychol. 2021; (13):2636-47. doi: 10.1177/1359105320926530.
16. Horne JA, Ostberg O. A self-assessment questionnaire to determine morningness-eveningness in human circadian rhythms. Int J Chronobiol. 1976;4(2):97-110.
17. Delpouve J, Schmitz R, Peigneux P. Implicit learning is better at subjectively defined non-optimal time of day. Cortex. 2014; 58:18-22. doi: 10.1016/j.cortex.2014.05.006.
18. Castro-Santos L, Lima MO, Pedrosa AKP, Serenini R, Menezes RCE, Longo-Silva G. Sleep and circadian hygiene practices association with sleep quality among Brazilian adults. Sleep Medicine. 2023; 6. doi: 10.1016/j.sleepx.2023.100088
19. Longo-Silva G, Pedrosa AKP, Bezerra de Oliveira PM, da Silva J, Menezes RC, Marinho PM, et al. Beyond sleep duration: Sleep timing is associated with BMI among Brazilian adults. Sleep Medicine. 2023; 6(15). doi: 10.1016/j.sleepx.2023.100082
20. Longo-Silva G, Bezerra de Oliveira PM, Pedrosa AKP, Ribeiro da Silva J, Bernardes RS, Egito de Menezes RC, et al. Breakfast skipping and timing of lunch and dinner: Relationship with BMI and obesity. Obes Res Clin Pract. 2022;16(6):507-13. doi: 10.1016/j.orcp.2022.10.012.
21. Roenneberg T, Wirz-Justice A, Merrow M. Life between clocks: daily temporal patterns of human chronotypes. J Biol Rhythms. 2003; 18(1):80-90. doi: 10.1177/0748730402239679.
22. Roenneberg T, Pilz LK, Zerbini G, Winnebeck EC. Chronotype and Social Jetlag: A (Self-) Critical Review. Biology (Basel). 2019 12;8(3):54. doi: 10.3390/biology8030054.
23. Kiyotoki S, Nishikawa J, Nagata N, Niikura R, Doyama H, Imagawa A, et al. Exploration of the characteristics of chronotypes in upper gastrointestinal tract diseases: a multicenter study in Japan. Chronobiol Int. 2021;38(4):534-42. doi: 10.1080/07420528.2020.1830791.
24. Liu M, Ahmed WL, Zhuo L, Yuan H, Wang S, Zhou F. Association of Sleep Patterns with Type 2 Diabetes Mellitus: A Cross-Sectional Study Based on Latent Class Analysis. Int J Environ Res Public Health. 2022; 20(1):393. doi: 10.3390/ijerph20010393.
25. Atoui S, Chevance G, Romain AJ, Kingsbury C, Lachance JP, Bernard P. Daily associations between sleep and physical activity: A systematic review and meta-analysis. Sleep Med Rev. 2021; 57:101426. doi: 10.1016/j.smrv.2021.101426.
26. Wu X, Tao S, Zhang Y, Zhang S, Tao F. Low physical activity and high screen time can increase the risks of mental health problems and poor sleep quality among Chinese college students. PLoS One. 2015;10(3):e0119607. doi: 10.1371/journal.pone.0119607.
27. Sato S, Basse AL, Schönke M, Chen S, Samad M, Altıntaş A, et al. Time of Exercise Specifies the Impact on Muscle Metabolic Pathways and Systemic Energy Homeostasis. Cell Metab. 2019; 30(1):92-110.e4. doi: 10.1016/j.cmet.2019.03.013.
28. Ezagouri S, Zwighaft Z, Sobel J, Baillieul S, Doutreleau S, Ladeuix B, et al. Physiological and Molecular Dissection of Daily Variance in Exercise Capacity. Cell Metab. 2019; 30(1):78-91.e4. doi: 10.1016/j.cmet.2019.03.012.
29. Mead MP, Baron K, Sorby M, Irish LA. Daily Associations Between Sleep and Physical Activity. Int J Behav Med. 2019; 26(5):562-8. doi: 10.1007/s12529-019-09810-6.
30. Miyazaki T, Hashimoto S, Masubuchi S, Honma S, Honma KI. Phase-advance shifts of human circadian pacemaker are accelerated by daytime physical exercise. Am J Physiol Regul Integr Comp Physiol. 2001; 281(1):R197-205. doi: 10.1152/ajpregu.2001.281.1.R197.
31. Robbins R, Quan SF, Barger LK, Czeisler CA, Fray-Witzer M, Weaver MD, et al. Self-reported sleep duration and timing: A methodological review of event definitions, context, and timeframe of related questions. Sleep Epidemiol. 2021; 1:100016. doi: 10.1016/j.sleepe.2021.100016.
32. Biddle DJ, Robillard R, Hermens DF, Hickie IB, Glozier N. Accuracy of self-reported sleep parameters compared with actigraphy in young people with mental ill-health. Sleep Health. 2015; 1(3):214-20. doi: 10.1016/j.sleh.2015.07.006