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PHYSICAL ACTIVITY IS ASSOCIATED WITH HIGHER SLEEP EFFICIENCY IN THE GENERAL POPULATION: THE COLAUS STUDY

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ABSTRACT

Study objectives: To evaluate the association of objective physical activity (PA) and sedentary behaviour (SB) with sleep duration and quality.

Methods: Cross-sectional study including 2649 adults (53.5% women, 45-86 years) from the general population. Proportions of time spent in PA and SB were measured using 14-day accelerometry. Low PA and high SB status were defined as the lowest and highest tertile of each behaviour. 'Inactive', 'Weekend warrior' and 'Regularly active' weekly patterns were also defined. Sleep parameters were derived from the accelerometer and validated questionnaires.

Results: High PA, relative to low PA, was associated with higher sleep efficiency [76.6 *vs.* 73.8%, p<0.01] and lower likelihood of evening chronotype [relative-risk ratio (RR) and 95%CI: 0.71 (0.52; 0.97)]. Similar associations were found for low SB relative to high SB. 'Weekend warriors', relative to 'Inactives', had higher sleep efficiency [76.4 *vs.* 73.9%, p<0.01] and lower likelihood of evening chronotype [RR: 0.63 (0.43; 0.93)]. 'Regularly actives', relative to 'Inactives', had higher sleep efficiency [76.7 *vs.* 73.9%, p<0.01] and tended to have less frequently an evening chronotype [RR: 0.75 (0.54; 1.04), p=0.09]. No associations were found for PA and SB with sleep duration, daytime sleepiness, insomnia, and risk of sleep apnea (after adjustment for body mass index).

Conclusions: High PA and low SB individuals, even if they do not sleep longer, have higher sleep efficiency and have less frequently an evening chronotype.

Keywords: accelerometry; epidemiology; pattern; physical activity; sedentary behaviour; sleep.

STATEMENT OF SIGNIFICANCE

Physically active, less sedentary individuals have better sleep efficiency than inactive, sedentary individuals. Both physical activity evenly distributed over the week or concentrated on weekends are associated with improved sleep efficiency.

INTRODUCTION

The impact of physical activity (PA) [1] and sedentary behaviour (SB) [2] on cardiovascular disease (CVD) is well established, but the underlying mechanisms are incompletely understood. Mora et al. [3] suggested that only half of PA-mediated reduction in CVD incidence was explained by known cardiovascular risk factors.

Sleep duration and sleep disorders are associated with incident CVD [4,5]. Therefore, it can be speculated that PA and SB might impact CVD by modulating sleep. In small clinical trials, PA was related to better subjective and objective sleep [6]. These findings have also been replicated in epidemiological studies, where physically active individuals had higher sleep duration [7,8], quality and efficiency [9], and lower risks of insomnia [10,11], excessive daytime sleepiness [7,12] and sleep apnea [13,14]. However, all these findings were limited by the fact that they were based on: (i) self-reported PA [8-12,14,15], that is prone to recall bias, or (ii) non-validated sleep questionnaires [7,10-12]. Interestingly, a recent study found that objective PA shows little associations with sleep when exploring a large panel of parameters [16]. Finally, previous studies only considered PA levels; however it has been shown that PA distribution over week (i.e. weekly activity pattern) also exerts an effect on CVD. Indeed, exercising 1-2 times per week, called the 'Weekend warrior' pattern, could decrease the benefits of PA possibly due to the short-lived effects of PA [17].

Today, light and wearable accelerometers allow an easy and objective assessment of PA and SB [18], as well as sleep estimation [19]. Also, well validated sleep questionnaires such as the Pittsburgh Sleep Quality Index (PSQI) [20], the Epworth sleepiness scale [21], the Berlin questionnaire for risk of sleep apnea [22], and the Insomnia Severity Index (ISI) [23] are currently available.

Therefore, this study aimed to assess sleep parameters according to PA and SB status and patterns in a large population-based sample aged 45-86 years from the city of Lausanne, Switzerland. Our hypothesis was that sleep characteristics would differ between activity status and weekly patterns.

METHODS

Recruitment of participants

The detailed description of the recruitment of the CoLaus study and the follow-up procedures has been described previously [24,25]. Briefly, the CoLaus study is a population-based cohort exploring the biological, genetic and environmental determinants of CVD. A non-stratified, representative sample of the population of Lausanne (Switzerland) was recruited between 2003 and 2006 based on the following inclusion criteria: (i) age 35-75 years and (ii) willingness to participate. The second follow-up occurred ten years after the baseline survey and included an optional module assessing the participant's PA for 14 days.

Physical activity

PA was assessed using a wrist-worn triaxial accelerometer (*GENEActiv*, Activinsights Ltd, United Kingdom). This device has been validated against reference methods [26]. The accelerometers were pre-programmed with a 50 Hz sampling frequency, and subsequently attached to the participants' right wrist. Participants were requested to wear the device continuously for 14 days in their free-living conditions. Accelerometry data were downloaded using the *GENEActiv* software version 2.9 (*GENEActiv*, Activinsights Ltd, United Kingdom) and collapsed into 60-second epoch files. Data were analyzed using the *GENEActiv macro file* 'General physical activity' version 1.9 [27] based on intensity cutoffs validated among middle-aged adults [26]: SB (<241 g.min), light intensity PA (241-338 g.min) and moderate-to-vigorous PA (MVPA) (>338 g.min). Conversely, no information was available regarding the criteria used for non-wear time (proprietary). Based upon a previous study [28], a valid day was defined as ≥10 h (i.e. 600 min) and ≥8 h (i.e. 480 min) of diurnal wear-time on week days and weekend days, respectively. For each participant, the proportion of time (in percentage) spent in MVPA and in SB was averaged for all valid days and separately for valid week and weekend days. At least 5 week days and 2 weekend days of valid accelerometry data were required (see exclusion criteria).

For PA status, participants were split into tertiles of average proportion of time spent in MVPA and classified as 'low PA' if they were in the first tertile and as 'high PA' otherwise. For SB status, participants were split into tertiles of average proportion of time spent in SB and classified as 'high SB' if they were in the highest tertile and as 'low SB' otherwise.

Weekly activity patterns were defined according to PA status and its distribution throughout the week (**Supplementary figure 1**). For the distribution of PA, average proportion of time spent in MVPA on weekend days was divided by average proportion of time spent in MVPA on weekdays, and split into tertiles. Participants were categorized as 'PA mainly on weekends' if they were in the highest tertile and as 'PA throughout the week' otherwise. This classification allowed creating three mutually exclusive activity patterns as previously described [28]: 1) 'Inactive': low PA; 2) 'Weekend warrior': high PA & PA mainly on weekends; and 3) 'Regularly active': high PA & PA throughout the week.

Sleep measurement

Objective sleep duration and efficiency were derived from accelerometry and analyzed with R-package GGIR version 1.5-9 (http://cran.r-project.org) [19]. Sleep duration was defined as time with no change in arm angle greater than 5° for 5 min or more during a predefined nocturnal sleep window (21:00-09:00). The full R code with all parameterization can be found in **Supplementary file 1**. Data cleaning was performed by replacing sleep duration or efficiency as missing values if they were lower than 3h or 40%, respectively.

Subjective sleep quality was derived from the PSQI [20], a 19-item questionnaire evaluating sleep over the previous month. Seven items scaling 0-3 are derived: sleep quality, latency, efficiency, duration, disturbances, daytime dysfunction, and use of sleep medications; and then summed to obtain the global PSQI score (range: 0-21). Poor sleep quality was defined as a PSQI score >5 [20].

Self-reported sleep duration was derived from one item of the PSQI. Participants indicated the average number of hours of actual sleep per night in the previous month. A sleep duration ≤6 hours per night was considered as 'short sleep' [29].

Daytime sleepiness was derived from the Epworth Sleepiness Scale [21]. Participants rated how likely they were to doze off in eight daily situations scaling 0-3. Items were then summed to obtain the total daytime sleepiness score (range: 0-24). Daytime sleepiness was defined as an Epworth score >10 [21].

Risk of sleep apnea was derived from the Berlin questionnaire [22], asking participants about the presence of snoring behaviour and waketime sleepiness or fatigue, and the history of obesity or hypertension. Participants with persistent and frequent symptoms in any two of these three domains were considered to be at high risk for sleep apnea [22].

Participants reporting no sleep problems and not taking any sleep medication were considered as having no insomnia. For the other participants, insomnia severity was derived from the Insomnia Severity Index (ISI) [23], a 7-item questionnaire evaluating the nature, severity, and impact of insomnia over the last month; namely difficulties falling sleep, sleep maintenance problems, and early morning awakening, sleep dissatisfaction, interference of sleep disturbances with daytime functioning, noticeability of sleep problems by others, and distress caused by the sleep difficulties. Items were scaled 0-4 and then summed to obtain the global ISI score (range: 0-28). Clinically significant insomnia was defined as an ISI score ≥15 (moderate to severe intensity) [23].

Chronotype assessment was derived from the classification of the Morningness-Eveningness Questionnaire of Horne and Ostberg [30], i.e. participants were asked to characterize themselves as ‘definite evening’, ‘moderate evening’, ‘intermediate’, ‘moderate morning’, or ‘definite morning’. The chronotype was then summarized into three categories (intermediate/morning/evening).

Other data

Socio-demographic factors included age, gender and professional occupation. Participants were considered as having a professional occupation if they were currently working. Self-rated health (very good/good/average or bad) was collected during an interview. Behavioural factors such as

smoking and alcohol consumption were assessed by self-reported questionnaire. Alcohol consumption was considered as low if the participant reported to drink 0-13 units per week and high otherwise. Depression risk was assessed by the Center for Epidemiological Studies-Depression Scale (CES-D), and increased depression risk was defined by a CES-D score ≥17 for men and ≥23 for women [31]. Participants indicated their current medication which was then coded according to the Anatomical Therapeutics Chemical (ATC) Classification System of the World Health Organization. Psycholeptic or psychoanaleptic medications were defined by an ATC code beginning with 'N05' and 'N06', respectively.

Body weight and height were measured to the nearest 0.1 kg and 5 mm (Seca® scale, Seca® height gauge, Hamburg, Germany), with participants in light indoor clothes standing without shoes. Body mass index (BMI) was computed as weight/height^2. A fasting venous blood sample was drawn and glucose measurement was performed by the clinical laboratory of the Lausanne university hospital. Diabetes was defined by a fasting glucose ≥7.0 mmol/l and/or if the participant reported having an anti-diabetic treatment.

Exclusion criteria

Participants were excluded if they: (i) did not participate in accelerometry; (ii) had less than 5 weekdays or 2 weekend days of valid accelerometry data or (iii) had any missing data in professional occupation, self-rated health, alcohol consumption or psychotropic medication (**Figure 1**).

Statistical analysis

Statistical analyses were conducted using Stata version 14.1 for windows (Stata Corp, College Station, Texas, USA). In bivariate analyses, continuous variables were expressed as average ± standard deviation and between-group comparisons were performed using Student t-test and one-way analysis of variance (ANOVA). For ANOVA, post-hoc pairwise comparisons were performed using the method of Scheffe [32]. Categorical variables were expressed as percentage and between-group comparisons were performed using chi-square test of independence.

For continuous parameters of sleep, multivariable analysis comparing sleep parameters between activity status and weekly patterns groups were conducted using ANOVA and results were expressed as multivariable-adjusted average ± standard error. Post-hoc pairwise comparisons were performed using the method of Scheffe [32].

For dichotomous parameters of sleep, multivariable analyses were conducted using logistic regression and results were expressed as multivariable-adjusted odds-ratio and 95% confidence interval (CI).

For chronotype, multivariable analyses were conducted using multinomial logistic regression, with the 'Intermediate' group as base outcome and results were expressed as multivariable-adjusted relative-risk ratio (RR) and 95% CI.

Further analyses were performed including all participants irrespective of objective sleep duration and efficiency, and of missing items in daytime sleepiness questionnaire.

Additional analyses for PA and SB status were conducted to evaluate the effect of (i) a 10%-increment of the proportion of time spent in each activity and (ii) a 10h-increment of weekly PA. Additional analyses for weekly activity patterns were conducted to evaluate the effect of one standard deviation increase in daily PA while controlling for PA level. For continuous parameters of sleep, statistical analyses were conducted using linear regression and results were expressed as multivariable-adjusted coefficient and 95% CI. For dichotomous and categorical variables, multivariable analyses were conducted using simple and multinomial logistic regression, respectively.

All multivariable models were adjusted for age (continuous), gender (male/female), self-rated health (very good/good/average or bad), alcohol consumption (low/high), psychotropic medication (no/yes) and professional occupation (no/yes). Further adjustments for BMI (continuous), diabetes (no/yes), or increased depression risk (no/yes) were performed. Statistical significance was assessed for a two-sided test with $p<0.05$.

Ethical statement and consent

The institutional Ethics Committee of the University of Lausanne, which afterwards became

the Ethics Commission of Canton Vaud approved the baseline CoLaus study (reference 16/03, decisions of 13th January and 10th February 2003); the approval was renewed for the first (reference 33/09, decision of 23rd February 2009) and the second (reference 26/14, decision of 11th March 2014) follow-up. The full decisions can be obtained from the authors upon request. The study was performed in agreement with the Helsinki declaration and in accordance with the applicable Swiss legislation. All participants gave their signed informed consent before entering the study.

RESULTS

Selection procedure and characteristics of participants

Of the initial 4881 participants, 2649 (54.3%) were retained for analysis. The selection procedure is indicated in **Figure 1.** The response rates for sleep questionnaires varied from 63.9% (PSQI) to 82.2% (ISI), mainly due to missing items. Included and excluded participants' characteristics are presented in **Table 1**. Included participants were younger, less likely female, had a better self-rated health and lower prevalence of diabetes, and were more prone to have a professional occupation than excluded ones.

Participants' characteristics per activity status are presented in **Table 2**. Younger age, lower BMI, female gender, lower prevalence of diabetes, reporting a better health, and being professionally active were associated with high PA and low SB status, non-smoking status with high PA only. Participants' characteristics per weekly activity patterns are presented in **Table 3**. Younger age, lower BMI, female gender, non-smoking status, lower prevalence of diabetes, reporting a better health, and being professionally active were associated with the 'Weekend warrior' pattern.

Association of activity status with sleep

The associations between PA and SB status and sleep parameters are described in **Table 4**. In bivariate analysis, high PA and low SB status were associated with higher objective sleep efficiency, lower risk of sleep apnea, and lower likelihood of evening chronotype. These associations persisted

after multivariable adjustment (**Table 4**). No associations were found for the other sleep parameters (objective and self-reported sleep durations, subjective sleep quality, daytime sleepiness, and insomnia) (**Table 4**). Results did not change after including all participants irrespective of objective sleep duration and efficiency, and of missing items in daytime sleepiness questionnaire (**Supplementary table 1**). Most associations persisted after additional adjustments for BMI (**Supplementary table 2**), diabetes (**Supplementary table 3**), or depression risk (**Supplementary table 4**). Nevertheless, no association remained for PA and SB with sleep apnea risk when adjusted for BMI (**Supplementary table 2**), and only a non-significant trend (p=0.06) persisted for PA with lower likelihood of evening chronotype when adjusted for depression risk (**Supplementary table 4**).

Additional analyses that evaluated 10%-increment of the proportion of time spent in PA and SB and 10h-increment of weekly PA are presented in **Supplementary table 5** and **6**. Similar associations were found: increases in proportion of time spent in PA and increases in weekly PA were associated with higher objective sleep efficiency, lower risk of sleep apnea and lower likelihood of evening chronotype.

Association of weekly activity patterns with sleep

The associations between weekly activity patterns and sleep parameters are presented in **Table 5**. In bivariate analysis, the 'Weekend warriors' had a higher prevalence of daytime sleepiness in comparison to the other patterns, and a lower risk of sleep apnea with respect to the 'Inactives' while the 'Regularly actives' stood in between (**Table 5**). Both 'Weekend warrior' and 'Regularly active' patterns had higher objective sleep efficiency and lower likelihood of evening chronotype relative to the 'Inactives' (**Table 5**). After multivariable adjustment, the 'Weekend warriors' had higher objective sleep efficiency, lower risk of sleep apnea, and lower likelihood of evening chronotype than the 'Inactives'. Similarly, 'Regularly actives' had higher objective sleep efficiency and lower risk of sleep apnea while a non-significant trend remained for lower likelihood of evening chronotype (p=0.09) than the 'Inactives'. There was no persisting association between activity patterns and daytime sleepiness

(**Table 5**). Finally, no associations were found between patterns and the other sleep parameters (objective and self-reported sleep durations, subjective sleep quality, and insomnia). Results did not change after including all participants irrespective of objective sleep duration and efficiency, and of missing items in daytime sleepiness questionnaire (**Supplementary table 7**). Adjusting for BMI led to similar results except that activity patterns were no longer associated with risk of sleep apnea (**Supplementary table 8**). Additional analyses that evaluated 10%-increment in standard deviation of daily proportion of time spent in PA showed no association (**Supplementary table 9**).

DISCUSSION

This study showed that high PA and low SB are related to higher objective sleep efficiency, and lower likelihood of evening chronotype. Further, both PA evenly distributed over the week or concentrated on weekends are associated with improved sleep efficiency.

Association of activity status with sleep

High PA and low SB status were related to higher objective sleep efficiency, which is consistent with a previous study that used polysomnography [9]. Even if changes in sleep efficiency seem moderate (i.e. 2.8% and 3.1% within PA and SB status), they might be clinically relevant [33] as they are in the same magnitude order as decrement in sleep efficiency due to obstructive sleep apnea [34] or periodic limb movement disorder [35]. Since lower sleep efficiency has been related to mortality [33], and conditions disturbing sleep structure such as obstructive sleep apnea have been shown to be associated with increased CVD and mortality [36], it is possible that the lower sleep efficiency might be one of the mechanisms mediating low PA and high SB association with CVD.

Participants adopting high PA or low SB had lower risk of sleep apnea, but this difference was no longer significant after controlling for BMI. This finding is in agreement with a prior epidemiological study [14], but it has been contradicted by others showing an independent association [13,15]. Overall, exercise interventions have been shown to improve sleep apnea without decreasing BMI [37]. Finally,

our results suggest that the effect of PA on sleep apnea is mediated by changes in BMI, or that the association is too small to be detected using our sample size.

High PA and low SB status were negatively associated with evening chronotype, which is in agreement with another study showing lower PA levels among evening type adolescents [38]. Interestingly, a study indicated that participants with evening chronotype had a higher likelihood of type 2 diabetes and hypertension as compared with morning types [39]. Still, any influence of PA on chronotype needs to be further tested in longitudinal studies.

No associations were found for PA and SB status with objective and self-reported sleep durations, subjective sleep quality, daytime sleepiness and insomnia. This is in agreement with some previous studies [16,40,41] but not with others showing longer sleep duration [7,8], increased subjective sleep quality [8,9], lower rate of insomnia [10,11], and lower daytime sleepiness [7,12] among active individuals. For sleep duration, the lack of association may be due to the older age range of our sample (45-86 years old) since it was previously shown that the influence of PA on sleep decreases with age [7]. Other contradictory findings could be due to the use of self-reported PA [9,10], since it has been shown to be differently associated with sleep than objective PA [8].

Association of weekly activity patterns with sleep

In comparison to the 'Inactive' pattern, the 'Weekend warriors' had higher objective sleep efficiency, lower risk of sleep apnea, and lower likelihood of evening chronotype. Relative to the 'Inactives', the 'Regularly actives' had also higher objective sleep efficiency and lower risk of sleep apnea while only a tendency remained for lower likelihood of evening chronotype. After adjustment for BMI, the associations with sleep apnea risk were no longer significant. We failed to find any study to which we could compare our results. Our findings suggest that either distributing PA throughout the week or concentrating it on weekends improves sleep efficiency and is associated with lower likelihood of evening chronotype. Therefore, PA distribution does not seem to significantly impact the beneficial effect of PA on sleep.

Strengths and limitations

To the best of our knowledge, this is the first study exploring the association of both objectively-measured activity and sleep among adults. Importantly, and contrary to other studies [7,16], self-reported sleep characteristics were collected using validated questionnaires. Finally, both PA and SB were assessed, as high PA levels can be associated either with high or low SB levels, and reciprocally.

This study also has several limitations. First, due to its cross-sectional setting, reverse causation (i.e. sleep disturbances leading to changes in PA and SB levels and weekly activity patterns) cannot be ruled out. It would thus be important to confirm prospectively the results of this study, so that directional causality can be established. The next follow-up of the CoLaus cohort will hopefully solve this issue. Second, the accelerometer was worn on the right wrist, which is the dominant side for most people; hence, overall PA might have been overestimated. Still, previous findings found no impact of device location on PA assessment [26]. Third, *GENEActiv* accelerometers have been suggested to over-report MVPA [42]; still, as MVPA levels were categorized into tertiles and not absolute values this should not impact the validity of our results. Fourth, although sleep detection algorithm has been validated by polysomnography and predicted sleep duration with an accuracy of 83% [19], the validation procedure was conducted among 28 sleep clinic patients wearing the accelerometer on their non-dominant wrist. Further, the algorithm overestimated sleep duration by an average of 31 minutes. Hence, the validation data might not be applicable to our sample, as most participants had no sleep complaints and the accelerometer was worn on the dominant wrist. Still, it has been shown that wear side does not influence PA assessment [26], and in the absence of other validation procedures, this is the best methodology that could be applied in our study. For future studies, it would be important that the algorithm be also validated in a larger sample of subjects without sleep complains. Finally, due to an important exclusion rate (i.e. 45.7%), the retained sample might be no longer representative of the general population. Still, included participants showed demographic characteristics relatively similar to the Lausanne population (**Supplementary table 10**).

Conclusion

High PA and low SB individuals, even if they do not sleep longer, have higher sleep efficiency and less evening chronotype.

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ABBREVIATIONS

ANOVA: Analysis of Variance

ATC: Anatomical Therapeutics Chemical

BMI: Body Mass Index

CVD: Cardiovascular Disease

ISI: Insomnia Severity Index

MVPA: Moderate-to-Vigorous Physical Activity

PA: Physical Activity

PSQI: Pittsburgh Sleep Quality Index

SB: Sedentary Behaviour

DISCLOSURE STATEMENT

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FIGURE CAPTIONS

Figure 1: Selection procedure. [a], less than 5-week days with minimum 10 h of diurnal wearing time or less than 2 weekend days with minimum 8 h of diurnal wearing time. [b], alcohol consumption, neurotropic medication or professional occupation.

TABLES

Table 1: Characteristics of excluded and included participants. The CoLaus study, Switzerland, 2014-2017.

	Included	**Excluded**	**P-value**
Sample size	2649	2232	
Age (years)	61.6 ± 9.8	64.5 ± 10.9	<0.01
Body mass index (kg/m^2)	26.4 ± 4.6	26.5 ± 4.8	0.27
Female	53.5	56.9	0.02
Self-rated health			<0.01
Very good	22.8	19.6	
Good	56.9	55.1	
Average or bad	20.3	25.3	
Smoking status			0.08
Never	42.6	41.0	
Former	39.5	38.4	
Current	17.9	20.6	
High alcohol consumption	14.0	13.0	0.38
Work	57.5	46.8	<0.01
High PA status	66.7	66.4	0.91
Diabetes	9.2	13.4	<0.01
Increased depression risk	11.9	11.9	0.99

PA, physical activity. Results expressed as mean ± standard deviation for continuous variables and as percentage for categorical variables. Between-group comparisons performed using student t-test for continuous variables and using chi-square test of independence for categorical variables.

Table 2: Characteristics of participants, stratified by activity status. The CoLaus study, Switzerland, 2014-2017.

	Physical activity			Sedentary behaviour		
	Low	**High**	**P-value**	**High**	**Low**	**P-value**
Sample size	882	1767		893	1756	
Age (years)	65.6 ± 10.5	59.6 ± 8.8	<0.01	64.6 ± 10.6	60.1 ± 9.1	<0.01
Body mass index (kg/m^2)	27.7 ± 5.0	25.7 ± 4.3	<0.01	27.7 ± 5.0	25.7 ± 4.3	<0.01
Female	44.7	58.0	<0.01	40.3	60.3	<0.01
Self-rated health			<0.01			<0.01
Very good	16.4	26.0		17.4	25.6	
Good	57.3	56.8		57.8	56.5	
Average or bad	26.3	17.3		24.9	17.9	
Smoking status			<0.01			0.12
Never	39.5	44.2		40.5	43.7	
Former	39.5	39.5		39.7	39.4	
Current	21.1	16.3		19.8	16.9	
High alcohol consumption	15.0	13.5	0.30	14.7	13.6	0.46
Work	43.5	64.5	<0.01	47.3	62.7	<0.01
Diabetes	16.1	5.7	<0.01	14.9	6.3	<0.01
Increased depression risk	13.6	11.1	0.07	13.7	11.0	0.06

Results expressed as mean ± standard deviation for continuous variables and as percentage for categorical variables. Between-group comparisons performed using student t-test for continuous variables and using chi-square test of independence for categorical variables.

Table 3: Characteristics of participants, stratified by weekly activity patterns. The CoLaus study, Switzerland, 2014-2017.

	Inactive	**Weekend warrior**	**Regularly active**	**P-value**
Sample size	882	617	1150	
Age (years)	65.6 ± 10.5	57.4 ± 8.1	60.8 ± 9.0	<0.01
Body mass index (kg/m^2)	27.7 ± 5.0	25.1 ± 4.0	26.0 ± 4.4	<0.01
Female	44.7	58.8	57.5	<0.01
Smoking status				0.03
Never	39.5	45.0	43.8	
Former	39.5	38.9	39.8	
Current	21.1	16.1	16.4	
Self-rated health				<0.01
Very good	16.4	28.0	24.9	
Good	57.3	56.6	56.9	
Average or bad	26.3	15.4	18.3	
High alcohol consumption	15.0	14.4	13.0	0.40
Work	43.5	79.6	56.4	<0.01
Diabetes	16.1	4.6	6.4	<0.01
Increased depression risk	13.6	10.5	11.3	0.18

Results expressed as mean ± standard deviation for continuous variables and as percentage for categorical variables. Between-group comparisons performed using one-way analysis of variance for continuous variables and using chi-square test of independence for categorical variables.

Table 4: Association of physical activity and sedentary behaviour status with sleep parameters. The CoLaus study, Switzerland, 2014-2017.

	Physical activity			Sedentary behaviour		
	Low	**High**	**P-value**	**High**	**Low**	**P-value**
Sample size	882	1767		893	1756	
Objective sleep duration (h) §						
Bivariate	7.1 ± 1.0	7.1 ± 1.0	0.48	7.1 ± 1.0	7.1 ± 1.0	0.76
Multivariable-adjusted	7.1 ± 0.03	7.1 ± 0.02	0.88	7.1 ± 0.03	7.1 ± 0.02	0.56
Objective sleep efficiency (%) §						
Bivariate	73.5 ± 8.4	76.8 ± 8.0	<0.01	73.1 ± 8.4	77.0 ± 7.9	<0.01
Multivariable-adjusted	73.8 ± 0.29	76.6 ± 0.20	<0.01	73.6 ± 0.28	76.7 ± 0.20	<0.01
Self-reported sleep duration (h) §						
Bivariate	7.0 ± 1.1	7.0 ± 1.0	0.95	6.9 ± 1.1	7.0 ± 1.0	0.46
Multivariable-adjusted	6.9 ± 0.05	7.0 ± 0.03	0.49	6.9 ± 0.05	7.0 ± 0.03	0.33
Short sleep †						
Bivariate	27.6	25.1	0.27	27.9	24.9	0.18
Multivariable-adjusted	1 (ref)	0.89 (0.69; 1.14)	0.34	1 (ref)	0.87 (0.68; 1.10)	0.25
Poor sleep quality †						
Bivariate	34.6	31.8	0.25	33.8	32.2	0.52
Multivariable-adjusted	1 (ref)	1.08 (0.85; 1.39)	0.52	1 (ref)	1.05 (0.82; 1.33)	0.72
Excessive daytime sleepiness †						
Bivariate	10.3	11.0	0.63	9.5	11.4	0.21
Multivariable-adjusted	1 (ref)	0.94 (0.68; 1.30)	0.70	1 (ref)	1.15 (0.84; 1.59)	0.38
Increased risk of sleep apnea †						
Bivariate	28.2	18.8	<0.01	27.9	18.8	<0.01
Multivariable-adjusted	1 (ref)	0.72 (0.57; 0.91)	<0.01	1 (ref)	0.73 (0.58; 0.92)	<0.01
Insomnia †						
Bivariate	4.4	5.9	0.17	4.5	5.8	0.21
Multivariable-adjusted	1 (ref)	1.56 (0.98; 2.48)	0.06	1 (ref)	1.47 (0.93; 2.32)	0.10
Chronotype						
Bivariate			<0.01			<0.01
Intermediate	11.6	13.7		11.6	13.7	
Morning	38.4	45.1		35.7	46.5	
Evening	50.0	41.2		52.7	39.8	
Multivariable-adjusted						
Morning	1 (ref)	1.07 (0.78; 1.47)	0.66	1 (ref)	1.18 (0.87; 1.62)	0.29
Evening	1 (ref)	0.71 (0.52; 0.97)	0.03	1 (ref)	0.64 (0.47; 0.86)	<0.01

For continuous variables (§), statistical analyses were performed using student t-test (bivariate) and ANOVA (multivariable); results were expressed as average ± standard deviation (bivariate) and as multivariable-adjusted average ± standard error. For dichotomous categorical variables (†), statistical analyses were performed using chi-square test of independence (bivariate) and logistic regression (multivariable); results were expressed as percentage (bivariate) and as multivariable-adjusted odds-ratio and (95% confidence interval). For chronotype, statistical analyses were performed using multinomial logistic regression comparing the 'Morning' and 'Evening' groups to the 'Intermediate' one and results were expressed as multivariable-adjusted relative-risk ratio and (95% confidence interval). All multivariable models were adjusted for age (continuous), gender (male/female), self-rated health (very good/good/average or bad), alcohol consumption (low/high), psychotropic medication (no/yes) and professional occupation (no/yes).

Table 5: Association of weekly activity patterns with sleep parameters. The CoLaus study, Switzerland, 2014-2017.

	Inactive	Weekend warrior	Regularly active	P-value
Sample size	882	617	1150	
Objective sleep duration (h) §				
Bivariate	7.1 ± 1.0	7.0 ± 0.9	7.1 ± 1.0	0.72
Multivariable-adjusted	7.1 ± 0.03	7.1 ± 0.04	7.1 ± 0.03	0.87
Objective sleep efficiency (%) §				
Bivariate	73.5 ± 8.4 [a]	76.7 ± 7.6 [b]	76.8 ± 8.1 [b]	<0.01
Multivariable-adjusted	73.9 ± 0.29 [a]	76.4 ± 0.34 [b]	76.7 ± 0.24 [b]	<0.01
Self-reported sleep duration (h) §				
Bivariate	7.0 ± 1.1	6.9 ± 1.0	7.0 ± 1.0	0.38
Multivariable-adjusted	6.9 ± 0.05	7.0 ± 0.05	7.0 ± 0.04	0.77
Short sleep †				
Bivariate	27.6	25.0	25.2	0.54
Multivariable-adjusted	1 (ref)	0.84 (0.62; 1.15)	0.91 (0.70; 1.19)	
Poor sleep quality †				
Bivariate	34.6	30.5	32.6	0.39
Multivariable-adjusted	1 (ref)	1.07 (0.78; 1.46)	1.09 (0.84; 1.42)	
Excessive daytime sleepiness †				
Bivariate	10.3	14.1	9.2	0.02
Multivariable-adjusted	1 (ref)	1.15 (0.79; 1.69)	0.83 (0.58; 1.18)	
Increased risk of sleep apnea †				
Bivariate	28.2	16.6	20.1	<0.01
Multivariable-adjusted	1 (ref)	0.61 (0.44; 0.83) *	0.77 (0.60; 1.00) *	
Insomnia †				
Bivariate	4.4	5.4	6.1	0.32
Multivariable-adjusted	1 (ref)	1.50 (0.84; 2.68)	1.59 (0.97; 2.59)	
Chronotype				
Bivariate				<0.01
Intermediate	11.6	15.1	12.9	
Morning	38.4	44.2	45.5	
Evening	50.0	40.7	41.5	
Multivariable-adjusted				
Morning	1 (ref)	0.98 (0.67; 1.45)	1.12 (0.80; 1.56)	
Evening	1 (ref)	0.63 (0.43; 0.93) *	0.75 (0.54; 1.04)	

For continuous variables (§), statistical analyses were performed using student t-test (bivariate) and ANOVA (multivariable); results were expressed as average ± standard deviation (bivariate) and as multivariable-adjusted average ± standard error. For dichotomous categorical variables (†), statistical analyses were performed using chi-square test of independence (bivariate) and logistic regression (multivariable); results were expressed as percentage (bivariate) and as multivariable-adjusted odds-ratio and (95% confidence interval). For chronotype, statistical analyses were performed using multinomial logistic regression comparing the 'Morning' and 'Evening' groups to the 'Intermediate' one and results were expressed as multivariable-adjusted relative-risk ratio and (95% confidence interval). All multivariable models were adjusted for age (continuous), gender (male/female), self-rated health (very good/good/average or bad), alcohol consumption (low/high), psychotropic

medication (no/yes) and professional occupation (no/yes). Post-hoc pairwise comparisons of averages were performed using the method of Scheffe; values with differing superscripts differ at $p<0.05$. Significant ($p<0.05$) odds ratios or relative-risk ratios are indicated with *.