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ORIGINAL ARTICLE

Blood Pressure Circadian Pattern and Physical Exercise Assessment by Accelerometer and 7-Day Physical Activity Recall Scale

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BACKGROUND
The relationship between regular physical activity, measured objectively and by self-report, and the circadian pattern of 24-hour ambulatory arterial blood pressure (BP) has not been clarified.

METHODS
We performed a cross-sectional study in a cohort of healthy patients. We included 1,345 patients from the EVIDENT study (mean age 55 ± 14 years; 59.3% women). Physical activity was assessed using the 7-day physical activity recall (PAR) questionnaire (metabolic equivalents (MET)/hour/week) and the Actigraph GT3X accelerometer (counts/minute) for 7 days; ambulatory arterial BP was measured with a radial tonometer (B-pro device).

RESULTS
The dipper-pattern patients showed a higher level of activity than nondipper patients, as assessed by accelerometer and 7-day PAR. Physical activity measures correlated positively with the percent drop in systolic BP (SBP; $\rho = 0.19$ to 0.11; $P < 0.01$) and negatively with the systolic and diastolic sleep to wake ratios ($\rho = -0.10$ to -0.18; $P < 0.01$) and heart rate ($\rho = -0.13$; $P < 0.01$). In logistic regression, considering the circadian pattern (1, dipper; 0, nondipper) as the dependent variable, the odds ratio of the third tertile of counts/minute was 1.79 (95% confidence interval [CI], 1.35–2.38; $P < 0.01$) and of MET/hour/week was 1.33 (95% CI, 1.01–1.75; $P = 0.04$) after adjustment for confounding variables.

CONCLUSIONS
Physical activity, as evaluated by both the accelerometer and the 7-day PAR, was associated with a more marked nocturnal BP dip and, accordingly, a lower SBP and diastolic BP sleep to wake ratio.

CLINICAL TRIAL REGISTRATION
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Compared with clinical blood pressure (BP), ambulatory arterial BP monitoring is a stronger cardiovascular risk predictor[1–3] and has a greater association with target organ damage.[4,5] In both hypertensive patients and the general population, the increase in nocturnal BP is associated with more cardiovascular complications.[6,7] A recent metaanalysis by Fagard *et al.*,[8] confirms these associations and concludes that the dipping pattern and the sleep-to-wake BP ratio significantly and independently predict mortality and cardiovascular events in hypertensive patients without a history of major cardiovascular disease.

The BP drop caused by physical exercise is common in both clinical[9] and ambulatory arterial BP, both while awake and during sleep.[10,11] It has also been found that aerobic endurance training induces significant net reductions of nighttime and daytime ambulatory BP of 3.0/2.4 mm Hg and 3.3/3.5 mm Hg, respectively,[12] and it may reduce left ventricular afterload.[13]

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Accelerometers (Actigraph GT3X; Actigraph, Shalimar, FL), which had been previously validated,[28] were used. Subjects wore the accelerometer fastened with an elastic strap to the right side of the waist for 7 consecutive days, except for bathing and performing activities in the water. The data were recorded at 1-minute intervals. Total physical activity was expressed in counts/minute. The intensity of physical activity (low, moderate, or high) was determined according to the cutoff points proposed by Freedson *et al.*,[29]

Statistical analysis

The continuous variables were expressed as the mean ± standard deviation for normally distributed continuous data, median (interquartile range) for asymmetrically distributed continuous data, and frequency distribution for categorical data. Statistical normality was tested using the Kolmogorov-Smirnov test. The difference in means between 2-category quantitative variables was analyzed using the independent-samples Student *t* test for normally distributed continuous data, the Mann–Whitney *U* test for asymmetrically distributed continuous data, and the Kruskal-Wallis test for comparisons of more than 2 categories. The χ^2 test was used to contrast categorical data. A Spearman correlation was used to analyze the relationship between continuous asymmetrically distributed data. We performed 2 multiple linear regression analyses, considering the systolic sleep to wake ratio × 100 as the dependent variable (to facilitate the interpretation) and the counts/minute and MET/hour/week as the independent variables. We adjusted the models in a second step with age and sex and a third step with body mass index (BMI), SBP, antihypertensive drugs (1, yes; 0, no), and diabetes (1, yes; 0, no). We also performed 2 multiple logistic regression analyses that considered the circadian pattern (1, dipper; 0, nondipper) as the dependent variable and the tertiles of counts/minute and of MET/hour/week as the independent variables (first tertile, the least exercise; third tertile, the most exercise). We adjusted the models in a second step with age and sex and a third step with BMI, SBP, antihypertensive drugs (1, yes; 0, no), diabetes (1, yes; 0, no), and hypertension (1, yes; 0, no). In the analysis, we considered both risers and nondippers as nondippers. The data were analyzed using SPSS version 18.0 (SPSS Inc., Chicago, IL). A value of $P < 0.05$ was considered to be statistically significant.

RESULTS

We analyzed 1,345 patients with a mean age of 55 ± 14 years, of whom 59.3% (798) were women; 60.4% had a dipping pattern, 34.8% nondipping, and 4.8% rising. Table 1 shows the demographic and clinical characteristics of the patients, as categorized by circadian pattern (dippers and nondippers, including risers). Dipper-pattern patients were older, predominantly male, and had higher awake BP and lower sleep BP than nondipper patients. Nondipper patients included a higher proportion of smokers, and they had a higher heart rate. There was no difference in the proportion of hypertensive patients or in those taking antihypertensive drugs.

Physical exercise, assessed by accelerometer and measured in both counts/minute and in the time spent in moderate and intense physical activity as well as in calorie expenditure, was greater in the dipper-pattern patients ($P < 0.01$). In addition, nondipper patients spent more time in sedentary activities ($P \leq 0.01$). No difference was found between the light-intensity activities of the 2 groups (Table 2). According to 7-day PAR, the dipper patients devoted more time to moderate and intense activity and had a greater amount of activity (MET/hour/week, as measured by both leisure time and total time) compared with nondippers. This also determined a higher proportion of active patients in the dipper group (34% vs. 28%; $P = 0.03$; Table 2).

Table 3 shows the correlations of physical activity with different measures of BP and heart rate. Physical activity measures (counts/minute and MET/hour/week) were positively correlated with systolic dipping and negatively correlated with the systolic and diastolic sleep to wake ratios and heart rate, although the latter decreased or disappeared in patients on antihypertensive drugs. When analyzed separately for dippers and nondippers, these relationships were maintained in both subgroups. In multiple linear regression (Table 4), considering the systolic sleep to wake ratio as a dependent variable, both counts/minute and MET/hour/week were significantly different in all 3 models without adjustment (first model: B = −0.01, $P < 0.01$ and B = −0.01, $P \leq 0.01$, respectively); with adjustment for age (years) and sex (second model: B = −0.01, $P < 0.01$ and B = −0.01, $P = 0.05$); and with adjustment for BMI (kg/m^2), SBP (mm Hg), diabetes, and antihypertensive drugs (third model: B = −0.01, $P < 0.01$ and B = −0.01, $P \leq 0.01$).

In logistic regression analysis (Table 5), considering the circadian pattern (dipper vs. nondipper) as the dependent variable, the odds ratio (OR) of the third tertile of counts/minute compared with the first tertile was 1.89 (95% confidence interval [CI], 1.44–2.48; $P < 0.01$). Even though it decreased after adjustment (OR = 1.79; 95% CI, 1.34–2.37), the statistical significance remained ($P < 0.01$). The OR of the third tertile of MET/hour/week was slightly lower than that of counts/minute (OR = 1.41; 95% CI, 1.08–1.83; $P = 0.01$). Although it also decreased after adjustment (OR = 1.33; 95% CI, 1.01–1.75; $P = 0.04$), its statistical significance also remained.

Figure 1 shows the mean values of the systolic sleep to wake ratio according to the counts/minute and MET/hour/week tertiles. The highest systolic sleep to wake ratio occurred in the first tertile and the lowest was observed in the third, that is, the nocturnal BP dip increased with increasing physical activity, as evaluated by both methods.

We found no difference in the awake SBP between the tertiles of physical activity evaluated by the accelerometer and the 7-day PAR.

DISCUSSION

We investigated a large group of patients who represent those in the general population without serious illness treated by family practitioners in Spain. We found greater physical activity, assessed by both the accelerometer (objective measure) and the 7-day PAR questionnaire (subjective measure), in the 24-hour SBP dipper-pattern patients than in nondippers. This group of patients spent

Table 1. Baseline characteristics of patients according to circadian pattern

	Pattern nondipper (533)		Pattern dipper (812)		
	Mean/Median/ Number	SD/IQR/(%)	Mean/Median/ Number	SD/IQR/(%)	*P* value
Age, years	53.8	14.1	55.7	13.5	0.01
Gender, n (%)					<0.01
Male	189	(34.6)	358	(65.4)	
Female	344	(43.1)	454	(56.9)	
Smoking status, n (%)					0.02
Never	244	(38.3)	393	(61.7)	
Current	135	(46.6)	155	(53.4)	
Past	154	(36.8)	264	(63.2)	
Alcohol, gr/week	10	70–0	10	70–0	0.959
Body mass index, kg/m^2	26.9	29.8–24.1	26.6	29.3–23.9	0.11
Office SBP, mm Hg)]	124	17	125	17	0.08
Office DBP, mm Hg	77	11	77	10	0.55
Heart rate, bpm	73	11	71	11	<0.01
Central SBP, mm Hg	116	16.	117	16	0.05
24-hour SBP, mm Hg	121	17	121	17	0.57
24-hour DBP, mm Hg	77	11	76	11	0.58
Awake SBP, mm Hg	122	18	127	18	<0.01
Awake DBP, mm Hg	78	12	80	12	<0.01
Sleep SBP, mm Hg	117	19	109	15	<0.01
Sleep DBP, mm Hg	74	11	69	10	<0.01
Fasting glucose, mg/dL	89	99–83	89	97–83	0.34
Glycated hemoglobin, %	5.5	5.7–5.3	5.5	5.8–5.3	0.95
Creatinine, mg/dL	0.80	0.90–0.70	0.80	0.92–0.70	0.01
Total cholesterol, mg/dL	214	39	213	38	0.82
Triglycerides, mg/dL	104	144–72	95	129–72	0.05
HDL, cholesterol, mg/dL	57	67–48	57	69–48	0.83
LDL, cholesterol mg/dL	132	36	133	34	0.84
Hypertension, n (%)	159	(30.2)	227	(28.1)	0.08
Diabetes, n (%)	53	(10.0)	59	(7.3)	0.42
Dyslipidemia, n (%)	153	(29.0)	254	(31.4)	0.36
Antihypertensive drugs, n (%)	164	(30.8)	230	(28.3)	0.36
Antidiabetic drug, n (%)	53	(10.1)	58	(7.1)	0.06
Lipid lowering drugs, n (%)	95	(17.8)	170	(20.9)	0.18

Values are means (SDs) for normally distributed continuous data and medians (IQR) for asymmetrically distributed continuous data and number and proportions for categorical data. *P*-values are for comparison of subgroups by Student *t test,* for independent groups, Mann–Whitney *U* and χ^2. Pattern dipper: systolic sleep to awake ratio <0.9. Pattern nondipper: systolic sleep to awake ratio ≥0.9 (including nondipper, 0.9–1 and riser >1).

Abbreviations: DBP, diastolic blood pressure; HDL, high-density lipoprotein; IQR, interquartile range; LDL, low-density lipoprotein; SBP, systolic blood pressure; SD, standard deviation.

less time performing sedentary activities and expended more kilocalories/day. There was a greater proportion of active patients (according to the American College of Sports Medicine's criteria for cardiorespiratory training[27]) among dipper-pattern patients. We also found a negative relationship between the level of physical activity and the systolic and diastolic sleep to wake ratios after adjusting for potential confounding variables. According to our data, the decrease in the sleep to awake SBP ratio associated with increased physical activity seems to be more related to the

Table 2. Physical exercise according to circadian pattern assessment by accelerometer and 7-PAR day

	Nondipper (533)		Dipper (812)		
Accelerometer	**Median**	**IQR**	**Median**	**IQR**	***P* value**
Counts/minute	221.04	282.28 – 157.50	242.98	318.77–182.70	<0.01
Sedentary (minutes/day)	1,075.71	1,129.11–1,023.15	1,063.78	1,114.60–1,008.28	<0.01
Light (minutes/day)	326.64	360.73–271.64	325.68	368.14–277.71	0.64
Moderate (minutes/day)	41.01	59.05–23.07	48.21	69.74–29.89	<0.01
Heavy and very heavy (minutes/day)	0.00	0.17–0.00	0.00	0.84–0.00	0.01
Kilocalories/day	1,394.25	2,292.33–715.08	1,787.43	2,900.25–927.84	<0.01
7–PAR day					
Minutes of moderate activity/week	30.00	227.50–0.00	60.00	269.75–0.00	0.02
Minutes of moderate or heavy/very heavy activity/week	70.00	275.00–0.00	120.00	330.00–0.00	<0.01
Kilocalories/kilo/week	231.42	241.56–227.14	232.60	244.00–227.50	0.09
MET/hour/week	5.33	24.00–0.00	9.33	26.12–0.00	<0.01
METs hour/week in leisure time	4.00	18.67–0.00	6.75	22.67–0.00	0.01
Active/sedentary according 7-par day					0.04
Sedentary. n (%)	381	(71.5)	536	(66.0)	
Actives, n (%)	152	(28.5)	276	(34.0)	

Values are medians (ICR) for asymmetrically distributed continuous data and number and proportions for categorical data. Circadian pattern: dipper, systolic sleep to awake ratio <0.9; nondipper, systolic sleep to awake ratio ≥0.9 (including non dipper, 0.9–1 and riser >1). *P*-values are for comparison of subgroups by Mann–Whitney *U* and χ^2. Active were considered as those doing at least 30 minutes of moderate activity, five days a week or at least 20 minutes of hard activity, 3 days a week

Abbreviations: IQR, interquartile range; MET, metabolic equivalent of task; PAR, physical activity recall.

Table 3. Correlations of physical exercise (counts/minute and MET/hour/week) with office and ambulatory blood pressure monitoring measurement

	Global (n = 1,345)		No antihypertensive drug (n = 951)		On antihypertensive drug (n = 394)	
Variables	**Counts/minute**	**MET/hour/week**	**Counts/minute**	**MET/hour/week**	**Counts/minute**	**MET/hour/week**
SBP	–0.07*	–0.04	–0.02	–0.05	–0.04	–0.04
DBP	0.02	0.065*	0.02	0.03	0.05	0.11*
Heart rate	–0.13**	–0.13**	–0.15**	–0.16**	–0.13*	–0.09
24-hour SBP	–0.03	0.02	–0.01	0.01	–0.01	0.03
24-hour DBP	0.03	0.10**	0.04	0.09*	0.05	0.12
Awake SBP	–0.02	0.03	0.01	0.02	0.02	0.04
Awake DBP	0.05*	0.10**	0.06	0.09*	0.09	0.13*
Sleep SBP	–0.09**	–0.02	–0.05	–0.02	–0.10	–0.03
Sleep DBP	–0.02	0.06*	–0.01	0.06	–0.01	0.07
Systolic dipping, %	0.19**	0.12**	0.16**	0.08**	0.26**	0.16**
Central SBP	–0.04	–0.03	0.01	–0.06	–0.01	0.03
Sleep to awake ratio for SBP	–0.18**	–0.11**	–0.14**	–0.08**	–0.27**	–0.17**
Sleep to awake ratio for DBP	–0.18**	–0.10**	–0.15**	–0.08**	–0.24**	–0.14**

P values by Spearman correlation. * $P < 0.05$, ** $P < 0.01$.

Abbreviations: DBP, diastolic blood pressure; MET, metabolic equivalent of task; SBP, systolic blood pressure.

Table 4. Multiple regression with sleep to awake ratio of SBP as the dependent variable and physical activity as the independent variable

Dependent variable: Ratio sleep to awake SBP	B	95% CI		*P* value	Dependent variable: Ratio sleep to awake SBP	B	95% CI		*P* value
Model 1									
Counts/minute	–0.01	–0.01	–0.01	<0.01	MET/hour/week	–0.01	–0.02	–0.01	<0.01
Model 2									
Counts/minute	–0.01	–0.01	–0.01	<0.01	MET/hour/week	–0.01	–0.02	–0.01	<0.01
Sex	–0.86	–1.59	–0.13	0.02	Sex	–1.03	–1.77	–0.29	<0.01
Age, years	–0.04	–0.06	–0.01	<0.01	Age, years	–0.03	–0.06	–0.01	0.03
Model 3									
Counts/minute	–0.01	–0.01	–0.01	<0.01	MET/hour/week	–0.01	–0.02	–0.00	<0.01
Sex	–1.09	–1.85	–0.34	<0.01	Sex	–1.29	–2.05	–0.53	<0.01
Age, years	–0.05	–0.08	–0.02	<0.01	Age, years	–0.05	–0.08	–0.02	<0.01
BMI, kg/m^2	0.13	0.04	0.21	<0.01	BMI, kg/m^2	0.05	0.05	0.22	<0.01
SBP, mm Hg	–0.01	–0.03	0.02	0.75	SBP, mm Hg	–0.01	–0.03	0.02	0.86
Diabetes	1.37	0.01	2.72	0.05	Diabetes	1.60	0.247	2.96	0.02
Antihypertensive drugs	0.39	–0.51	1.28	0.39	Antihypertensive drugs	0.51	–0.39	1.41	0.27

Dependent variable: systolic sleep to awake ratio × 100. Independent variables: counts/minute and MET/hours/week. Adjusted variables: BMI, SBP, sex (1, male; 0, female), age, antihypertensive drugs (1, yes; 0, no), diabetes (1, yes; 0, no).

Abbreviations: BMI, body mass index; CI, confidence interval; SBP, systolic blood pressure.

decline of the sleep systolic BP than to an increase of the awake SBP.

Finally, patients in the third tertile of physical activity (>278 counts/minute and >17.5 MET/hour/ week) are approximately 50% more likely to have a dipper pattern (ORs: counts/minute, 1.786; MET/hour/week, 1.332) than those doing less physical activity.

Assessment of physical activity using questionnaires has often been challenged due to the influence of the patient's subjective perception. This study combined 2 tools to evaluate exercise: the 7-day PAR, in which the patient self-reported the activity performed within the previous week, and the accelerometer, which objectively assessed that activity. The results of both measurements were in agreement regarding the relationship between physical activity and circadian patterns. Therefore, in addition to ensuring the validity of the data reported by the patient, this approach confirmed the influence of physical activity on the circadian pattern of BP.

In general, studies that have analyzed this relationship have been conducted in patients with a confounding risk factor or disease, and none has been performed in such a large sample of the general population. Van de Laar *et al.*,[30] found that habitual vigorous physical activity, but not light to moderate activity, is favorably associated with brachial and femoral compliance. These results agree with those found in our work, where more intensive exercise was associated with a greater decrease of night BP.

In a sample of 265 diabetics, Cardoso *et al.*,[16] found that patients with high fitness levels, as assessed by the Duke activity status index,[31] were more likely to have a dipper pattern (OR, 2.1; 95% CI, 1.2–3.5) that is similar to our results in the general population (OR, 1.8; 95% CI, 1.3–2.4). Leary *et al.*,[32] who monitored BP and physical activity simultaneously, estimated that for every unit of physical activity performed during the day (assessed by Actigraph), nocturnal BP dropped 4%. We found a similar relationship between regular physical activity and nocturnal BP dip in patients with and without antihypertensive treatment ($r = 0.19$, $P < 0.01$), as assessed by both accelerometer and 7-day PAR. Kario *et al.*,[33] described a positive correlation between physical activity and BP, as determined simultaneously. These researchers also found that physical activity was negatively correlated with the systolic and diastolic sleep to wake ratios ($r = -0.16$ and $r = -0.16$, respectively) and with heart rate ($r = -0.21$). These results support the data provided here in a general population that assessed regular physical activity regardless of the time of determination of ambulatory arterial BP. Finally, Park *et al.*,[18] found a different response to physical exercise in patients who were previously dippers or nondippers; those who were previously nondippers responded better in terms of the nocturnal drop. This fact supports the physiological role of exercise in correcting less beneficial patterns, most likely because of its effects on the sympathetic nervous system and renin–angiotensin system.[12,34]

This study has several limitations. The main limitation was the source of the data for the cross-sectional study, which prevented us from establishing a causal relationship between physical exercise and circadian pattern. Because we performed a single measurement of 24-hour BP, there might have been variations in the circadian pattern if repeated on another day. Physical exercise was assessed with an accelerometer and the 7-day PAR during the same week, and although the results are consistent, the fact that the patients were being evaluated by the device might have influenced their activity that week. We studied a heterogeneous group of patients representative of the population, which means that a portion of patients was on antihypertensive drug

Table 5. Logistic regression with dipper/nondipper as dependent variables and tertiles of physical exercise (counts/min and MET/hour/week) as independent variables

T_COUNTS_MIN	B	*P* value	OR	95% CI: OR		T_METSWEEK	B	*P* value	OR	95% CI: OR	
Model 1											
T_1	0	<0.01				T_1	0	0.03			
T_2	0.11	0.45	1.11	0.85	1.44	T_ 2	0.26	0.06	1.29	0.99	1.69
T_3	0.64	<0.01	1.89	1.44	2.48	T_3	0.34	0.01	1.41	1.089	1.83
Model 2											
T_1	0	<0.01				T_1	0	0.07			
T_2	0.12	0.39	1.12	0.86	1.46	T_2	0.24	0.08	1.27	0.979	1.66
T_3	0.64	<0.01	1.90	1.44	2.51	T_3	0.28	0.04	1.33	1.02	1.74
Sex (1)	–0.28	0.02	0.76	0.60	0.95	Sex (1)	–0.29	0.01	0.74	0.59	0.94
Age, years	0.01	<0.01	1.01	1.00	1.02	Age, years	0.01	0.02	1.01	1.00	1.02
Model 3											
T_1	0	<0.001				T_1	0	0.09			
T_2	0.07	0.61	1.07	0.82	1.40	T_2	0.21	0.13	1.24	0.94	1.63
T_3	0.58	<0.01	1.79	1.35	2.38	T_3	0.29	0.04	1.33	1.01	1.755
Sex (1)	–0.30	0.02	0.74	0.58	0.94	Sex(1)	–0.31	0.01	0.73	0.57	0.93
Age, years	0.01	<0.01	1.01	1.00	1.02	Age, years	0.01	<0.01	1.01	1.00	1.022
Antihipertensive drugs (1)	0.20	0.16	1.23	0.92	1.63	Antihipertensive drugs (1)	0.25	0.08	1.28	0.96	1.69
Diabetes, (1)	0.38	0.07	1.47	0.96	2.24	Diabetes (1)	0.39	0.06	1.49	0.98	2.27
SBP, mm Hg	0.01	0.13	1.01	0.99	1.01	SBP, mm Hg	0.01	0.09	1.01	0.99	1.01
BMI, kg/m^2	–0.03	0.02	0.97	0.94	0.99	BMI, kg/m^2	–0.03	0.01	0.97	0.94	0.99

Dependent variable: circadian pattern (1, dipper; 0, nondipper). Independent variables: T_COUNTS_MIN; tertiles counts/minute (T1, <195; T2, 195–278; T3, >278); T_METSWEEK: tertiles MET/hours/week (T1, <1; T2, 1–17.5; T3, >17.5). Adjusted variables: BMI, SBP, sex (1, male; 0, female), age, antihypertensive drugs (1, yes; 0, no), diabetes (1, yes; 0, no).

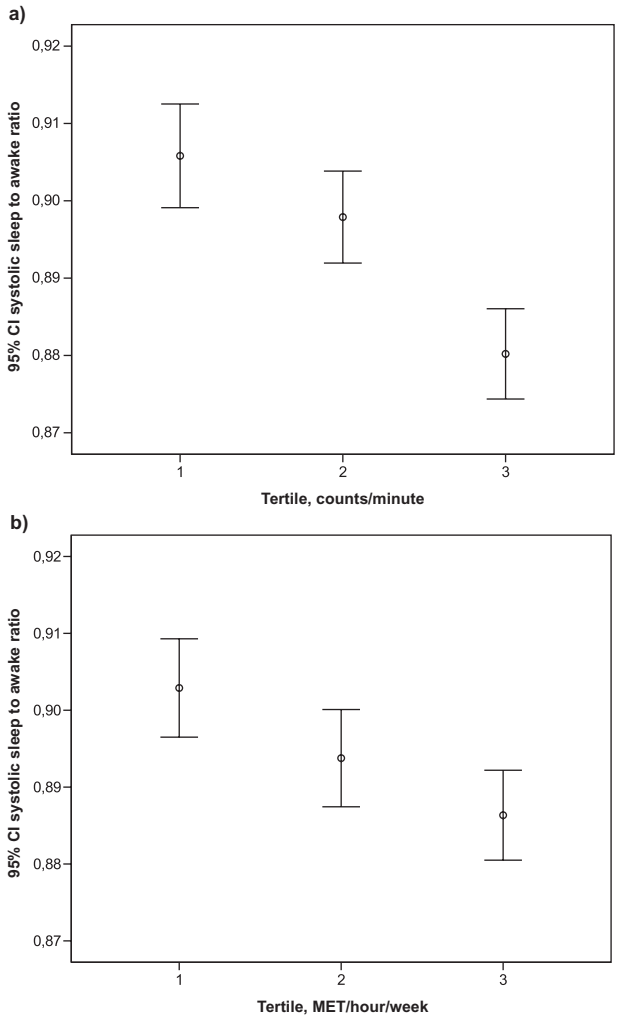

Figure 1. Systolic sleep to wake ratio according to counts/minute and MET/hour/week tertiles. Tertiles of counts/minute (T1, <195; T2, 195–278; T3, >278). Tertiles of MET/hour/week (T1, <1; T2, 1–17.5; T3, >17.5). *P* values by Kruskal-Wallis test: (**a**) counts/minute, $P < 0.01$; (**b**) MET/hour/week, $P \leq 0.01$.

therapy, which may have affected their circadian BP patterns. However, no significant differences were found when antihypertensive drug users were analyzed separately. Finally, it should be noted that the nonsimultaneous measurement of BP and physical exercise is a strength, rather than a weakness, of this study, as we intended to avoid the influences of other measurements that have been observed in other studies[17,35] and because the objective of this study was to analyze the influence of regular physical activity on the circadian pattern of BP. The study population consisted of patients who visited a family physician at public health centers in Spain; therefore, the results found in this population cannot be generalized to other populations.

We found that physical activity, as evaluated by both the accelerometer and the 7-day PAR, was associated with a more marked nocturnal BP dip and, accordingly, a lower SBP and DBP sleep to wake ratio. An interesting hypothesis would therefore be that this particular nocturnal pattern plays a role in the beneficial health effects of regular exercise.

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DISCLOSURE

The authors declared no conflict of interest.

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