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Relationship among nocturnal sleep deficit, excess weight and metabolic alterations in adolescents

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ABSTRACT

Introduction. Sleep modulates neuroendocrine function and metabolism; therefore, changes in sleep duration may lead to developing obesity during adolescence.

Objective. To assess the possible association among nocturnal sleep duration, the presence of overweight and metabolic alterations in a group of adolescents.

Population and Methods. Cross-sectional, analytical study conducted at a school in Valencia, Venezuela, during the 2012-2013 school year. Participants were 12 to 17 year-old adolescents. A survey on nocturnal sleep duration was administered; weight, height and waist circumference were recorded; and glycemia, lipid profile and insulinemia levels were measured. Body mass index and the homeostasis model assessment of insulin resistance (HOMA-IR) index were calculated.

Results. Ninety adolescents were included. Compared to the group with normal weight, adolescents with excessive weight had, in average, fewer sleep hours Sundays through Thursdays ($p < 0.05$) and a higher rate of sleep deficit and sleep debt ($p < 0.05$). Low HDL cholesterol and insulin resistance was significantly associated with sleep debt ($p < 0.05$). Among adolescents with sleep debt, the risk of having excess weight was 2.70 times higher (95% CI= 1.09-6.72; p= 0.032) regardless of age, gender, sexual maturity, sleep deficit Sundays through Thursdays, and history of cardiovascular disease and diabetes in first-degree relatives.

Conclusions. Nocturnal sleep deficit and sleep debt were significantly associated with excess weight and metabolic alterations related to a high cardiometabolic risk.

Key words: *adolescence, sleep, childhood obesity, insulin resistance.*

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INTRODUCTION

Adolescents gain greater autonomy and independence in their eating and sleeping habits and are therefore more vulnerable to overnutrition and sleep disorders. The National Venezuelan Institute of Nutrition reported a 12.03% of overweight in adolescents (13-17 years old), while obesity affected 9.33% of youth in the 2008-2010 period.[1] In addition, nocturnal sleep insufficiency (<8 h/day) is also prevalent among adolescents.[2,3]

Sleep is a restorative process that modulates neuroendocrine function and metabolism.[4]

For this reason, reduced sleep duration may lead to metabolic and hormonal deregulation, thus favoring food intake,[5] obesity and cardiometabolic risk. A systematic review and a meta-analysis of studies conducted on adolescents indicated a reverse association between sleep duration and obesity, although some studies have not disclosed such finding in young women.[6]

The expression "sleep debt" is widely used to describe the effects associated with sleep deprivation, notwithstanding its causes, and is defined as the accumulation of lost sleep hours in relation to daily sleep requirements.[7] Along with normal maturational changes, adolescents tend to delay their bedtime, and this combined with starting their academic and social activities even earlier results in a sleep deprivation pattern that is usually compensated on weekends.[8]

Although North American and European studies have revealed a relationship between sleep and obesity in adolescents,[9,10] there are no data available in Venezuela. Considering that socio-cultural and environmental conditions that impact on the habits of adolescents may vary among countries, we proposed to assess nocturnal sleep duration and debt and any possible association with obesity and metabolic alterations

in a sample of adolescents from the district of Valencia, Venezuela.

POPULATION AND METHODS

This was a field study with an analytical-correlational, cross-sectional, non-experimental design using a purposive, non-probability sampling. The study protocol was approved by the Ethics Committee of Universidad de Carabobo.

The study population was made up of adolescents (12-17 years old) enrolled at a private school in the district of Valencia, State of Carabobo, Venezuela, during the 2012-2013 school year. The purpose of the investigators was to assess all the above-mentioned population; however, the estimated required sample size to meet the study objective was calculated considering obesity prevalence in Venezuelan youth (9%),[1] a 95% confidence level, and a 5% accuracy. The resulting sample size was 89 adolescents.

A written notice was provided to the eligible population to invite them to participate, which explained the study objectives and the research protocol. Adolescents and parents and/or their representatives were asked to sign the informed consent/assent at the same time. Inclusion criteria were having signed the informed consent/assent and attending the scheduled assessments. Exclusion criteria were as follows: body mass index (BMI) with a Z score below -2 as per the World Health Organization (WHO) 2007 growth reference standard,[11] personal history of cardiovascular disease, uncontrolled blood hypertension (HTN), cancer diagnosis, diabetes mellitus (DM), kidney or liver failure, any chronic neurological, autoimmune or inflammatory disease (rheumatoid arthritis or ankylosing spondylitis), any thyroid or adrenal disease, recent major trauma or surgery, insulin, corticosteroid or psychotropic therapy, participation in a weight loss program, and employment activity with alternating day and/or night shifts.

A survey was administered to adolescents and parents to collect personal data, medical history of HTN, DM, transient ischemic attack (TIA), stroke both in participants and their first-degree relatives. Adolescents retrospectively indicated, by recalling, the time they went to bed and woke up each day of the week. Based on this information, we were able to establish sleep duration during the week and on weekends. In this study, Fridays and Saturdays were considered weekend days. The following indicators were estimated: SS-T: average sleep hours on a weekday (Sundays through Thursdays), SF-S: average sleep hours on a weekend day (Fridays and Saturdays), WS: overall week weighted sleep hours, calculated as follows: [(average number of sleep hours during the week x 5) + (average number of sleep hours during the weekend x 2)]/7. Sleep deficit and sleep excess were defined, respectively, when indicators were below or above the 10th and90th percentiles of previously reported nocturnal sleep duration for their age.[12]

There is no uniformity in the literature regarding how sleep debt is calculated. As Leger, et al.,[13]we assumed that individuals compensated sleep lost during the week by sleeping in on weekends, so we estimated the difference in sleep hours between both periods (SF-S - SS-T). If such difference was ≥2 h, it was defined as sleep debt (SD).

Weight and height were measured using a previously calibrated mechanical scale (Health o meter) (accuracy= 0.1 g and 0.1 cm, respectively), with adolescents on a standing position and with their heads adjusted to the Frankfurt plane and shoulders relaxed so as to prevent lordosis.[14] Adolescents were barefoot, wearing their school uniform but no socks, accessories and/or jewelry. BMI (kg/m^2) and Z scores for BMI were estimated using the AnthroPlus software, version 1.02, based on the WHO 2007 child growth reference standard and the BMI cut-off points recommended by the WHO.[11]

With subjects standing, their waist circumference (WC) was measured using a tape measure positioned at the midline between the last rib and the iliac crest at the end of an unforced expiration. The presence of abdominal obesity was established based on the Venezuelan pediatric reference for WC.[15] Sexual maturity status was established by self-assessment of pubertal development by looking at standard photographs of Tanner stages.[16,17]

A 10-mL blood sample was collected following a 12-14 hour fasting and having eaten a light meal at dinner. Serum glucose, total cholesterol (TC), HDL cholesterol (HDL-C) and triglycerides (TGL) were determined using enzymatic-colorimetric methods. LDL cholesterol (LDL-C) was determined according to Friedewald formula. The following cardiovascular risk ratios were estimated: TC/HDL-C, LDL-C/

HDL-C, TGL/HDL-C, and non-HDL cholesterol (TC-HDL-C). Based on serum glucose and insulin levels measured using ELISA, the homeostasis model assessment of insulin resistance (HOMA-IR) index was obtained.[18]

DM was defined as glycemia ≥126 mg/dL.[19] TC, LDL-C, HDL-C, TGL and non-HDL cholesterol alterations were defined as per the cut-off points recommended by the National Heart, Lung and Blood Institute (NHLBI) for adolescents,[20] while recommendations for adults were used for TC/HDL-C and LDL-C/HDL-C ratios.[21] A TGL/HDL-C ≥2.0 was considered elevated.[22]

Based on gender and pubertal maturity stages, insulinemia and the HOMA-IR index were considered high if they were ≥90th percentile reported by Barja, et al.[23]

Central tendency and absolute and relative frequencies were estimated as descriptive statistics. The Kolmogorov-Smirnov test was used to check if outcome measures followed a normal distribution. Student unpaired *t* tests or Mann-Whitney U tests were used to compare sleep indicators, as applicable, by age and anthropometric nutritional status. Chi-square tests and Fisher's exact tests were used to assess the possible association among sleep duration alterations, excess weight and metabolic alterations. A logistic regression analysis allowed to establish if excess weight or abdominal obesity, coded as present= 1 or absent= 0, have been predicted by the presence of SD, regardless of age, gender, sexual maturity, sleep deficit Sundays through Thursdays and history of HTN, TIA, stroke and DM in first-degree relatives. A forward stepwise selection was used for introducing/removing outcome measures into/from the logistic regression model. The significance level was estimated at $p < 0.05$. Analyses were performed using the PASW Statistics software, version 18.0 for Windows.

RESULTS

One hundred and seven adolescents signed the consent/assent form and attended the scheduled assessment. Once inclusion/exclusion criteria were applied, the sample was made up of 90 adolescents (*Figure 1*). The group's average age was 14.8 ± 1.4 years old, 58.9% (n= 53) were aged 15 to 17 years old and 41.1% (n= 37), 12 to 14 years old. Most participants were girls (72.2%, n= 65). The relative frequency of first-degree relatives with a history of HTN, TIA, stroke and DM was 30%, 5.6%, 1.1% and 5.6%, respectively. *Table 1* shows anthropometric and metabolic indicators assessed by gender, with expected anthropometric differences.

SF-S, WS and the difference of sleep hours between weekends and weekdays (SF-S - SS-T) were significantly higher in adolescents aged 12 to 14 years old compared to 15 to 17 year-olds (*Table 2*). No significant differences by gender were observed in relation to the analyzed sleep indicators.

Table 3 shows the frequency of sleep duration alterations in the overall sample and by age, pointing out that 42.2% of participants had sleep deficit on SS-T; 53.3% had SD; and 61.1% slept in excess on Fridays and Saturdays. Sleep deficit on SS-T (OR= 0.295, 95% CI= 0.122-0.711; *p*= 0.005) and SD (OR= 0.368, 95% CI= 0.153-0.884; *p*= 0.020) were significantly more common among 12 to 14 year-old adolescents than among 15 to 17 year-old ones. The frequency of sleep duration alterations, including excess sleep, was not associated with gender (data not shown).

In terms of BMI, 21.1% of participants (n= 19) were overweight and 14.4% (n= 13) were obese; 42.2% (n= 38) had abdominal obesity as per their WC. Given the low number of obesity cases, sleep duration and debt were compared by BMI and studied individuals were grouped into two new categories: normal weight and excess weight, and the latter included overweight and obese participants (*Table 4*). SS-T was observed to be significantly lower in adolescents with excess weight when compared tonormal weight ones; similarly, WS tended to be lower (p= 0.053). The same analysis performed by grouping individuals by WC showed that the difference in sleep hours between weekends and weekdays (SF-S - SS-T) was significantly higher in adolescents with abdominal obesity than in those with a normal WC (2.49 ± 1.72 versus 1.73 ± 1.77 hours; *p*= 0.046); the remaining sleep indicators showed no variation in terms of WC (data not shown).

Rates of sleep deficit S-T (OR= 2.443, 95% CI= 1.009-5,911; *p*= 0.038), sleep deficit F-S (OR= 3.284, 95% CI= 1.232-8.757; *p*= 0.016) and SD (OR= 2.708, 95% CI= 1.091-6.721; *p*= 0.025) in adolescents with excess weight were significantly higher compared to those who had a normal BMI (*Table 5*). The presence of abdominal obesity was also significantly associated with SD (OR= 3.632, 95% CI= 1.488-8.863; *p*= 0.004). Neither excess weight nor abdominal obesity were significantly associated with excessive sleep duration.

Sleep deficit S-T was associated with insulin resistance (OR= 3.348, 95% CI= 1.095-10.231;

FIGURE 1. *Flowchart of study sample selection*

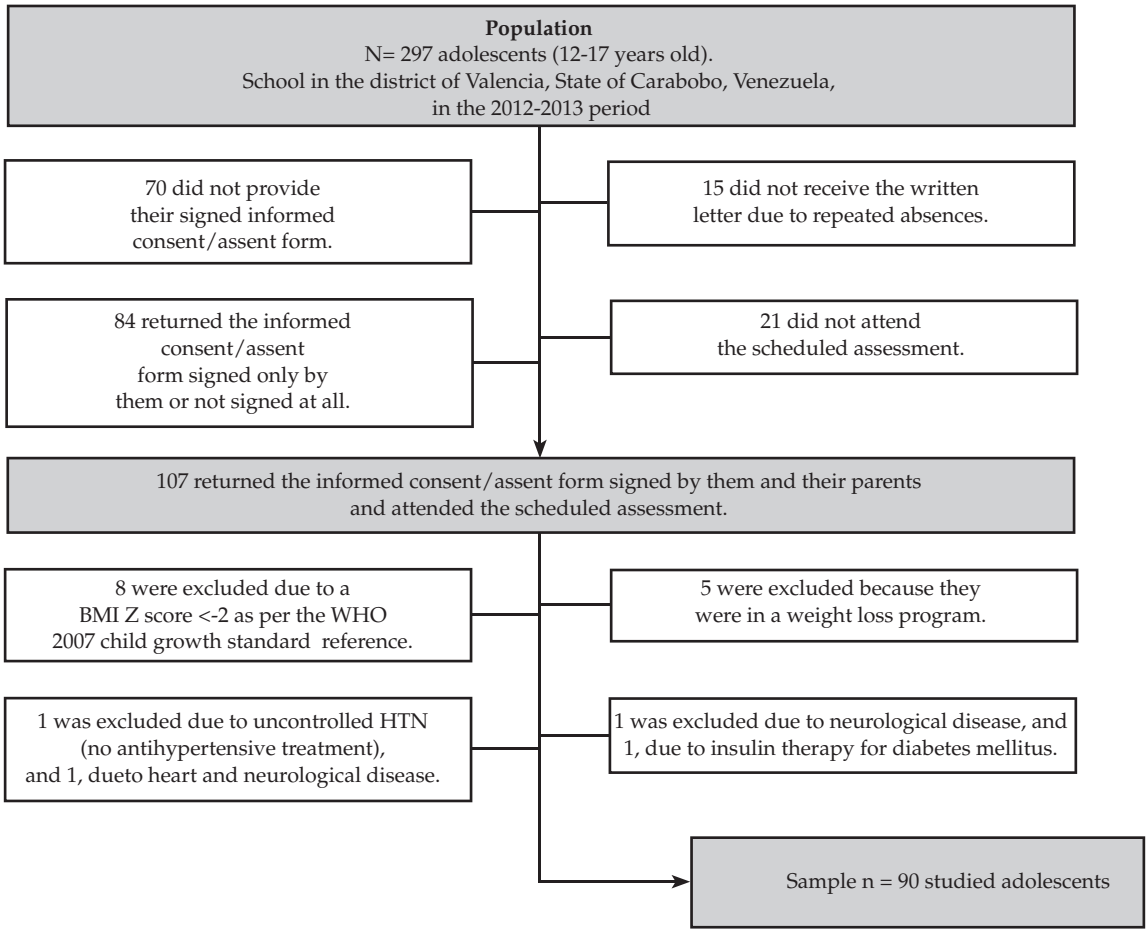

TABLE 1. *Anthropometric and metabolic indicators assessed for the overall sample and by gender*

Outcome measures	Overall group (n = 90)	Males (n = 25; 27.8%)	Females (n = 65; 72.2%)	p
Weight (kg)	58.2 ± 14.3	63.9 ± 13.7	56.0 ± 14.1	0.008
Height (m^2)	1.60 ± 0.08	1.67 ± 0.09	1.57 ± 0.07	0.000
BMI (kg/m2)	22.7 ± 4.5	22.8 ± 4.1	22.6 ± 4.7	0.893
BMI Z score	0.62 ± 1.16	0.82 ± 1.07	0.55 ± 1.20	0.336
WC (cm)	73.1 ± 11.5	76.1 ± 10.8	72.0 ± 11.7	0.043
Glycemia (mg/dL)	85.3 ± 5.6	87.2 ± 5.5	84.6 ± 5.9	0.052
TGL (mg/dL)	68.3 ± 35.6	60.4 ± 34.0	71.3 ± 35.9	0.193
TC (mg/dL)	141.7 ± 29.3	137.6 ± 31.1	143.3 ± 28.6	0.404
HDL-C (mg/dL)	33.3 ± 6.3	32.6 ± 5.4	33.5 ± 6.6	0.567
LDL-C (mg/dL)	94.7 ± 25.2	92.8 ± 25.7	95.5 ± 25.2	0.647
TC/HDL-C ratio	4.34 ± 0.98	4.24 ± 0.85	4.39 ± 1.03	0.527
LDL-C/HDL-C ratio	2.91 ± 0.86	2.86 ± 0.80	2.93 ± 0.90	0.716
TGL/HDL-C ratio	2.16 ± 1.32	1.89 ± 1.06	2.26 ± 1.40	0.238
Non-HDL TC (mg/dL)	108.4 ± 27.5	104.8 ± 28.6	109.8 ± 27.2	0.450
Insulin (mIU/mL)	12.5 ± 5.6	11.2 ± 5.6	12.9 ± 5.5	0.226
HOMA-IR index	2.63 ± 1.19	2.40 ± 1.23	2.71 ± 1.18	0.318

Results expressed as arithmetic mean ± standard deviation. Student t test or Mann-Whitney U test, as applicable.
BMI: body mass index; WC: waist circumference; TGL: triglycerides; TC: total cholesterol;
HDL-C: high-density lipoprotein cholesterol; LDL-C: low-density lipoprotein cholesterol.

p= 0.027) and hyperinsulinemia (OR= 5.4, 95% CI= 1.338-21.791;p= 0.013); the six adolescents with hyperinsulinemia and the four adolescents with insulin resistance had sleep deficit S-T. In addition, the number of cases with low HDL-C (OR= 3.903, 95% CI= 1.137-13.397; p= 0.023) and with insulin resistance (OR= 3.854, 95% CI= 1.002-15.232; p= 0.041) was significantly higher among adolescents with SD. None of the studied metabolic alterations was associated with excessive sleep duration ($p \geq 0.05$).

The risk of excess weight in adolescents with SD was 2.70 times higher (95% CI= 1.09-6.72; p= 0.032) when compared to those with no SD. Similarly, the risk of having abdominal obesity was 3.92 times higher (95% CI= 1.54-10.03; p= 0.004) in adolescents with SD versus those with no SD, regardless of age, gender, sexual maturity, presence of sleep deficit S-T and history of TIA, stroke and DM in first-degree relatives, although this was not the case with family history of HTN (95% CI= 1.40-10.02; p= 0.011).

DISCUSSION

In this study, WS hours for the overall sample were 8.37 h/day, similar to what has been

TABLE 2. *Nocturnal sleep indicators for the overall sample and by age*

Sleep indicators	**Overall sample (n= 90)**	**Age group**		**p**
		12-14 years old (n= 37)	**15-17 years old** (n= 53)	
Sleep Sundays through Thursdays (S_{S-T}, hours)	7.78 ± 1.11	7.99 ± 1.11	7.63 ± 1.10	0.138
Sleep Fridays and Saturdays (S_{F-S}, hours)	9.86 ± 1.95	10.59 ± 1.76	9.36 ± 1.94	0.003
Week weighted sleep (WS, hours)	8.37 ± 1.10	8.73 ± 1.04	8.13 ± 1.08	0.009
Difference between sleep hours on weekends and weekdays (S_{F-S} - S_{S-T}, hours)	2.08 ± 1.94	2.60 ± 1.82	1.72 ± 1.95	0.034

Results expressed as arithmetic mean ± standard deviation. Unpaired Student t test.

TABLE 3. *Nocturnal sleep duration alterations for the overall sample and by age group*

Nocturnal sleep duration alterations	**Overall sample** n (%)	**Age group**		**Fisher's exact test**	**p**
		12-14 years old n (%)*	**15-17 years old** n (%)*		
Sleep deficit S-T	38 (42.2)	22 (59.5)	16 (30.2)	0.009	0.005
Sleep deficit F-S	10 (11.1)	4 (10.8)	6 (11.3)	1.000	0.610
Weekly sleep deficit	23 (25.6)	13 (35.1)	10 (18.9)	0.092	0.068
Sleep debt	48 (53.3)	25 (67.6)	23 (43.4)	0.032	0.020
Excess sleep S-T	6 (6.7)	1 (2.7)	5 (9.4)	0.394	0.207
Excess sleep F-S	55 (61.1)	25 (67.6)	30 (56.6)	0.380	0.204
Weekly excess sleep	16 (17.8)	4 (10.8)	12 (22.6)	0.173	0.121

overall n= 90; 12-14 year-old group n= 37; 15-17 year-old group n= 53.
* Percentages were estimated based on the total number of subjects in each age group.
S-T: Sundays through Thursdays; F-S: Fridays and Saturdays.

TABLE 4. *Nocturnal sleep indicators by body mass index category*

Sleep indicators	**Normal weight(n = 58)**	**Excess weight (n = 32)**	**p**
Sleep Sundays through Thursdays (S_{S-T}, hours)	7.98 ± 1.04	7.42 ± 1.15	0.021
Sleep Fridays and Saturdays (S_{F-S}, hours)	9.95 ± 1.95	9.72 ± 1.99	0.596
Week weighted sleep (WS, hours)	8.54 ± 1.04	8.08 ± 1.14	0.053
Difference between sleep hours on weekends and weekdays (S_{F-S} - S_{S-T}, hours)	1.96 ± 1.94	2.30 ± 1.95	0.440

Results expressed as arithmetic mean ± standard deviation. Unpaired Student t test.

observed in Spanish adolescents (8.35 h/day)[24] and in adolescents from ten different European cities (8 h/day).[9] However, breaking down results by weekday, the average number of sleep hours S-T was 7.78 h/day versus 9.86 h/day on F-S, and these figures are lower than those reported in a sample of French adolescents (8.43 h/day and 10.01 h/day, respectively).[13] In addition, and although it is not easy to make comparisons given the dissimilar definitions used by authors for sleep deficit and debt, this research revealed that sleep deficit rates S-T and SD are higher than those reported by other studies on European adolescents.[9,13]

The difference in sleep hours between weekends and weekdays (SF-S - SS-T) was significantly higher among 12-14 year-old adolescents when compared to the 15-17 year-old group. Besides, cases of sleep deficit S-T and SD were significantly more frequent in the younger adolescents (12-14 years old), although this group had a greater average of sleep hours F-S, probably because they try to compensate lost hours of sleep on weekdays by sleeping in on weekends; however, in many cases, such compensation was not enough. Such observations disagree with those made by other authors, who have described a reduction in sleep duration among Saudi adolescents as their age increased, with no significant differences by gender,[2] and a higher SD among 15-year old French adolescents when compared to 11-year old ones.[13] Such disagreement may be accounted for by differences in the socio-cultural and socio-economic contexts. In addition, it could be pointed out that during the early stages of adolescence, there is probably a greater tendency to devote leisure time to technology-related activities and spend nights playing videogames and using social networks. It is also probable that, at present, parents tend to pay less attention to the number of hours their children spend doing such activities at night. On their side, older and more independent groups, tend to spend their leisure time interacting with the opposite sex and going out every week at night, especially on Fridays and Saturdays. This is probably reflected on the lower average number of hours of sleep F-S in 15-17 year-old adolescents.

In this study, sleep deficit was significantly associated with excess weight, although that was not the case of excess sleep, and this confirms the results of a meta-analysis conducted by Chen, et al.,[6] and of other recent cross-sectional[9] and longitudinal[10,25] studies. Regardless of age, gender, sexual maturity, presence of sleep deficit S-T and history of TIA, stroke and DM in first-degree relatives, the risk of excess weight was almost three times higher in adolescents with SD. Likewise, the risk of abdominal obesity was almost four times higher, which is consistent with the fact that sleep duration is a risk factor for excess weight and visceral fat accumulation in adolescents. In line with the above, it has been demonstrated that a longer sleep duration at the beginning of a three-month weight management program could predict the reduction of one kg/m² or more at the end of it.[26]

The presence of SD was associated with low HDL-C and insulin resistance levels, which is consistent with the observations made by other authors.[27,28] The following are the biological and behavioral mechanisms proposed as an explanation for weight gain and metabolic alterations induced by a short sleep duration: increased appetite due

TABLE 5. *Nocturnal sleep duration alterations by body mass index category*

Nocturnal sleep duration alterations	**Normal weight** n (%)	**Excess weight** n (%)	**Fisher's exact test**	**p**
Sleep deficit S-T	20 (34.5)	18 (56.3)	0.074	0.038
Sleep deficit F-S	5 (8.6)	5 (15.6)	0.319	0.250
Weekly sleep deficit	10 (17.2)	13 (40.2)	0.222	0.016
Sleep debt	26 (44.8)	22 (68.8)	0.046	0.025
Excess sleep S-T	6 (10.3)	0 (0)	0.085	0.065
Excess sleep F-S	38 (65.5)	17 (53.1)	0.267	0.176
Weekly excess sleep	11 (19.0)	5 (15.6)	0.780	0.464

overall n= 90; normal weight group n= 58; excess weight group n= 32.
Percentages were estimated based on the total number of subjects in each body mass index category group.
S-T: Sundays through Thursdays; F-S: Fridays and Saturdays.

to ghrelin hypersecretion (orexigenic hormone) and leptin hyposecretion (anorexigenic hormone), reduced energy expenditure, more chances of eating during the night, diets with a low nutritional quality, and reduced physical activity due to the fatigue induced by sustained alertness.[5,29] An hyperactive sympathetic nervous system and hypercortisolemia may contribute to insulin resistance in association with sleep reduction.[5]

It is recommended that health and educational entities develop educational campaigns aimed at adolescents and parents on how sleep helps to maintain a good cardiometabolic health status. In addition, new longitudinal studies should be conducted with larger sample sizes and including other outcome measures (socio-economic stratum, diet and recreational activities).

Lastly, this research poses certain limitations given its cross-sectional design and because causative and temporal relations among assessed outcome measures cannot be confirmed. Besides, the sample was made up of individuals from a single school so it cannot be taken as representative of adolescents from other schools, cities or socio-economic strata. In addition, sleep duration in this study was self-reported instead of being recorded through polysomnographies (the gold standard); therefore, sleep duration may have been under-reported. Confounding outcome measures, such as physical activity in the studied population, were not assessed, so it is not possible to establish their impact on our findings.

CONCLUSIONS

In our sample of adolescents from the district of Valencia, Venezuela, nocturnal sleep deficit and sleep debt were significantly associated with excess weight and the presence of metabolic alterations related to a high cardiometabolic risk. ■

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