

RESEARCH ARTICLE



The role of physical activity on obstructive sleep apnea severity and hypoxic load, and the mismatch between subjective and objective physical activity assessments

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Summary

Obesity is the primary risk factor for the development of obstructive sleep apnea, and physical inactivity plays an important role. However, most studies have either only evaluated physical activity subjectively or objectively in obstructive sleep apnea. The objectives of this study were: (i) to assess the relationship between obstructive sleep apnea severity (both apnea–hypopnea index and desaturation parameters) and both objectively and subjectively measured physical activity after adjustment for anthropometry and body composition parameters; and (ii) to assess the relationship between objective and subjective physical activity parameters and whether obstructive sleep apnea severity has a modulatory effect on this relationship. Fifty-four subjects (age 47.7 ± 15.0 years, 46% males) were categorized into groups according to obstructive sleep apnea severity: no obstructive sleep apnea; mild obstructive sleep apnea; and moderate-to-severe obstructive sleep apnea. All subjects were evaluated with subjective and objective physical activity, anthropometric and body composition measurements, and 3-night self-applied polysomnography. A one-way ANOVA was used to evaluate the differences between the three obstructive sleep apnea severity groups and multiple linear regression to predict obstructive sleep apnea severity. Differences in subjectively reported sitting time ($p \leq 0.004$) were found between participants with moderate-to-severe obstructive sleep apnea, and those with either mild or no obstructive sleep apnea ($p = 0.004$). Age, body mass index and neck

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circumference explained 63.3% of the variance in the apnea–hypopnea index, and age, body mass index and visceral adiposity explained 67.8% of the variance in desaturation parameters. The results showed that the person's physical activity does not affect obstructive sleep apnea severity. A weak correlation was found between objective and subjective physical activity measures, which could be relevant for healthcare staff encouraging patients with obstructive sleep apnea to increase their physical activity.

KEYWORDS

apnea–hypopnea index, body mass index, neck circumference, nocturnal hypoxic parameters, sleep-disordered breathing, visceral adiposity

1 | INTRODUCTION

Sleep disorders and short sleep duration, in parallel with obesity and physical inactivity, are some of the main health challenges in modern society (Ding et al., 2018). Obstructive sleep apnea (OSA) is one of the most prevalent sleep disorders, affecting about one billion adults worldwide (Benjafield et al., 2019). OSA characteristics are repeated episodes of partial (hypopnea) or complete (apnea) airway collapse during sleep, resulting in oxygen desaturations and arousal (Lee et al., 2008). OSA is associated with chronic conditions, such as hypertension, cardiovascular diseases (Mitra et al., 2021), metabolic syndrome, depression (Simpson et al., 2015) and weight gain (Ong et al., 2013). The apnea–hypopnea index (AHI) is the traditional parameter used to define OSA severity, referring to the average number of apnea and hypopnea events per hour of sleep. However, the AHI developed in 1970 has been criticized for simplicity and needs to be updated (Pevernagie et al., 2020). For example, the AHI does not consider important factors such as the duration of respiratory events or depth and characteristics of related oxygen desaturations (Pevernagie et al., 2020), and thus, new methods to estimate the severity of OSA have been developed during the past decade. These nocturnal hypoxic parameters, describing the conditions where the oxygen saturation levels (SpO_2) are reduced below normal baseline, are bringing new insight into OSA severity estimation (Kulkas, Tiihonen, Eskola et al., 2013; Kulkas, Tiihonen, Julkunen et al., 2013). For example, desaturation severity (DesSev) and recovery severity (RecSev) parameters allow the detection of the total desaturation area from baseline to nadir and back to baseline (Karhu et al., 2022).

Obesity is the primary risk factor for the development of OSA (Hargens et al., 2013), with over 70% of patients with OSA having a body mass index (BMI) over 30 kg m^{-2} (Malhotra & White, 2002). Obesity contributes to OSA through increased body weight, but fat distribution also plays a major role (Carter & Watenpugh, 2008). Visceral adiposity (accumulation of fat around the internal organs in the abdominal cavity) has a stronger association with OSA than other types of obesity in males (Kim et al., 2021; Kritikou et al., 2013), while general adiposity predicts OSA in females (Kritikou et al., 2013). Furthermore, greater neck circumference indicates more severe OSA in both sexes (Meurling et al., 2019). Other risk factors include male sex, age (40 years or older; Young et al., 2002) and physical inactivity (Simpson et al., 2015).

A physically active lifestyle is one of the most important health-promoting behaviours that favourably impact chronic diseases often coexisting with OSA (Hargens et al., 2013). Physical activity (PA) and exercise are also known key factors in obesity reduction. PA is defined as any bodily movement the skeletal muscles produce that results in energy expenditure (Caspersen et al., 1985). Global recommendations on health-related PA advise at least 150 min of moderate PA, or more than 75 min of vigorous PA a week for adults aged 18–64 years (World Health Organization, 2020). Exercise training is defined as a planned, structured and repetitive PA aimed to improve physical fitness (Caspersen et al., 1985), and is a potential non-pharmacological treatment option for patients with OSA (Iftikhar et al., 2017).

Previous studies have generally shown an inverse association between PA and OSA, but these studies have only assessed PA either subjectively or objectively, not both, and most studies do not assess body composition parameters (Da Silva et al., 2008; Hall et al., 2020; Mônico-Neto et al., 2018; Murillo et al., 2016; Quan et al., 2007; Simpson et al., 2015). To the best of our knowledge, only one study has assessed PA both subjectively and objectively in patients with OSA (Igelström et al., 2013). This study found an overestimation of PA in a group of 39 obese patients with moderate-to-severe OSA recruited from a sleep clinic. Whether this overestimation is different from controls and affected by OSA severity, obesity levels or other confounders remains to be studied.

In this context, the objectives of this study were: (i) to assess the relationship between the OSA severity (both AHI and desaturation parameters) and both objectively (steps per day) and subjectively measured PA (International Physical Activity Questionnaire [IPAQ], sitting time from IPAQ, and exercise per day in minutes daily in an app) by considering the effects of anthropometry and body composition parameters; and (ii) to assess the relationship between the different objective and subjective PA parameters and the role of OSA severity on this relationship.

2 | METHODS

2.1 | Participants

In total, 65 participants were recruited. Fifty-four participants (83%; age = 47.7 ± 15.0 years, BMI = $28.5 \pm 5.3 \text{ kg m}^{-2}$, 46.3% males)

fulfilled the inclusion criteria and were included in the analysis. The studied cohort included healthy participants, snorers, and individuals with suspected or confirmed sleep apnea, with a wide range of BMI, age and sex. A minimum of 4 hr of good quality oxygen saturation and other sleep study signals from at least 1 night out of the 3-night self-applied polysomnography (PSG) were required. Also, included participants had to use a wrist-worn wearable for at least 10 hr per day for 4 out of 7 days. One participant had less than 4 hr of scorable SpO_2 and sleep signals, seven did not fulfil the wearable criteria, and three did not fulfil either criterion. Participants were categorized into three groups, according to OSA severity using the AHI: no OSA ($\text{AHI} < 5$, $n = 17$); mild OSA ($\text{AHI} 5\text{--}14.9$, $n = 19$); moderate-to-severe OSA ($\text{AHI} \geq 15$, $n = 18$; “Sleep-Related Breathing Disorders in Adults”, 1999). All participants were informed about the purpose of this study, and signed written consent was a prerequisite for participation. The study was approved by National Bioethics Committee of Iceland, ref. no. 21-070 and respected the Declaration of Helsinki.

2.2 | Measurements

All participants underwent a comprehensive battery of tests, including: (a) 3-night self-applied PSG; (b) basic anthropometry and body composition; and (c) PA measurements.

(a) Three-night self-applied PSG. All participants had a 3-night sleep study using self-applied PSG (Nox Medical, A1s, Reykjavík, Iceland). A 3-night sleep study was performed to detect the night-to-night variability in OSA severity (Newell et al., 2012). The setup included frontal electroencephalogram (AF4, AF3, AF8 and AF7) and electrooculography (E1, E2, E3 and E4) recordings (Kainulainen et al., 2021). Nasal airflow was determined based on a cannula measurement, oxygen saturation based on oximetry, heart rate based on electrocardiography and oximetry, respiratory movements based on respiratory inductance plethysmography, thorax and abdominal belts, activity and body position based on an accelerometer, and leg movements with left and right anterior tibialis electromyography. In addition, an audio recording was performed to detect snoring. Expert sleep technologists manually scored all sleep studies according to the American Academy of Sleep Medicine (AASM) manual, version 2.6 (American Academy of Sleep Medicine., 2020). The average AHI from valid nights was used to determine OSA severity. The oxygen desaturation index (ODI) was calculated based on manually scored $\geq 3\%$ blood oxygen desaturation (American Academy of Sleep Medicine, 2020). ODI 4% was calculated automatically through Automatic Blood Oxygen Saturation signal analysis software (ABOSA), which was also used to automatically calculate nocturnal hypoxic parameters, capturing the hypoxic load (Karhu et al., 2022). The nocturnal hypoxic parameter, DesSev, was calculated as the sum of desaturation areas normalized with total sleep time. The corresponding recovery variable, RecSev, was calculated the same way (Karhu et al., 2022; Kulkas, Tiihonen, Eskola et al., 2013). The sum of DesSev and RecSev ($\text{DesSev} + \text{RecSev}$; Figure 1) was also calculated to detect the total area from baseline to nadir and back to baseline.

Other parameters calculated were sleep time spent with SpO_2 below 90% (T90%) and the average value of SpO_2 during sleep (SpO_2 avg.; American Academy of Sleep Medicine, 2020).

(b) Basic anthropometry and body composition measurements. Anthropometric measurements, including height, weight (to calculate BMI; Keys & Brozek, 1953) and neck circumference, were measured and calculated following International Society for the Advancement of Kinanthropometry (ISAK) recommendations (2011). A digital scale (TANITA MC-780, Tokyo, Japan) measured the weight to the nearest 0.1 kg. Body composition was measured with a bioelectrical impedance device (Multifrequency Segmental Body Composition Analyser TANITA MC-780MA, Tokyo, Japan). The device has high accuracy and test-retest reliability (Verney et al., 2015). Total fat mass, muscle mass, body water and visceral adiposity index (from 1 to 59) were reported for further statistical analysis.

(c) PA measurements. PA was evaluated subjectively using the IPAQ – long version (Ainsworth et al., 2000) and an exercise diary (Schmitz et al., 2022), and an objective wearable measurement (ScanWatch, Withings, Paris, France; Lechat et al., 2021). The IPAQ subjectively assesses the health-enhancing PA (walking, moderate and vigorous intensity activities) of the last 7 days through five domains: job-related PA; transportation PA; household-related PA; leisure-time PA; and total sitting time (an indicator of inactivity). The sum of walking and moderate or vigorous intensity activities was reported as the weekly PA, recorded as the metabolic equivalent of task minutes per week (MET-min per week). IPAQ is a validated and frequently used self-reported measure of PA (Ainsworth et al., 2000; Dyrstad et al., 2014). The IPAQ sedentary score was also calculated as the total sitting time per day (minutes) of the last 7 days: “During the last 7 days, how much time did you spend sitting on a weekday?”, and “During the last 7 days, how much time did you spend sitting on a weekend day?” answered in time units (Ainsworth et al., 2000). Exercise duration per day (minutes) was evaluated subjectively with a daily exercise question within the Sleep Revolution mobile application sleep diary for 7 days: “How much did you exercise?” answered in minutes (Schmitz et al., 2022). A wearable device objectively measured the daily PA, using the total step count (steps per day; Lechat et al., 2021). Participants were asked to use the wearable device on their non-dominant hand around the clock for 1 week. The PA was quantified as the average number of steps covered per day for 7 days. A valid day was defined as a minimum of 10 hr of daily heart rate recordings.

2.3 | Procedure

Once included in the study, the participants visited the laboratory at Reykjavik University Sleep Institute (RUSI), Reykjavik, Iceland. After all anthropometric and body composition measurements, the participants downloaded a mobile application (Withings Health Mate, Withings, Paris, France). All participants received the wearable device to use for 1 week, and a self-applied PSG for the 3-night home sleep study. At home, participants answered the IPAQ, and other questionnaires using the Research Electronic Data Capture (REDCap) platform (Harris et al., 2009).

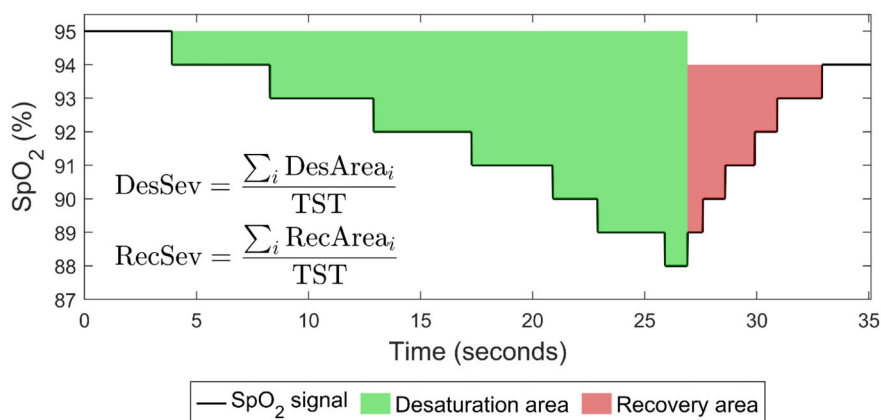


FIGURE 1 The calculation of desaturation severity (DesSev) and recovery severity (RecSev) from the oxygen saturation (SpO₂) signal. TST, total sleep time (Karhu et al., 2022).

2.4 | Statistical analysis

All the variables satisfied the tests of homoscedasticity (Levene's variance homogeneity test) and normality (the Kolmogorov–Smirnov test) of the distribution. AHI and DesSev + RecSev were log-transformed to satisfy the normality of the distribution. Basic descriptive statistics (mean and standard deviations) were calculated. A one-way ANOVA established the differences between the three OSA severity groups using the Bonferroni post hoc test. The eta-squared (η^2) effect size was calculated. The effect size η^2 was considered small ($\eta^2 < 0.01$), medium ($0.01 \leq \eta^2 < 0.06$) or large ($\eta^2 \geq 0.06$; Richardson, 2011). Sex-stratified multiple linear regression (stepwise) identified the predicting factors of the AHI and DesSev + RecSev for all participants. The number of predicting variables was limited in the model to prevent spurious relations among variables (Norman & Streiner, 2000). However, we used more strict criteria, and only seven variables were used (age, BMI, neck circumference, visceral adiposity, IPAQ, steps per day, and sitting time per day). These variables were selected as they cover anthropometric, body composition and PA fields. Spearman correlation coefficients between different objective and subjective PA measures were calculated for each OSA severity group. All results were presented as mean $\pm$ standard deviation. The limit for statistical significance was set to $p < 0.05$, and IBM SPSS statistics 28 was used for all statistical analysis.

3 | RESULTS

As expected, participants with moderate-to-severe OSA were older and had higher obesity levels and worse sleep quality than participants without OSA (Table 1). However, the participants in the moderate-to-severe OSA group reported less sitting time than the participants in other groups ($p < 0.004$; $\eta^2 = 0.204$). In addition, participants with moderate-to-severe OSA had a tendency to have lower values of objectively measured PA and calculated IPAQ; however, these differences were not statistically significant.

Table 2 shows the sex-stratified results of the multiple linear regression (stepwise) for the AHI and DesSev + RecSev. Among all participants, the model explained 63.3% of the variance in the AHI

with age, BMI and neck circumference. For males and females, the models explained 61.2% and 61.7%, respectively, of the variance in the AHI with age and BMI. Among all participants, the model explained 67.8% of the variance in DesSev + RecSev with visceral adiposity, age and BMI. For males and females, the models predicted 62.6% and 63.3%, respectively, of the variance in DesSev + RecSev with age and BMI. Therefore, the PA parameters did not have a significant effect on the model performance after the stepwise inclusion of age and relevant obesity variables.

Table 3 shows the correlations between objective and subjective assessments of PA in each of the three groups. A correlation was found between objective and subjective measures of steps per day and exercise minutes per day in the app ($r = 0.522$, $p = 0.022$), and between two subjective PA measures: IPAQ and exercise minutes per day in the app ($r = 0.469$, $p = 0.043$) in the mild OSA group only. No significant correlations were found between the other PA measures in the other groups. However, the strength of the correlation, albeit non-significant, was higher for the exercise minutes per day in the app than for the IPAQ with objective PA measurements.

4 | DISCUSSION

This study evaluated the role of PA in OSA severity after adjustment for body composition and other confounders. To the best of our knowledge, this is the first study that has evaluated both objective and subjective PA levels in participants with and without OSA with extensive body composition assessment. The main findings of this study were that based on the objective PA measures, participants with moderate-to-severe OSA underestimated their subjectively measured sitting time compared with those with mild and no OSA due to no significant differences in other PA parameters. However, no marked differences were found in the relationships between different subjective and objective PA measures for the three OSA severity groups. Also, the daily exercise question in an app had a stronger correlation with objective PA assessment than the IPAQ, albeit non-significant, likely because of limited number of participants. Importantly, PA had no effects on OSA severity after adjustment for body composition, a likely mediator for any PA effects found in earlier studies.

TABLE 1 Demographics of participants presented as mean and standard deviation (SD) for different OSA severity groups.

	(A)	(B)	(C)				
	No OSA	Mild OSA	Moderate-to-severe OSA				
	<i>n</i> = 17	<i>n</i> = 19	<i>n</i> = 18				
	Mean ± SD	Mean ± SD	Mean ± SD	<i>F</i>	<i>p</i>	η^2	Diff.
General							
Age (years)	37.3 ± 14.6	47.9 ± 14.4	57.3 ± 8.8	10.524	< 0.001	0.292	A < C
Males (%)	11.8	68.4	55.6				
Sleep parameters							
TST (min)	383.5 ± 62.7	375.2 ± 41.4	383.1 ± 51.7	0.148	0.863	0.006	n.s.
Sleep efficiency (%)	92.2 ± 3.1	89.0 ± 5.4	86.8 ± 7.5	3.967	0.025	0.135	A > C
Arousal index (events per hr)	10.6 ± 4.0	12.6 ± 3.5	19.5 ± 8.9	10.684	< 0.001	0.295	A, B < C
AHI (events per hr)	2.3 ± 1.4	9.3 ± 2.5	30.6 ± 12.5	70.357	< 0.001	0.734	A, B < C
Nocturnal hypoxic parameters							
ODI _{3%} (events per hr)	2.3 ± 1.5	8.5 ± 3.6	26.6 ± 12.6	48.756	< 0.001	0.657	A, B < C
ODI _{4%} (events per hr)	1.0 ± 0.8	4.66 ± 2.4	17.7 ± 11.7	28.622	< 0.001	0.529	A, B < C
DesSev (%-point)	0.0 ± 0.0	0.1 ± 0.1	0.6 ± 0.5	16.619	< 0.001	0.538	A, B < C
RecSev (%-point)	0.0 ± 0.0	0.1 ± 0.0	0.3 ± 0.2	18.400	< 0.001	0.558	A, B < C
DesSev + RecSev (%-point)	0.03 ± 0.0	0.17 ± 0.1	0.84 ± 0.8	17.256	< 0.001	0.545	A, B < C
T90% (%)	1.11 ± 1.5	6.16 ± 9.3	21.42 ± 25.0	8.254	< 0.001	0.405	A, B < C
SpO ₂ avg. (%)	94.60 ± 1.2	93.34 ± 1.6	91.81 ± 1.9	13.386	< 0.001	0.495	A, B > C
Anthropometry							
BMI (kg m ⁻²)	25.7 ± 4.8	28.4 ± 5.4	31.3 ± 4.4	5.782	0.005	0.185	A < C
Neck circumference (cm)	35.7 ± 3.3	38.7 ± 3.6	39.9 ± 4.9	5.113	0.009	0.167	A < C
Body composition							
Fat mass (%)	30.4 ± 7.2	28.6 ± 7.8	33.1 ± 6.7	1.751	0.184	0.064	n.s.
Visceral adiposity	6.4 ± 3.8	9.3 ± 3.9	11.5 ± 4.2	7.336	0.002	0.223	A < C
PA							
IPAQ (MET min per week)	3254.8 ± 2795.4	3258.7 ± 4400.6	2400.5 ± 2304.2	0.506	0.671	0.021	n.s.
Steps per day (<i>n</i>)	5365.6 ± 1755.9	5710.1 ± 1894.9	5062.8 ± 2934.6	0.380	0.686	0.015	n.s.
Exercise min per day (min)	21.8 ± 20.3	24.4 ± 27.9	12.4 ± 13.1	1.583	0.215	0.058	n.s.
Physical inactivity							
Sitting time (min)	340.6 ± 94.1	349.4 ± 118.6	240.0 ± 91.3	6.286	0.004	0.204	A, B > C

Note: Significant values denoted in bold, n.s., no statistically significant difference.

Also, one-way ANOVA (analysis of variance), *F*, η^2 , and differences between groups using the Bonferroni post hoc test are provided.

Abbreviations: AHI, apnea-hypopnea index; BMI, body mass index; DesSev, desaturation severity; DesSev + RecSev, total desaturation and recovery severity; IPAQ, International Physical Activity Questionnaire; MET min per week, metabolic equivalents minutes per week; ODI_{3%}, oxygen desaturation index for ≥ 3% desaturation, manually scored; ODI_{4%}, oxygen desaturation index for ≥ 4% desaturation automatically calculated with ABOSA; OSA, obstructive sleep apnea; PA, physical activity; RecSev, recovery severity; SpO₂ avg., average oxygen saturation during sleep; TST, total sleep time; T90%, percentage of sleep time with oxygen saturation < 90%.

Interestingly, participants with moderate-to-severe OSA reported spending less time sitting compared with participants with mild and no OSA despite no such differences being found for objective PA variables. Controversially there was a trend, albeit non-significant, for moderate-to-severe OSA participants to have the lowest average PA values in all other PA assessments. As participants with moderate-to-severe OSA were significantly older than participants in other OSA severity groups, these results are in line with a previous

study showing that older adults tend to underestimate their sitting time when subjectively measured (Harvey et al., 2015).

A stepwise multiple linear regression was performed to obtain a multivariate model explaining OSA severity (i.e. the AHI and DesSev + RecSev) in all participants as well as sex-stratified (Table 2). All models showed that age, anthropometric and body composition parameters (BMI and neck circumference) explained the majority of the variance in AHI, which is in line with the literature (Edwards

TABLE 2 A stepwise multiple linear regression analysis of predicting factors for AHI and DesSev + RecSev for all participants and by sex.

	Sex	R	R ²	ΔR^2	SEE	B	SE	β	t	p	Selected variables
AHI	Total	0.710	0.656	0.633	0.350	0.037	0.013	0.271	2.892	< 0.001	Age, BMI, neck circumference
	Male	0.806	0.649	0.612	0.227	0.041	0.013	0.462	3.258	< 0.001	Age, BMI
	Female	0.804	0.647	0.617	0.380	0.053	0.013	0.517	4.173	< 0.001	Age, BMI
DesSev + RecSev	Total	0.836	0.699	0.678	0.376	0.041	0.011	0.325	3.603	< 0.001	Age, BMI, visceral adiposity,
	Male	0.813	0.661	0.626	0.348	0.019	0.005	0.501	3.693	< 0.001	Age, BMI
	Female	0.813	0.661	0.633	0.374	0.023	0.005	0.513	4.277	< 0.001	Age, BMI

Note: The models' explanatory variables included age, BMI, neck circumference, visceral adiposity, IPAQ, steps per day, and sitting time per day.

Abbreviations: AHI, apnea-hypopnea index; B, unstandardized coefficient; BMI, body mass index; DesSev + RecSev, total desaturation and recovery severity; IPAQ, International Physical Activity Questionnaire; p, significance; R, the correlation between the predicted values and the observed values; R², the percentage of variation explained; ΔR^2 , a corrected goodness-of-fit; SE, standard error; SEE, standard error of estimation; t, coefficients/standard error; β , standardized coefficient.

TABLE 3 Spearman correlation coefficients calculated between objective and subjective measures of PA.

	No OSA				Mild OSA				Moderate-to-severe OSA			
	Steps	IPAQ	Exerc.	Sitting	Steps	IPAQ	Exerc.	Sitting	Steps	IPAQ	Exerc.	Sitting
Steps per day (n)	–				–				–			
IPAQ (MET min per week)	0.066	–			0.363	–			–0.220	–		
Exercise per day (min)	0.423	0.120	–		0.522*	0.469*	–		0.450	–0.034	–	
Sitting time (min per week)	–0.106	–0.452	–0.007	–	–0.381	–0.461	–0.361	–	–0.14	–0.226	–0.091	–

Note: Statistically significant values denoted in bold.

Abbreviations: Exerc., exercise minutes per day; IPAQ, International Physical Activity Questionnaire; MET min per week, metabolic equivalent of task minutes per week; OSA, obstructive sleep apnea.

*Correlation is significant at the level of $p < 0.05$.

et al., 2014; Hargens et al., 2013; Kim et al., 2021; Kritikou et al., 2013; Malhotra & White, 2002; Meurling et al., 2019). In addition, we found a similar phenomenon in case of DesSev + RecSev: age, anthropometric and body composition parameters (BMI and visceral adiposity) explained the majority of the variance in DesSev + RecSev. These results highlight the fact that baseline PA measures are minimally associated with OSA severity; however, we consider that this is due to the strong association between PA measures and anthropometric and body composition parameters.

Low correlations were found between different subjective and objective PA measures (Table 3). These results align with previous studies indicating that subjective measures tend to overestimate PA compared with objectively measured PA, resulting in poor correlation (Igelström et al., 2013; Steene-Johannessen et al., 2016). In addition, correlations were of similar strength and non-significant for participants in the three OSA severity groups, despite the mild OSA group having significant correlations between exercise per day and step count, and between exercise per day and IPAQ. This indicates that OSA status does not affect the correlation between subjective and objective PA assessment. Importantly, the daily exercise question in

our Sleep Revolution app had a stronger relationship with objective PA than the IPAQ (Schmitz et al., 2022). This is in line with earlier studies showing reduced memory bias with digital logging of events closer to their occurrence, even though the IPAQ only asks about the last 7 days (Vallo Hult et al., 2022). Similarly, Igelström et al. (2013) found a stronger relationship between a daily logbook and objective PA than the IPAQ (Igelström et al., 2013).

The novelty of our findings is the lack of additive effects of PA, measured either objectively or subjectively, for OSA severity after adjustment for BMI and body composition parameters. This indicates that the role of PA is either mediated by these factors or that overall PA may be too variable to affect OSA severity systematically. However, our results contradict with findings of Mendelson et al.'s (2016) randomized controlled trial on PA and OSA severity, reporting improvement in OSA severity with increased PA (Mendelson et al., 2016). However, in our study, we only looked at general PA without instructions about increased PA, which could explain the different results. A tailored exercise program, to increase PA and exercise levels, and using objective measures of PA should be recommended for patients with OSA (Igelström et al., 2013; Kline

et al., 2011; Mendelson et al., 2016; Sengul et al., 2011). In the present study, 7.4% of the participants had less than 10 min of continuous PA per week, 11.1% PA was low, 40.7% were moderately active, and 37.1% were highly active according to the criteria of the long version of the IPAQ (Ainsworth et al., 2000). Also, 3.7% did not complete the IPAQ.

This study has some limitations. First, the study was a pilot study and therefore limited by a small sample size and three AHI severity groups. However, the 3-night self-applied PSG for OSA diagnosis enabled the detection of the night-to-night variation in OSA severity (Newell et al., 2012) and limited the first-night effect on sleep quality, i.e. the AHI and DesSev + RecSev were calculated as averages over the successful PSG recordings. Second, the effects of Covid-19 could have affected participant's sleep, PA and exercise levels as some restrictions were still obligatory by the government during the time of this study.

5 | CONCLUSIONS

The main finding of the present study was that participants with moderate-to-severe OSA underestimated their sitting time compared with objectively measured PA, which was not observed in participants with no-to-mild OSA. In addition, no significant effects of PA were found on OSA severity after adjustment for age, BMI and body composition. This indicates that PA measures are either mediated by these variables or baseline PA activity is too variable to have a systematic effect on OSA severity. Furthermore, there was little or no correlation between objective and subjective PA measures regardless of OSA severity, indicating that subjective PA measures either over- or underestimate general PA. The present results highlight the fact that healthcare professionals should encourage patients with OSA to increase their PA levels and communicate with them to understand whether they are subjectively over- or underestimating their PA levels. A combination of objective PA measures and a daily logbook provides healthcare professionals more accurate information about the general PA of OSA patients than subjective measures alone.

AUTHOR CONTRIBUTIONS

Katrin Y. Fridgeirsdottir: Conceptualization; data curation; formal analysis; methodology; writing – original draft; writing – review and editing. **Kristín A. Ólafsdóttir:** Data curation; funding acquisition; project administration; writing – review and editing. **Anna Sigridur Islind:** Data curation; funding acquisition; writing – review and editing. **Timo Leppänen:** Funding acquisition; data curation; writing – review and editing. **Erna S. Arnardóttir:** Conceptualization; methodology; funding acquisition; project administration; supervision; writing – original draft; writing – review and editing. **Jose M. Saavedra:** Conceptualization; methodology; funding acquisition; supervision; writing – original draft; writing – review and editing; formal analysis.

CONFLICT OF INTEREST STATEMENT

ESA reports honoraria from Nox Medical, ResMed, Jazz Pharmaceuticals, Linde Healthcare, Wink Sleep, Apnimed and Vistor as well as

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DATA AVAILABILITY STATEMENT

Research data are not shared.

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