Relationship Between Sitting Time, Physical Activity, and Metabolic Syndrome Among Adults Depending on Body Mass Index (BMI)

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Statistical Analysis C
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Background: The aim of this study was to assess the possible relationship between sitting time and physical activity and the risk of occurrence of metabolic syndrome and its components. Analyses were conducted in the whole sample, and with stratification according to BMI. We have formulated a hypothesis that individuals with different BMIs have different responses to metabolic health modifiers such as physical activity and sitting time.

Material/Methods: Altogether, the data from 10 367 participants from urban and rural areas, aged 37–66 years were used in the study (7479 of whom were overweight or obese). The definition of metabolic syndrome devised by the IDF Joint Interim Statement criteria using an ethnic-specific cut-off point for waist circumference as the central obesity criterion was used.

Results: In all analyzed BMI groups, longer sitting time was only associated with abdominal obesity (all p for trend <0.05). In participants declaring low physical activity levels, the risk of metabolic syndrome and abnormal triglycerides concentration was higher compared to those declaring high physical activity, regardless of BMI (all p for trend <0.05). In the group with overweight or obesity, low physical activity was associated with a higher risk of abdominal obesity (p for trend <0.05), increased glucose concentration (p for trend <0.05), and elevated blood pressure (p for trend <0.05). In participants with a normal BMI, these associations did not occur.

Conclusions: Our data suggest that physical activity helps preventive metabolic syndrome and its abnormal components, especially in participants who are overweight or obese.

MeSH Keywords: Blood Glucose • Body Mass Index • Cholesterol, HDL • Hypertriglyceridemia • Obesity, Abdominal • Sedentary Lifestyle • Hypertension

Abbreviations: PA – physical activity; ST – sitting time; MetS – metabolic syndrome; OR – odds ratio

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Background

Metabolic syndrome (MetS) is defined as the accumulation of risk factors such as abdominal obesity, abnormal glycemia and dyslipidemia, and blood hypertension [1,2], which increase the risk of type 2 diabetes, cardiovascular diseases, some tumors, and all-cause mortality [3–9]. The results of numerous studies have proven that the risk of MetS can be modified through lifestyle [10], adequate sleep duration [11], regular exercise, smoking cessation, moderation in drinking alcohol, and stress management techniques [12,13]. In recent years, in MetS prophylaxis, special attention is paid not only to the role of physical activity (PA) but also to sedentary behaviors. By a majority of researchers, they are regarded as 2 independent types of behavior which can have different determinants, and which can independently affect metabolic health [14–19]. Generally, it is thought that a high level of PA is related to a lower risk of MetS [16,20–22], whereas a longer time devoted to sedentary behavior increases this risk [16,21,23–28]. Some studies have not confirmed the association between lower PA and/or longer time of sedentary behavior and metabolic risk [29–32].

Studies have shown that overweight and obesity are associated with a greater risk of MetS, but metabolic risk factors also appear in individuals with normal BMI [33,34]. BMI can be a factor differentiating the course of many metabolic and adaptive processes in the body [35–38] as well as a factor differentiating gene expression of some factors involved in lipid uptake and processing [39]. It can also be a factor conditioning a different response of the body to certain lifestyle elements that are modifiers of metabolic risk factors (for example, the consumption of certain foods) [40]. We therefore accept the hypothesis that individuals with a different BMI also have a different response to metabolic health modifiers such as physical activity (PA) and sitting time (ST). Recent studies seem to confirm that PA influences energy homeostasis and metabolic risk factors in lean individuals in a different way than in overweight and obese individuals [41–43].

PA and sedentary behaviors have rarely been analyzed simultaneously as 2 separate behaviors, independently affecting metabolic health in people of various body masses (normal weight versus overweight/obese) [44–47]. In the studies of obese individuals, higher PA and shorter time of sedentary behavior contributed to maintaining metabolic health [48–50]. Camhi et al. [51] showed that in obese adults, only PA and not sitting time influences their metabolic health. Crichton and Alkerwi [45] observed positive associations between all sedentary behavior time variables and triglycerides, LDL, and total cholesterol concentration in normal-weight individuals. However, they did not find any significant correlations between any intensity level of PA or sedentary behavior time variables and lipid levels in those overweight or obese subjects.

Philips et al. [52] also failed to demonstrate any association between metabolic health status and physical activity, regardless of BMI. Therefore, the results of these studies are ambiguous. In Poland there have been no studies conducted in which PA and sedentary behavior were analyzed as 2 separate behaviors influencing the risk of MetS independently and with stratification according to BMI. The aim of the present study was to investigate the relationship between sitting time, total physical activity, and metabolic syndrome and its components in individuals with normal BMI, as well as in overweight and obese individuals.

Material and Methods

Research material was obtained from the PONS project (Polish-Norwegian Study), which is prospective research on the condition of health of the inhabitants of the Świętokrzyskie voivodeship in Poland, conducted in 2010–2012. Cross-sectional data were used in the analysis. The studies included anthropometric measurements, blood pressure measurements, and analyses of collected fasting-blood samples. An extensive interview was carried out in order to collect information about the subjects' lifestyle during the last year. Detailed data regarding the project, research procedure, and group selection were described in previously published papers [53,54]. All men and women ages 45–64 residing in the Kielecki region in Poland were invited to take part in the study. The participation rate was 12%. The research group included a small number of younger (37–44) and older (65–66) volunteers, who constituted 0.66% of participants. Altogether, 13 172 people ages 37–66 were enrolled in this study. The following participants were excluded from the study: participants lacking data concerning body mass and/or height (N=65; 0.49%); those with a BMI <18.5 kg/m^2 (N=58; 0.44%), individuals with cardiovascular disease, stroke, or tumor history, or lacking data concerning the occurrence of the abovementioned diseases (N=1998; 15.17%); and those with incomplete data related to socio-demographic variables and lifestyle (N=691; 5.25%). As a result, in further analysis of the data, 10 367 participants were assessed, including 2888 individuals with a normal body mass and 7479 overweight or obese subjects.

Assessment of biomarkers and blood pressure

Blood pressure was measured using the blood pressure monitor Omron, model M3 Intellisense. Measurements were made twice, and the average of the 2 measurements was used in analyses. The glucose concentration in the blood serum was obtained by means of the enzyme method with hexokinase. The concentration of triglycerides was determined by means of the phosphoglyceride oxidase-peroxidase method, and the HDL cholesterol concentration was obtained using the colorimetric

non-precipitation method. Laboratory tests were performed with Integra 800 (La Roche Diagnostics, Switzerland).

Anthropometric measurements

The measurements of body weight were done by means of an electronic scale (Tanita SC 240MA). Body height measurements were done by means of the scales' stadiometer. These measurements were used to calculate BMI (kg/m^2). The waist circumference was measured halfway between the lower rib edge and the upper iliac crest by means of metric measurement.

Socio-demographic variables

The socio-demographic factors included: sex (men; women), age (37–51 and 52–66), place of residence (urban, rural), education (university, lower than university), marital status (married or in a relationship, single or a widow/widower).

Lifestyle

The International Physical Activity Questionnaire (IPAQ) was used to assess physical activity (PA). The questionnaire included detailed questions related to activities done by a respondent during the last week, connected with their professional work, active movement, housework, recreation, and sports. The IPAQ has been evaluated in 14 studies and found to have good test-retest reliability and a modest Spearman correlation (r=0.30) with PA measured by accelerometer [55]. Total physical activity was calculated by multiplying the MET indicator assigned to a given activity by the average number of days it was performed, its duration in minutes per day, and it was presented in the MET-min/week units. In compliance with the recommendations of the authors of the IPAQ questionnaire IPAQ [56], 3 PA categories were distinguished – low, moderate, and high – in accordance with the following procedure: 3.3 METs (based on walking METs), moderate intensity: 4.0 METs, (for leisure and domestic domains, and yard work); 5.5 METs (for vigorous garden/yard work); 3.0 METs (for doing inside chores); 6.0 METs (for cycling); and high PA: 8.0 METs (for work and leisure domains). Sitting time (ST) during the last week was determined on the basis of time spent in a sitting position on weekdays and weekends. Next, the average number of minutes spent sitting per day was calculated. The data concerning coffee and alcohol consumption were collected with the use of the Food Frequency Questionnaire (FFQ). PONS FFQ was constructed based on a previously developed and validated questionnaire for the Polish branch of the PURE study. It was characterized by good validity and reproducibility in relation to the referential method [57]. The participants of the study were asked about the frequency of consumption of standard portions of food products during the last year. In the case of coffee, 1 cup (250 ml) constituted 1 portion. Alcohol consumption was determined

on the basis of the frequency of consumption of standard portions of alcoholic beverages during the last 30 days. The answers related to the frequency of consumption of each product from the questionnaire were transformed into daily consumption doses and then standardized by a z-score. All individuals were divided into 3 groups according to their smoking status: current smokers were respondents who smoked cigarettes on a daily basis during the study, former smokers were those who had not smoked for longer than 6 months, and nonsmokers were the rest of the participants.

Definitions of terms

A normal BMI 18.5–24.9 kg/m^2 and overweight and obesity were BMI ≥25.0 kg/m^2. Metabolic syndrome (MetS) was defined according to the IDF guidelines (International Diabetes Federation Task Force on Epidemiology and Prevention; joint interim statement in 2009) as meeting 3 or more of the 5 following criteria: waist circumference ≥94 cm in males and ≥80 cm in females; fasting glucose ≥100 mg/dl (5.5 mmol/l) or diabetes treatment; triglycerides ≥150 mg/dL (1.7 mmol/l) or drug treatment for elevated triglycerides, HDL cholesterol <40 mg/dL (1.0 mmol/l) in males and <50 mg/dl (1.3 mmol/l) in females or drug treatment to reduce HDL cholesterol, and systolic blood pressure ≥130 mmHg or diastolic blood pressure ≥85 mmHg or drug treatment for hypertension. A MET is defined as the resting metabolic rate, which is the amount of oxygen consumed at rest sitting quietly in a chair approximately 3.5 ml O_2/kg/min (1.2 kcal/min for a 70-kg person) [58].

Statistical analysis

The distribution of quantitative variables such as sitting time (ST) and coffee and alcohol consumption was verified using Kolmogorov-Smirnov and Lilliefors tests. A significance level of p≤0.05 indicated that the samples did not come from a normal distribution. Thus, in addition to mean values and standard deviations, the median and 95% CI were calculated. These values were calculated in 2 BMI groups: for participants with a normal BMI and for participants with overweight and obesity. Non-parametric tests were used in further analyzes.

For the qualitative data (age, sex, education, place of residence, marital status, smoking, PA, BMI categories and the metabolic syndrome components of abdominal obesity, elevated blood pressure, increased glucose, triglycerides concentration, and decreased HDL concentration), the structure indicators were calculated. The non-parametric chi-square test was used to assess the relationship between the structure indicators. In the analysis of quantitative variables (ST and coffee and alcohol consumption), significant differences were calculated between the medians of individuals with a normal BMI and those with overweight and obesity, using the non-parametric Mann-Whitney U

Table 1. Characteristics of socio-demographic variables, lifestyle and metabolic parameters in study participants depending on BMI.

Variables	Normal BMI (18.5–24.9 kg/m²) N=2888		Overweight and obesity (BMI ≥25.0 kg/m²) N=7479		p
Age: 37–51 years N (%)	1054	(36.47)	1853	(24.77)	0.000[a]
Sex: men N (%)	680	(23.53)	2780	(37.16)	0.000[a]
Place of living: city N (%)	1967	(68.06)	4517	(60.38)	0.000[a]
Education: university N (%)	1128	(39.03)	2131	(28.49)	0.000[a]
Marital status: single N (%)	690	(23.88)	1407	(18.81)	0.000[a]
Former smokers N (%)	759	(26.27)	2661	(35.58)	0.000[a]
Current smokers N (%)	815	(28.21)	1296	(17.33)	0.000[a]
Coffee (servings/day)×(SD); Me (95%CI)	1.35 / 1.00	(1.05) / (0.00–2.50)	1.23 / 1.00	(1.01) / (0.00–2.50)	0.000[b]
Alcohol (servings/day)×(SD); Me (95%CI)	0.073 / 0.03	(0.110) / (0.01–0.42)	0.069 / 0.03	(0.109) / (0.01–0.29)	0.626[b]
Abdominal obesity N (%)	799	(27.65)	6683	(89.33)	0.000[a]
Elevated blood pressure N (%)	1889	(65.36)	6045	(80.80)	0.000[a]
Increased glucose concentration N (%)	522	(18.06)	2697	(36.05)	0.000[a]
Decreased HDL cholesterol concentration N (%)	638	(22.08)	2498	(33.39)	0.000[a]
Increased triglycerides concentration N (%)	727	(25.16)	2957	(39.53)	0.000[a]
Metabolic syndrome N (%)	648	(22.42)	4174	(55.79)	0.000[a]
ST (min/day)×(SD); Me (95%CI)	387.9 / 385.7	(162.4) / (128.6–728.6)	389.0 / 385.7	(163.4) / (128.6–771.4)	0.839[b]
Vigorous PA, N (%)	136	(4.69)	506	(6.78)	
Moderate PA, N (%)	1740	(60.00)	4243	(56.82)	0.000[a]
Low PA, N (%)	1024	(35.31)	2718	(36.40)	

[a] – chi square – test; [b] – U Mann-Whitney test; ST – sitting time; PA – physical activity.

test (Table 1). In further statistical analysis, quantitative variables were categorized. Quartile values were calculated for the coffee and alcohol consumption variables, whereas overall reported sitting time was categorized as ≤2 h/day, >2 ≤4 h/day, >4 ≤6 h/day, and ≤6 h/day. Physical activity, according to IPAQ instructions, was divided into the following categories: vigorous, moderate, and low PA [poz. 29]. IPAQ reference groups in the adjusted model for the variables mentioned above were groups marked with the '0' code. Two models were presented: unadjusted and adjusted for age: 37–51 (0), 52–66 (1), sex: female -–0, male – 1; place of residence: urban – 0, rural – 1; education level: university – 0, lower than university – 1; marital status: in a stable relationship – 0, single or a widow/widower – 1; smoking: nonsmokers – 0, former smokers – 1, current smokers – 2; coffee consumption: quartiles (Q4–0), and alcohol consumption: quartiles (Q1–0). For the independent variable of sitting time, the reference point for the OR I 95CI calculations was the group with the shortest sitting time (≤2 h/day), and for physical activity it was vigorous PA. The basis for selection of the confounders was the analysis of the

Spearman correlation matrix between the variables and the dependent variable. The predictors which were strongly correlated with the dependent variables were taken into account. In order to avoid multicollinearity, the predictors strongly correlating with each other were not included. All p-values presented are 2-tailed and p<0.05 was considered statistically significant. Data were analyzed using Statistica 10.0 Software.

Results

The overweight and obese individuals, compared with the subjects with normal BMI, were more often male, older (52–66 years), inhabitants of rural areas, had less education, and were in a stable relationship (Table 1). In the group with overweight and obesity, there were more former smokers and fewer current ones. The participants with excess body mass declared lower coffee consumption, and they were also less physically active compared to the subjects with normal body mass, but there were no significant differences in ST and alcohol consumption.

In overweight and obese individuals, a significantly higher frequency of MetS occurrence was found, as well as each of its components.

In the unadjusted model, a longer ST was found in the general study population and in the groups with stratification according to BMI related to the risk of abdominal obesity (Table 2). Adjustment to the interfering variables showed that this relationship became even stronger and the ST of 2 or more hours per day significantly increased the risk of abdominal obesity in all analyzed groups (all p for trend <0.05). There were no significant associations found between ST and the risk of MetS and its other components.

In participants declaring low PA, the risk of MetS was higher compared to those declaring high PA, regardless of BMI (Table 3). These associations were statistically significant both in the unadjusted as well as in the model adjusted for confounders. In the general subject population as well as in the group with overweight and obesity, low PA was related to a greater risk of abdominal obesity and an increased glucose concentration. In individuals with a normal BMI, such associations were not found. A greater risk of elevated blood pressure was related to low PA in the group with overweight and obesity. In the general subject population, p for trend was significant, but only in the unadjusted model. A decreased HDL cholesterol concentration was connected with low PA in all subject groups, but only in the unadjusted model. After the inclusion of confounders, the above associations were no longer present. In participants declaring low PA, there was a higher risk of increased triglycerides concentration compared to those declaring high PA. These associations were significant in both models and in all groups of participants, distinguished in accordance with BMI.

Discussion

The results of the conducted analyses show a positive association between ST and the risk of abdominal obesity. However, there were no significant relationships between ST and MetS and its other components, neither in the general subject population nor after the consideration of stratification according to BMI. In papers by several authors, it has been confirmed that in the general population, sitting time was associated with a greater risk of abdominal obesity in women [59] and was positively correlated with waist circumference in men [60,61]. Also, a significant influence of sedentary behaviors on increased risk of MetS, regardless of PA, has been proven [14,16,25,27]. However, the other results of several different studies have been unambiguous. Altenburg et al. [62] demonstrated that over a 2-year period, higher levels of overall sedentary time and TV time were weakly but negatively associated with only

1 out of 13 studied cardio-metabolic risk factors (HDL cholesterol). Van der Velde et al. [63] found that a longer sedentary time was related to a lower HDL cholesterol concentration and a higher triglycerides concentration. However, these associations turned out to be insignificant after corrections for fitness and moderate-to-vigorous PA. Analysis of cross-sectional studies conducted by Powell et al. [64] showed, however, that increased sedentary time had a significant detrimental association with waist circumference, fasting glucose, triglycerides, and HDL cholesterol. However, a meta-analysis conducted by Wirth et al. [28] in older people showed that waist circumference was positively associated with sedentary behavior in 7 cross-sectional studies and 1 prospective observational study, which is consistent with the results of our research. No significant associations were found in 4 randomized controlled trials. There were no positive associations between sedentary behavior and systolic and diastolic blood pressure in 8 out of 11 and 9 out of 10 analyzed studies, respectively. Higher glucose levels were positively associated with sedentary behavior only in some cross-sectional studies. HDL cholesterol was negatively associated with sedentary behavior only in 2 prospective observational studies, while in the case of randomized controlled trials, no significant associations were noted. Maher et al. [65] showed that while there are weak relationships between cardio-metabolic biomarkers and sedentary behavior when analyses are adjusted for moderate-to-vigorous physical activity, the associations disappear when analyses are adjusted for total physical activity. They concluded that sedentary behaviors may not have an effect on metabolic biomarkers independent of physical activity. Also, Nilsson et al. [66] argued that the detrimental influence of a sedentary lifestyle on metabolic health is likely explained by variations in amounts of physical activity rather than the amount of sedentary time *per se*.

Very few studies have been published regarding the relationship between sedentary behavior and MetS and its components with BMI stratification. Crichton and Alkerwi [45] noted positive linear associations between sedentary behaviors and the concentration of triglycerides and LDL cholesterol in individuals with normal body mass (BMI <25 kg/m^2). Participants who reported the least sitting time (≤1 h/day) had lower levels of the lipids compared to the highest sitting time group (≥4 h/day). However, they did not notice any significant association between sedentary time and HDL cholesterol concentration; in overweight or obese participants (BMI ≥25 kg/m^2), there were no associations between the sedentary behavior time variables and lipids concentration, which is consistent with the results of our research. In Korean adults, high diastolic blood pressure and low HDL cholesterol were significantly associated with prolonged sedentary time [19]. These associations remained significant even after adjustment for BMI. Camhi et al. [51] stated that sitting time did not have a differentiating effect on metabolic health of obese adolescents or adults. Bell et al. [44]

Table 2. Odds ratio for the metabolic syndrome and it's components depending on sitting time (OR, 95% CI).

ST hrs/day	Total OR(95%CI)	p	Normal BMI OR(95%CI)	p	Owerweight and obesity OR(95%CI)	p
			Model I (adjusted)			
Metabolic syndrome						
≤2 hrs/day	1.0		1.0		1.0	
>2 ≥4 hrs/day	1.06 (0.93–1.22)	0.363	0.91 (0.68–1.22)	0.532	1.13 (0.96–1.32)	0.130
>4 ≥6 hrs/day	1.03 (0.90–1.17)	0.706	0.85 (0.63–1.14)	0.283	1.09 (0.93–1.27)	0.287
>6 hrs/day	1.02 (0.82–1.18)	0.802	0.78 (0.56–1.09)	0.143	1.14 (0.95–1.36)	0.154
P for trend		0.742		0.443		0.435
Abdominal obesity						
≤2 hrs/day	1.0		1.0		1.0	
>2 ≥4 hrs/day	**1.18 (1.02–1.37)**	**0.026**	1.34 (0.99–1.81)	0.060	**1.36 (1.07–1.72)**	**0.013**
>4 ≥6 hrs/day	**1.19 (1.03–1.38)**	**0.017**	**1.35 (1.00–1.82)**	**0.048**	**1.35 (1.07–1.71)**	**0.013**
>6 hrs/day	1.14 (0.96–1.34)	0.123	**1.44 (1.04–2.00)**	**0.029**	1.27 (0.97–1.66)	0.084
P for trend		0.111		0.158		0.076
Elevated blood pressure						
≤2 hrs/day	1.0		1.0		1.0	
>2 ≥4 hrs/day	0.96 (0.82–1.13)	0.651	0.89 (0.68–1.17)	0.402	1.01 (0.83–1.23)	0.912
>4 ≥6 hrs/day	0.94 (0.80–1.10)	0.431	0.85 (0.65–1.11)	0.225	0.99 (0.82–1.21)	0.953
>6 hrs/day	1.01 (0.85–1.12)	0.883	0.90 (0.67–1.22)	0.515	1.11 (0.88–1.38)	0.379
P for trend		0.678		0.685		0.655
Increased glucose concentration						
≤2 hrs/day	1.0		1.0		1.0	
>2 ≥4 hrs/day	1.04 (0.90–1.20)	0.597	1.13 (0.81–1.56)	0.467	1.02 (0.87–1.21)	0.774
>4 ≥6 hrs/day	0.95 (0.82–1.09)	0.474	0.81 (0.58–1.12)	0.203	0.99 (0.84–1.16)	0.872
>6 hrs/day	0.96 (0.82–1.13)	0.637	0.93 (0.64–1.33)	0.681	0.99 (0.82–1.19)	0.900
≤2 hrs/day		0.287		0.076		0.919
Decreased HDL cholesterol concentration						
≤2 hrs/day	1.0		1.0		1.0	
>2 ≥4 hrs/day	1.02 (0.88–1.18)	0.773	0.85 (0.63–1.15)	0.300	1.08 (0.92–1.28)	0.349
>4 ≥6 hrs/day	1.03 (0.89–1.58)	0.732	0.88 (0.66–1.19)	0.413	1.08 (0.91–1.27)	0.388
>6 hrs/day	1.02 (0.87–1.20)	0.789	0.80 (0.57–1.12)	0.196	1.12 (0.92–1.35)	0.253
P for trend		0.991		0.618		0.714
Increased triglycerides concentration						
≤2 hrs/day	1.0		1.0		1.0	
>2≥4 hrs/day	1.07 (0.93–1.23)	0.374	0.92 (0.69–1.22)	0.554	1.12 (0.95–1.32)	0.162
>4≥6 hrs/day	1.06 (0.92–1.22)	0.398	0.87 (0.65–1.16)	0.353	1.13 (0.96–1.33)	0.131
>6 hrs/day	1.01 (0.86–1.18)	0.915	0.81 (0.58–1.11)	0.192	1.10 (0.91–1.31)	0.318
P for trend		0.324		0.563		0.482

Table 2 continued. Odds ratio for the metabolic syndrome and it's components depending on sitting time (OR, 95% CI).

ST hrs/day	Total OR(95%CI)	p	Normal BMI OR(95%CI)	p	Owerweight and obesity OR(95%CI)	p
			Model II (adjusted)			
Metabolic syndrome						
≤2 hrs/day	1.0		1.0		1.0	
>2 ≥4 hrs/day	1.06 (0.91–1.23)	0.455	0.93 (0.66–1.31)	0.673	1.12 (0.94–1.34)	0.206
>4 ≥6 hrs/day	1.04 (0.89–1.03)	0.625	0.86 (0.61–1.22)	0.403	1.07 (0.90–1.28)	0.424
>6 hrs/day	1.13 (0.95–1.35)	0.169	1.21 (0.99–1.49)	0.065	1.21 (0.99–1.49)	0.065
P for trend		0.255		0.660		0.173
Abdominal obesity						
≤2 hrs/day	1.0		1.0		1.0	
>2 ≥4 hrs/day	**1.20 (1.01–1.41)**	**0.031**	**1.42 (1.01–2.02)**	**0.046**	**1.38 (1.06–1.81)**	**0.018**
>4 ≥6 hrs/day	**1.20 (1.02–1.41)**	**0.031**	**1.44 (1.02–2.023)**	**0.036**	**1.53 (1.17–2.00)**	**0.002**
>6 hrs/day	**1.34 (1.11–1.62)**	**0.002**	**1.64 (1.12–2.41)**	**0.010**	**1.50 (1.10–2.05)**	**0.011**
P for trend		**0.001**		**0.013**		**0.017**
Elevated blood pressure						
≤2 hrs/day	1.0		1.0		1.0	
>2 ≥4 hrs/day	0.90 (0.75–1.08)	0.249	0.73 (0.53–1.00)	0.051	1.00 (0.80–1.26)	0.971
>4 ≥6 hrs/day	0.80 (0.73–1.04)	0.139	**0.70 (0.51–0.95)**	**0.023**	0.96 (0.77–1.20)	0.748
>6 hrs/day	1.06 (0.86–1.30)	0.586	0.86 (0.60–1.23)	0.418	1.18 (0.91–1.53)	0.214
P for trend		0.643		0.689		0.424
Increased glucose concentration						
≤2 hrs/day	1.0		1.0		1.0	
>2 ≥4 hrs/day	1.03 (0.87–1.20)	0.758	1.02 (0.71–1.48)	0.900	1.03 (0.86–1.23)	0.770
>4 ≥6 hrs/day	0.96 (0.82–1.13)	0.666	0.83 (0.57–1.21)	0.343	1.00 (0.83–1.19)	0.962
>6 hrs/day	0.99 (0.82–1.19)	0.899	0.94 (0.62–1.44)	0.793	1.01 (0.81–1.24)	0.957
P for trend		0.646		0.279		0.953
Decreased HDL cholesterol concentration						
≤2 hrs/day	1.0		1.0		1.0	
>2 ≥4 hrs/day	0.96 (0.81–1.12)	0.592	0.85 (0.60–1.19)	0.337	1.00 (0.83–1.20)	0.999
>4 ≥6 hrs/day	0.96 (0.82–1.13)	0.617	0.84 (0.60–2.39)	0.318	0.99 (0.82–1.19)	0.882
>6 hrs/day	1.02 (0.85–1.22)	0.861	0.82 (0.56–1.21)	0.326	1.09 (0.88–1.34)	0.441
P for trend		0.698		0.756		0.589
Increased triglycerides concentration						
≤2 hrs/day	1.0		1.0		1.0	
>2 ≥4 hrs/day	1.01 (0.86–1.18)	0.941	0.87 (0.63–1.21)	0.401	1.06 (0.88–1.26)	0.558
>4 ≥6 hrs/day	1.03 (0.88–1.20)	0.735	0.83 (0.60–1.15)	0.272	1.09 (0.91–1.30)	0.361
>6 hrs/day	1.03 (0.86–1.23)	0.757	0.92 (0.63–1.34)	0.666	1.08 (0.87–1.33)	0.476
P for trend		0.517		0.693		0.361

ST – sitting time.

Table 3. Odds ratio for the metabolic syndrome and it's components depending on physical activity (OR, 95% CI).

PA	Total		Normal BMI		Owerweight and obesity	
	OR (95%CI)	p	OR (95%CI)	p	OR (95%CI)	p
Model I (unadjusted)						
Metabolic syndrome						
High PA	1.0		1.0		1.0	
Moderate PA	1.06 (0.98–1.15)	0.155	1.16 (0.98–1.25)	0.055	1.12 (1.01–1.23)	0.024
Low PA	**1.82 (1.54–2.16)**	**0.000**	**1.72 (1.14–2.46)**	**0.000**	**1.90 (1.55–2.23)**	**0.000**
P for trend		**0.000**		**0.020**		**0.000**
Abdominal obesity						
High PA	1.0		1.0		1.0	
Moderate PA	1.06 (0.97–1.56)	0.177	1.11 (0.93–1.32)	0.232	**1.28 (1.10–1.49)**	**0.002**
Low PA	**1.53 (1.25–1.87)**	**0.000**	1.24 (0.85–1.85)	0.255	**1.55 (1.11–2.17)**	**0.010**
P for trend		**0.001**		0.146		**0.003**
Elevated blood pressure						
High PA	1.0		1.0		1.0	
Moderate PA	1.00 (0.91–1.10)	0.951	0.99 (0.84–1.16)	0.868	1.02 (0.91–1.16)	0.684
Low PA	**1.62 (1.30–2.02)**	**0.000**	1.23 (0.83–1.81)	0.297	**1.73 (1.31–2.29)**	**0.000**
P for trend		**0.011**		0.653		**0.007**
Increased glucose concentration						
High PA	1.0		1.0		1.0	
Moderate PA	**1.11 (1.0–1.21)**	**0.022**	1.01 (0.83–1.24)	0.913	**1.16 (1.05–1.28)**	**0.004**
Low PA	**1.66 (1.40–1.97)**	**0.000**	1.35 (0.88–2.09)	0.736	**1.66 (1.37–2.00)**	**0.000**
P for trend		**0.000**		0.403		**0.000**
Decreased HDL cholesterol concentration						
High PA	1.0		1.0		1.0	
Moderate PA	1.05 (0.96–1.15)	0.251	1.06 (0.86–2.15)	0.151	1.09 (0.99–1.21)	0.081
Low PA	**1.28 (1.08–1.53)**	**0.006**	**1.29 (1.00–2.35)**	**0.046**	**1.26 (1.04–1.54)**	**0.019**
P for trend		**0.016**		**0.015**		**0.012**
Increased triglycerides concentration						
High PA	1.0		1.0		1.0	
Moderate PA	1.01 (0.92–1.10)	0.893	0.97 (0.81–1.20)	0.993	1.03 (0.93–1.13)	0.571
Low PA	**1.49 (1.26–1.77)**	**0.000**	**1.39 (1.17–2.76)**	**0.010**	**1.53 (1.27–1.85)**	**0.000**
P for trend		**0.003**		**0.033**		**0.002**

Table 3 continued. Odds ratio for the metabolic syndrome and it's components depending on physical activity (OR, 95% CI).

PA	Total		Normal BMI		Owerweight and obesity	
	OR (95%CI)	p	OR (95%CI)	p	OR (95%CI)	p
Model II (adjusted)						
Metabolic syndrome						
High PA	1.0		1.0		1.0	
Moderate PA	1.07 (0.98–1.18)	0.126	1.17 (0.89–2.28)	0.136	1.11 (0.99–1.24)	0.051
Low PA	**1.55 (1.27–1.88)**	**0.000**	**1.45 (1.17–1.88)**	**0.000**	**1.61 (1.28–2.03)**	**0.000**
P for trend		**0.000**		**0.009**		**0.000**
Abdominal obesity						
High PA	1.0		1.0		1.0	
Moderate PA	1.05 (0.95–1.16)	0.339	1.07 (0.88–1.30)	0.498	**1.19 (1.00–1.41)**	**0.046**
Low PA	**1.80 (1.43–2.26)**	**0.000**	1.48 (0.93–2.36)	0.094	**1.94 (1.34–2.83)**	**0.000**
P for trend		**0.000**		0.181		**0.001**
Elevated blood pressure						
High PA	1.0		1.0		1.0	
Moderate PA	1.04 (0.93–1.16)	0.499	0.99 (0.83–1.20)	0.984	1.07 (0.93–1.23)	0.321
Low PA	**1.34 (1.04–1.73)**	**0.024**	0.94 (0.60–1.48)	0.807	**1.47 (1.07–2.02)**	**0.016**
P for trend		0.078		0.908		**0.037**
Increased glucose concentration						
High PA	1.0		1.0		1.0	
Moderate PA	**1.18 (1.07–1.31)**	**0.001**	**1.19 (1.06–1.41)**	**0.041**	**1.23 (1.10–1.38)**	**0.000**
Low PA	**1.40 (1.14–1.70)**	**0.001**	1.18 (0.71–1.95)	0.522	**1.37 (1.10–1.71)**	**0.005**
P for trend		**0.000**		0.532		**0.000**
Decreased HDL cholesterol concentration						
High PA	1.0		1.0		1.0	
Moderate PA	1.02 (0.93–1.13)	0.675	1.12 (0.94–1.33)	0.067	1.04 (0.93–1.16)	0.478
Low PA	1.10 (0.91–1.35)	0.316	1.11 (0.91–1.35)	0.361	1.10 (0.88–1.37)	0.394
P for trend		0.324		0.314		0.250
Increased triglycerides concentration						
High PA	1.0		1.0		1.0	
Moderate PA	1.05 (0.95–1.15)	0.331	1.15 (0.96–1.25)	0.341	1.06 (0.95–1.19)	0.273
Low PA	**1.25 (1.03–1.52)**	**0.022**	**1.25 (1.04–2.52)**	**0.032**	**1.29 (1.04–1.61)**	**0.020**
P for trend		**0.033**		**0.044**		**0.025**

PA – physical activity.

reported lower self-reported sedentary time in the metabolically healthy non-obese subjects compared to the metabolically unhealthy non-obese ones. De Rooij et al. [46], using objective measurement methods, showed statistically significant differences in sedentary time per day between the metabolically healthy non-obese and metabolically unhealthy non-obese (553.3 *vs.* 576.6 min/day), as well as between the metabolically healthy obese and metabolically unhealthy obese (563.5 *vs.* 593.0 min/day).

In our own studies, among all participants, low PA was related to a higher risk MetS and abdominal obesity, an increased glucose and triglycerides concentration, and elevated blood pressure. In participants with a normal BMI, there were only associations between PA and the risk of MetS and increased triglycerides concentration. Among participants with overweight and obesity, significant associations were found between PA and MetS, as well as all its components, excluding HDL cholesterol concentration. In the literature, generally positive associations between PA and health are presented [20,21,66–68]. Bakrania et al. [69] emphasize that in adults, being physically active was related to a better health profile, even in those individuals whose high PA was accompanied by a high sedentary time. Some long-term studies, however, show bidirectional relationships between PA and sedentary lifestyle, and indicators of excessive adipose tissue and suggest that the initial body weight determines the decline in physical activity more so than vice versa [70–72].

Studies conducted with the stratification according to BMI provide unambiguous results. McGuire and Ross [30] noted that in individuals with abdominal obesity, light PA was not associated with any cardio-metabolic risk factors, and moderate-to-vigorous PA was independently associated with total cholesterol and triglycerides. Bell et al. [49] compared differences in total PA between all healthy and unhealthy BMI groups and demonstrated an independent effect of PA on metabolic risk factors. Similarly, Hu et al. [73] reported that higher levels of PA appeared to be beneficial at any adiposity level. In a prospective study on each level of PA, a graded increase of the risk of MetS occurrence was observed along with a BMI increase; however, there was no such graded association between PA and MetS in the analysis conducted in all BMI categories [74]. Crichton and Alkerwi [45], in the age group 18–70 years old, did not find any significant correlations between any intensity level of PA and lipid levels in normal weight participants or in those who were overweight or obese. A similar lack of differences in PA between the metabolically healthy and unhealthy subjects, regardless of BMI, was found in other studies [52]. Diniz et al. [33] showed that being physically active (according to HO criteria) was inversely associated with a metabolically healthy status in all BMI categories, but in univariate analysis these associations did not remain significant after adjustment

for confounders. These diverse results obtained by different authors may be the result of demographic differences and a different lifestyle of the studied populations, as well as the varied methodology of PA research.

In our studies, we found the existence of significant associations between PA and MetS and its components in overweight and obese subjects, while such associations were significantly weaker in participants with normal BMI, but it is unclear what the mechanisms involved might be.

The differences in our research results may be due to small differences in PA between normal-weight healthy and normal-weight unhealthy groups in the population we studied [34], while in studies by other researchers there were significant differences in activity in these groups [49]. In the overweight and obese participants, we observed many more dependencies between PA and MetS components due to the significantly higher PA differences between the metabolically healthy and unhealthy groups. Another explanation of the results obtained in the present study can be found in the results of a study analyzing the effects of *in vivo* exercise on *in vitro* metabolic adaptations in culture myotubes isolated from biopsies taken before and after 12 weeks of extensive endurance and strength training [75]. The authors found that the exercise-induced changes in the metabolism of fatty acids in myotubes were significantly higher in cells of overweight men compared to those with a normal BMI, while the total cellular glucose uptake and oxidation tended to be higher in the normal-weight group compared to the overweight group. O'Gorman and Krook [36] show that insulin sensitivity was increased in cultured myotubes established from severely obese participants after 48 h with low-frequency electrical pulse stimulation as an *in vitro* model of exercise. The results of recent studies have also shown that a greater PA was associated with a decreased brain response to high-calorie food cues after glucose ingestion in regions implicated in processing food rewards among young adults, and the results were stronger among individuals with obesity in stratified analyses [43]. The authors concluded that an increasing PA may reduce the brain's response to high-calorie food signals after caloric intake. The prolongment of PA time in the case of frequent exposure to palatable food cues can therefore mitigate the negative impact on the increased risk of obesity and metabolic disorders.

Limitations

First, the cross-sectional design of our study prevents any assessment of causality in the observed associations. Another limitation is the evaluation of ST and PA of participants with the use of a questionnaire. Self-assessment may lead to overestimation of some types of activities and underestimation of others. Moreover, the analysis was only carried out in 2 BMI

groups. Despite the large number of participants, calculating ORs separately for the groups with overweight and obesity I, II, III degrees in the adjusted models was not possible due to an insufficient number of relevant individuals.

Strengths

A strength of our study is the large number of subjects and the fact that it was a homogenous group in respect of age and ethnicity. The analysis also included a large number of confounders, such as alcohol and coffee consumption, smoking, and socio-demographic variables.

Conclusions

Sitting time was independently associated with only 1 metabolic risk factors (abdominal obesity); therefore, it has little support as a separate determinant of metabolic health. Only ST shorter than or equal to 2 h/day prevented abdominal

obesity. Our data confirmed that PA may have a preventive effect against metabolic syndrome and its abnormal components. In participants with a normal BMI, there were only associations between PA and the risk of MetS and increased triglycerides concentration. In participants with overweight and obesity, low PA was additionally significantly connected with the risk of abdominal obesity, increased glucose concentration, and elevated blood pressure. The results of our study partially confirm the hypothesis that PA can have different results in individuals with excessive BMI versus in those with normal BMI. Preventive measures involving increasing PA, which is aimed at decreasing the risk of metabolic syndrome and its components, may present diverse effects depending on BMI. The results of our study thus suggest that it is necessary to carry out long-term research on the influence of lifestyle on metabolic health, along with stratification according to BMI.

Conflict of interests

None.

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