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**Associations of mutually exclusive categories of physical activity and sedentary time  
with metabolic syndrome in older adults: An isothermal substitution approach**

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## Abstract

The aims of this study were to examine how theoretically reallocating time between mutually exclusive behavioral categories intensity of physical activity (PA) and sedentary time (SB) are associated with metabolic syndrome (MetS). Four hundred and six older adults (61.6% women) from the second wave of the EpiFloripa Ageing Cohort Study were included in the study (mean age  $71.7 \pm 5.9$  years). Isotemporal substitution analysis showed a decrease of 35% (OR: 0.65; 95% CI: 0.45-0.96) in the risk for MetS when replacing 30-min/day of SB with an equivalent amount of moderate-vigorous PA. Furthermore, it has been observed that older adults classified as low SB and physically active were 57% less likely to have MetS than participants classified as high sedentary and physically inactive (OR: 0.43; 95% CI: 0.19-0.97). This study highlights the importance of behavioral categories that may emerge concerning the interrelationships of PA and health in older adults, having important implications for future intervention programs and health interventions.

**Keywords:** behaviors categories, exercise, healthy aging

## Introduction

Metabolic syndrome (MetS) is a clustering of interrelated risk factors for cardiovascular disease and diabetes which includes dysglycemia, raised blood pressure, elevated triglyceride levels, low high-density lipoprotein cholesterol levels, and abdominal obesity (Alberti et al., 2009). It is especially prevalent in older adults, being associated with multiple negative health-related outcomes (Buyo et al., 2020; Gustavo de Sousa Barbalho et al., 2020; Merchant et al., 2020), and survival, because MetS could decrease the five-year survival rate of this population (Bijani et al., 2020). For this reason, preventing MetS is an important factor to avoid possible negative health adverse and promoting ageing with a higher quality of life.

Increasing physical activity (PA) and reducing sedentary behavior (SB) are common strategies that have been implemented to prevent MetS because they have been associated with this syndrome (de Rezende et al., 2014). PA is any movement caused by skeletal muscle contraction that increases energy expenditure, while SB refers to any activities that elicit minimal energy expenditure ( $\leq 1.5$  metabolic equivalents), while in a sitting, reclining, or lying posture (Tremblay et al., 2017). Evidence suggests that physical inactivity in older people (do not meet present PA recommendations) have a higher risk of MetS (Zisko et al., 2017). Likewise, it has been observed that SB is strongly associated with higher odds of MetS (Mankowski et al., 2015). Nevertheless, it is important to stress that most of the studies based their analyses on the independent effects of these behaviors on MetS, because they analyze the associations of meeting or not meeting PA recommendations, the time spent in PA intensities, or the time spent in SB with MetS separately (Bankoski et al., 2011; Zisko et al., 2017). However, today we know that PA and SB are mutually dependent upon one another. This is because during the waking time, when older adults are not in SB, they are usually performing some form of PA (Ekelund

et al., 2016; Manta et al., 2019). For this reason, it would be interesting to know the effect of PA and SB on MetS from another perspective, that is, to study the effect on MetS of the distinct categories that arise from the combined PA and SB.

Recently, novel statistical approaches in epidemiology as isotemporal substitution analyses offer the possibility to investigate theoretically how a change in one behavior affects on MetS, because they allow addressing the potential relationship of replacing time spent in one activity type to time in another activity (Mekary et al., 2009). Some studies performed with these analyses showed that replacing SB or inactive time with either time in light physical activity (LPA) or moderate to vigorous physical activity (MVPA) could have beneficial effects on cardio-metabolic markers (Cabanas-Sánchez et al., 2019; Galmes-Panades et al., 2019; Nilsson et al., 2018). Besides, it has been suggested that groups based on PA and SB can be related to MetS in older adults (Manta et al., 2019; Xu et al., 2019). It could contribute to understanding which older adults need special attention to prevent this syndrome (Manta et al., 2019).

To our knowledge, the effect of replacing SB with other types of PA on MetS has not been investigated specifically in older adults ( $\geq 60$  years). In addition, no study has evaluated the combined categories of objectively measured PA and SB based on Bakrania and colleagues (high SB and physically inactive, low SB and physically inactive, high SB and physically active, and low SB and physically active) (Bakrania et al., 2016), which are much more realistic categories of behavior. The approach to categorizing the population into one of four mutually exclusive categories would be more representative for a large proportion of the population. This allows to better identify and categorize the different types of behaviors that arise from the possible combinations in relation to the physical activity performed and the time spent in sedentary behavior of each individual. Therefore, the aims of this study were: (i) to examine how theoretically reallocating time between

time spent in SB and PA intensities (LPA and MVPA) are associated with MetS; and (ii) to examine how theoretically reallocating time between these intensity categories is associated with this outcome based on the combined categories of objectively measured PA and SB.

## Methods

### Study and participants

This was a cross-sectional sub-study that used data from the second wave of the Health Conditions of Older Adults in Florianópolis (EpiFloripa Ageing Cohort Study) with interviews conducted in 2013/2014 and clinical, imaging exams and monitoring tests conducted in 2014/2015 (Schneider et al., 2017). The study included older adults aged 60 years and older of both genders living in the urban area of Florianópolis, south Brazil. The sub-sample consisted of 604 older adults, who participated in the clinical exams stage of the study. All procedures were approved by the Ethics Committee on Research Involving Humans of the Federal University of Santa Catarina. The subject's physical, emotional, and psychological capability was taken into consideration for the written informed consent. It was obtained voluntarily from all participants prior to the interview and clinical examinations.

### Metabolic syndrome

MetS was defined as having at least 3 of the following components according to international criteria (Alberti et al., 2009): abdominal obesity for European individuals (waist circumference  $\geq 88$  cm in women and  $\geq 102$  cm in men), hypertriglyceridemia ( $\geq 150$  mg/dL), low HDL-c ( $< 50$  mg/dL in women and  $< 40$  mg/dL in men), high blood pressure (systolic blood pressure (SBP)  $\geq 130$  mmHg or diastolic blood pressure (DBP)  $\geq 85$  mmHg), or high fasting glucose ( $\geq 100$  mg/dL).

Waist circumference (WC) was measured in the narrowest part of the abdomen below the last rib. The midpoint between the lower costal margin and the iliac crest was evaluated during expiration, when the narrowest part could not be found. The measurement was performed twice with a 200-cm inelastic measuring tape with variation of 0.1 cm. If the

difference between the two measurements was  $\geq 1$  cm, another measurement was performed and the average of the two closest measurements was used. Arterial blood pressure was measured in both arms at two points during the interview, with an electronic blood pressure monitor (TechLine<sup>®</sup> Z-40, Taiwan, China). The arm showing the higher mean pressure level was used.

Fasting blood samples were collected and stored in a freezer at -80°C. To determine HDL-c levels was used the AHDL Flex<sup>®</sup> Reagent Cartridge, which uses accelerator selective detergent methodology Triglycerides were measured by an endpoint bichromatic colorimetric enzymatic method using the TGL Flex<sup>®</sup> Reagent Cartridge. Plasma glucose was detected by an adaptation of the hexokinase/glucose-6-phosphate dehydrogenase method using the GLUC Flex<sup>®</sup> Reagent Cartridge. The HDL-c and glucose were determined in fresh blood samples.

#### Accelerometer variables

The PA and SB levels were evaluated using GT3X and GT3X+ accelerometers (Actigraph LLC, Pensacola, FL, USA) and the data were analyzed with the Actilife software (Actigraph v.6.11.7). The device was used for seven consecutive days. The use of the accelerometer was monitored, and quality control was carried out on the second and fifth days through telephone contact. The accelerometer was attached on the right side of the hip with an elastic belt and the participants were instructed to remove it for sleeping, showering, or performing activities involving water (e.g., water gymnastics, fishing, and swimming). The exclusion criterion for using the device was to have low mobility. Thus, were considered ineligible wheelchairs users, bedridden and those with walking difficulties.



The data were considered valid when the participant had accumulated a minimum number of records over 4 days of use during the week (10 h/day) including one weekend day (8 h/day). Consecutive values of zero (with a tolerance of two minutes) over 60 minutes or more were interpreted as a period of non-use and were excluded from the analysis. The calculation of mean SB and mean PA levels considered these cutoff points (Freedson et al., 1998). Values from 0 to 99 counts/min were classified as SB, 100 to 1,951 counts/min as LPA,  $\geq 1,952$  counts/min as MVPA and values  $> 5,725$  counts/min as vigorous physical activity (VPA).

Four behavioral categories were defined according to Bakrania and colleagues (Bakrania et al., 2016) (high SB and physically inactive, low SB and physically inactive, high SB and physically active, and low SB and physically active). Low SB: quartile 1 of the ratio between the average SB and the average LPA. High SB: quartiles 2, 3 or 4 of the ratio between the average SB and the average LPA. Physically inactive:  $<150$  min of moderate-to-vigorous physical activity per week. Physically active:  $\geq 150$  min of MVPA per week.

#### Covariates

The following covariates were used: sex, age, education level, smoking habits, alcohol use and medical conditions. Education level was categorized as without formal education, 1-4, 5-11, and  $\geq 12$  years of schooling; smoking habit was categorized as never, former, and current smoker; alcohol use was categorized according to the number of doses consumed: non-consumer, non-abusive consumer, and abusive consumer. The presence of comorbidities was self-reported and included: spinal or back disease, arthritis or rheumatism, bronchitis or asthma, tuberculosis, cirrhosis, osteoporosis, chronic renal insufficiency, cancer, diabetes, hypertension, heart or cardiovascular disease, and stroke.

#### Statistical analyses

Descriptive statistics were summarized as mean  $\pm$  standard deviation and percentage. Time spent in SB, LPA and MVPA was standardized by dividing the measured time spent in each of these intensity categories by 30 min·d<sup>-1</sup>. Three different logistic regression models were used for the associations between these categories (according to 30-min/day periods of sedentary time and physical activity intensity levels) and MetS and their components: (i) single model, (ii) a partition model, and (iii) an isothermal substitution model. The single factor model assessed separately the associations between each intensity categories and MetS and their components without considering the other intensity categories. It is expressed as follows:

$$\text{MetS change} = (b_0) \text{ sedentary behavior} + (b_1) \text{ covariates}$$

The partition model simultaneously evaluated the associations between all intensity categories and MetS and their components considering the total waking time. It is expressed as follows:

$$\begin{aligned} \text{MetS change} = & (b_0) \text{ sedentary behavior} + (b_2) \text{ light physical activity} \\ & + (b_3) \text{ moderate to vigorous physical activity} \\ & + (b_1) \text{ covariates} \end{aligned}$$

The isothermal substitution model estimated the substitutional associations between replacing one intensity category with an equal amount of another (e.g., replacement of 30-min/day of SB with 30-min/day of MVPA) and MetS. This estimation can be accomplished by omitting the target intensity category from the model and entering the total waking time and the covariates (Kosaki et al., 2020). It is expressed as follows:

$$\begin{aligned} \text{MetS change} = & (b_2) \text{ light physical activity} \\ & + (b_3) \text{ moderate to vigorous physical activity} \\ & + (b_1) \text{ covariates} \end{aligned}$$

We also repeated the isotemporal substitution model to analyze the estimated effects of substituting SB or LPA with an equal amount of time spent in LPA or MVPA by previously established group-based behavioral categories (high SB and physically inactive, low SB and physically inactive, high SB and physically active, and low SB and physically active). Also, linear regression models were used to assess the estimated effect of replacing 30-min/day of SB with 30-min/day of LPA or MVPA by the same group-based behavioral categories on MetS components. Adjusted models were controlled for sex, age, education level, smoking habits, alcohol use and comorbidities. Statistical associations for the logistics regression models were reported as odds ratio (OR) with 95% confidence intervals (CI). Statistical associations for the linear regression models were reported as standardized regression coefficients ( $\beta$ ) with 95% confidence intervals (CI). Statistical significance was set at  $p < 0.05$ . All analyses were performed using Stata software v.14 (StataCorp, TX, USA).

## Results

Four hundred and six older adults (61.6% women) were included in the study (mean age  $71.7 \pm 5.9$  years). Overall, 58% of the participants had three or more comorbidities and 44% had MetS. The mean accelerometer wearing time per day was 23.2 hours and participants spent on average 43.8% of the wearing time in SB, 21.3% in LPA, and 1.3% in MVPA. Descriptive data regarding physical characteristics, accelerometer-derived physical activity intensities, and cardiometabolic variables are detailed in Table 1.

Table 2 shows the results of the single, partition, and isotemporal substitution models for the effects of SB, LPA, and MVPA (all per 30-min/day) on MetS and their components according to the logistic regression analysis. In the single models, every 30-min/day increment of SB was associated with a significantly increased OR for abdominal obesity and lower HDL-c even after adjustment for covariates. Increased LPA and MVPA were associated with a significantly decreased OR for abdominal obesity and lower HDL-c, and with abdominal obesity, lower HDL-c and lower glucose, respectively after adjustment. The unique PA intensity associated with lower MetS risk was for MVPA, showing that 30-min/day increment of this PA was associated with a 35% decrease in the risk for MetS. For the partition model, no associations were found. In the isotemporal substitution model, which substituted SB or LPA (30-min/day) with an equal amount of LPA or MVPA time, a 41% (OR: 0.59; 95% CI: 0.42-0.84) and 35% (OR: 0.65; 95% CI: 0.45-0.96) decrease in the risk for MetS was noted for the substitution of SB for MVPA and for LPA by MVPA, respectively, in the crude model. In the adjusted model, the significant effect was sustained for the substitution of SB by MVPA (OR: 0.65; 95% CI: 0.45-0.96), but not for LPA. In addition, the substitution of SB with an equal amount of MVPA was associated with a significantly decreased OR for some components of MetS after adjustment.

For the associations of behavioral categories with MetS and their components (Table 3), those who spent lower time in SB and were physically active were associated with a significantly decreased OR for MetS and some of their components. However, after adjustment, only was significant for those who were low sedentary and physically active, and for those who were physically inactive but low sedentary. Participants classified as low sedentary and physically active were 57% less likely to have MetS and abdominal obesity than participants classified as high sedentary and physically inactive (OR: 0.43; 95% CI: 0.19-0.97 and OR: 0.28; 95% CI: 0.12-0.63 for MetS and abdominal risk, respectively).

Finally, when we analyzed the isothermal substitution of 30-min/day of SB with time in LPA or MVPA on standardized MetS components, we observed that replacing 30-min/day of SB with LPA or MVPA was not associated with MetS components. However, when we performed the same analyses by groups-based on behavioral categories, we observed better results in the low sedentary and physically inactive group. The results indicated that replacing 30-min/day of SB with LPA or MVPA was associated with decreased abdominal obesity, diastolic and systolic blood pressure, triglycerides, fasting plasma glucose and increasing HDL-c. However, it was only significant for abdominal obesity ( $\beta = -0.20$ , 95% CI = -0.34, -0.06) when SB was substituted with LPA, and for HDL-c ( $\beta = 0.43$ , 95% CI = 0.03, 0.82) when SB was substituted with MVPA (Figure 1).

## Discussion

Results from this study showed that SB was associated with a higher risk of MetS and its components (abdominal obesity and low HDL-c) in older adults. On contrary, MVPA was associated with lower risk of MetS and their components (abdominal obesity, low HDL-c, and high fasting glucose). In addition, isothermal substitution showed that replacing 30-min/day of SB with an equivalent amount of MVPA decreases the risk for MetS in older adults. Furthermore, it has been observed that older adults classified as low SB and physically active have lower risk of MetS.

Note that isothermal substitution models indicated that the substitution of SB with LPA was not associated with lower risk for MetS or its individual components. Although this PA intensity has been associated with lower risk for MetS in middle age and older adults (Galmes-Panades et al., 2019), evidence for the preventive effects on this syndrome suggests that the associations are not as strong as in MVPA (Jefferis et al., 2016). Likewise, our results showed that replacing 30-min/day of SB with an equal amount of LPA was not associated with MetS and their components. The effects of LPA on MetS and other health outcomes remains inconclusive in this population, and our results theoretically may indicate that an effective reduction of MetS or their components may be more related to reducing SB and increased time in MVPA, but with no beneficial effects of reducing sedentary time in favor of LPA time, as previously observed in other studies (Nilsson et al., 2018). Although LPA might be more feasible, safe, and appropriate for older adults, our results suggest that MVPA may be more beneficial in reducing MetS, which should be taking to account in intervention programs or physical activity recommendations that have this target.

In addition, our results highlight the importance of taking in to account the physical activity behavioral categories. They showed that older adults that were classified as low

SB and physically active have 57% lower risk for MetS. A reduction in the risk for MetS was also observed in the other groups, but this was not significant. These results are in line with previous research, where it has been observed that older adults with high levels of PA have a lower risk of MetS (Manta et al., 2019; Xu et al., 2019). However, previous investigations have typically focused on dimensions of PA behaviors separately (e.g., meet Vs not meet PA recommendations, or high SB vs low SB), without considering that usually these dimensions are inevitably related in the behavior of a person. In accordance with the results from our study, it suggests that performing above-average PA or meeting the PA recommendation might not be enough. Previous studies indicate that just meeting or slightly exceeding PA recommendations did not reduce MetS risk (Xu et al., 2019). In addition, previous researches highlighted the importance of SB independent of PA, because SB may have independent cardio-metabolic risk factors or risk of MetS even in adults who meet PA recommendations (Chase et al., 2014), or in very active older adults (3.9 and 2.6 hours per day in LPA and MVPA, respectively) (Madden et al., 2020). In our study, we observed that older adults classified as physically active but sedentary were not associated with reduced risk of MetS. Therefore, physically active older adults ( $\geq 150$  min MVPA) may not obtain the expected benefits on MetS if they spend much of their waking time in SB. Overall, this indicates the importance of considering that an increased amount of time in one behavior inevitably infers reduced time in another. Likewise, it indicates that the benefits on health of the time in PA are related to the SB and inevitably they are dependent on the time spent on this. Therefore, the intervention programs in PA should carry out an approach strategy in the increase of PA and the reduction of SB together.

For this study, we performed the isothermal substitution with 30 minutes/day of change. Most studies that have performed isothermal substitutions in older adults have also used this amount of time. Those performed previously and related to MetS showed that

reallocating 30 min per day of inactive time or SB with 30 min per day of LPA or MVPA was associated with lower levels of cardiometabolic risk (Galmes-Panades et al., 2019; Nilsson et al., 2018). Probably, the choice of this amount of time is related to an adequate theoretical change, that is, easily achievable by this population. Although our results theoretically indicated that this amount is associated with reduced risk for MetS in older adults, it also suggests that it may not be enough, because when we analyzed by groups, it was observed that this amount of time was not associated with a reduction of most MetS components. It could indicate that to decrease MetS components it might need more than 30 minutes/day as it was observed recently (Galmes-Panades et al., 2019), or that there could be a dependent effect and a strong interrelation between the different categories of behavior and these health outcomes, which should be studied in clinical trials.

This study had several limitations that should be mentioned. First, although the study was performed on a representative sample of older adults living in the city of Florianopolis (Brasil) (Confortin et al., 2017, 2019), it is not representative of the entire population, which makes difficult the generalization of the findings. Second, the behavioral categories were defined according to Bakrania and colleagues (Bakrania et al., 2016), however, other types of behavioral categories could be defined differently. Third, the activity monitor did not include activities involving water-based physical activities (e.g., swimming, or underwater walking). Fourth, the isothermal substitution model is a theoretical and mathematical method for replacing time in one behavior with another, and therefore it is not realistic and could not substitute experimental evidence from intervention studies. Fifth, the accelerometer used in this study quantifies time spent in SB, LPA and MVPA according to specific count thresholds. However, it is limited to distinguish between several stationary behaviors or sedentary body postures, which may influence the interpretation and results of this study. Despite these limitations, the utilization of



isotemporal substitution analysis may be used as a potentially effective physical behavior change guidance for both practitioners and end-users, because these analyses have clinically interpretable results that may help to individualize physical activity or physical behavior programs. Furthermore, to our knowledge, the effect of replacing SB with other type of PA on MetS has not been investigated specifically in older adults ( $\geq 60$  years), and no study has evaluated the combined categories of objectively measured PA and SB on MetS.

In conclusion, the isotemporal substitution showed that replacing 30-min/day of SB with an equivalent amount of MVPA decrease the risk for MetS in older adults. Furthermore, it has been observed that older adults classified as low SB and physically active have lower risk of MetS. These results are in line with studies that indicate the linked between SB, PA and MetS, however, they highlight the importance of the behavioral categories that may emerge concerning the PA interrelationships. Finally, based on this research, we suggest the following practical implications for upcoming interventions and health programs:

- Future intervention programs should consider these mutually exclusive categories of physical activity and sedentary time in older adults.
- Programs based on reducing MetS in older adults should include MVPA rather than LPA.
- Programs based on the reduction of MetS in older adults should include actions to increase PA and reduce SB together.

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Table 1. Descriptive characteristics of the study (EpiFloripa Idoso Study)

	All
n	406
Women, no.(%)	250(61.6)
Age, years	71.7(5.9)
Years of schooling, no.(%)	
Without formal education	21(5.2)
1-4 years	144(35.5)
5-8 years	67(16.5)
9-11 years	61(15.0)
12 or more years	113(27.8)
Smoking, no.(%)	
No	252(62.1)
Smoked and stopped	128(31.5)
Current smoker	26(6.4)
Alcohol use, no.(%)	
Not consumer	217(53.5)
Non-abuse consumer	117(28.8)
Abusive consumer	72(17.7)
Comorbidity, no.(%) <sup>a</sup>	
0	25(6.2)
1-2	147(36.2)
3 or more	234(57.6)
Cardiovascular and metabolic variables, no.(%)	
Abdominal obesity	227(53.4)
High blood pressure	336(82.7)
Hypertriglyceridemia	100(24.6)
Low HDL-c	104(25.6)
High fasting glucose	166(40.9)
Metabolic syndrome	164(44.3)
Accelerometer-derived variables, no.(%)	
High sedentary <sup>b</sup>	304(69.0)
Physically inactive <sup>c</sup>	280(31.0)

Values are number and percentage or mean (standard deviation)

<sup>a</sup>Comorbidities: spinal or back disease, arthritis or rheumatism, bronchitis or asthma, tuberculosis, cirrhosis, osteoporosis, chronic renal insufficiency, cancer, diabetes, hypertension, heart or cardiovascular disease, and stroke.

High sedentary: quartiles 2, 3 or 4 of the ratio between the average sedentary behavior and the average light physical activity.

Physically inactive: <150 min of moderate-to-vigorous physical activity per week



Table 2. Associations of SB, LPA and MVPA with Metabolic Syndrome and Metabolic Syndrome components in older adults (n=406).

	MetS	MetS components				
		Abdominal obesity	High blood pressure	Hypertriglyceridemia	Low HDL-c	High fasting glucose
Single model						
Crude						
SB	<b>1.06*</b> (1.00, 1.12)	<b>1.07*</b> (1.01, 1.13)	0.96 (0.90, 1.04)	1.04 (0.98, 1.12)	<b>1.08**</b> (1.02, 1.15)	1.03 (0.96, 1.09)
LPA	0.96 (0.90, 1.02)	0.95 (0.90, 1.01)	1.04 (0.96, 1.13)	0.96 (0.89, 1.02)	<b>0.93*</b> (0.87, 0.99)	0.98 (0.92, 1.04)
MVPA	<b>0.58**</b> (0.41, 0.81)	<b>0.53***</b> (0.38, 0.73)	1.14 (0.75, 1.74)	0.84 (0.58, 1.22)	<b>0.58**</b> (0.41, 0.83)	<b>0.66*</b> (0.47, 0.93)
Adjusted						
SB	1.05 (0.99, 1.12)	<b>1.07*</b> (1.01, 1.14)	0.97 (0.90, 1.05)	1.04 (0.98, 1.11)	<b>1.08*</b> (1.01, 1.15)	1.03 (0.97, 1.09)
LPA	0.96 (0.90, 1.02)	0.95 (0.89, 1.01)	1.04 (0.96, 1.12)	0.96 (0.89, 1.03)	<b>0.93*</b> (0.88, 0.99)	0.98 (0.92, 1.04)
MVPA	<b>0.65*</b> (0.45, 0.93)	<b>0.58**</b> (0.40, 0.83)	1.13 (0.72, 1.79)	0.90 (0.61, 1.34)	<b>0.63*</b> (0.44, 0.92)	<b>0.68*</b> (0.48, 0.97)
Partition model						
Crude						
SB	1.19 (0.44, 3.27)	1.74 (0.66, 4.62)	1.09 (0.34, 3.49)	0.57 (0.20, 1.61)	1.45 (0.41, 5.49)	0.62 (0.24, 1.60)
LPA	1.16 (0.42, 3.22)	1.69 (0.63, 4.56)	1.14 (0.35, 3.71)	0.54 (0.19, 1.56)	1.45 (0.39, 5.43)	0.61 (0.23, 1.59)
MVPA	0.94 (0.79, 1.12)	0.99 (0.84, 1.16)	0.99 (0.82, 1.21)	0.88 (0.73, 1.05)	0.95 (0.76, 1.18)	0.87 (0.74, 1.04)
Adjusted						
SB	1.12 (0.42, 2.99)	1.51 (0.52, 4.36)	1.33 (0.40, 4.41)	0.53 (0.18, 1.55)	1.42 (0.51, 4.00)	0.62 (0.23, 1.62)
LPA	1.10 (0.41, 2.96)	1.45 (0.49, 4.26)	1.40 (0.41, 4.68)	0.51 (0.17, 1.50)	1.35 (0.47, 3.84)	0.60 (0.23, 1.61)
MVPA	0.93 (0.78, 1.10)	0.98 (0.82, 1.17)	1.03 (0.85, 1.26)	0.88 (0.73, 1.06)	0.98 (0.82, 1.16)	0.88 (0.74, 1.04)
Isotemporal substitution model						
Crude						
SB x LPA	0.98 (0.92, 1.04)	0.97 (0.92, 1.04)	1.04 (0.96, 1.13)	0.96 (0.89, 1.03)	0.95 (0.89, 1.01)	0.99 (0.94, 1.06)
SB x MVPA	<b>0.59**</b> (0.42, 0.84)	<b>0.54***</b> (0.39, 1.04)	1.08 (0.70, 1.67)	0.89 (0.61, 1.30)	<b>0.63*</b> (0.44, 0.90)	<b>0.67*</b> (0.47, 0.94)
LPA x MVPA	<b>0.61**</b> (0.42, 0.88)	<b>0.55**</b> (0.39, 0.80)	1.06 (0.67, 1.68)	0.93 (0.62, 1.39)	<b>0.66*</b> (0.45, 0.97)	<b>0.66*</b> (0.46, 0.96)
Adjusted						
SB x LPA	0.97 (0.91, 1.04)	0.96 (0.90, 1.03)	1.03 (0.95, 1.12)	0.95 (0.88, 1.02)	0.94 (0.88, 1.01)	0.99 (0.93, 1.06)
SB x MVPA	<b>0.65*</b> (0.45, 0.96)	<b>0.57**</b> (0.39, 0.84)	1.03 (0.64, 1.66)	0.89 (0.59, 1.35)	<b>0.68*</b> (0.46, 0.99)	<b>0.68*</b> (0.47, 0.99)
LPA x MVPA	0.68 (0.45, 1.01)	<b>0.60*</b> (0.40, 0.90)	1.02 (0.62, 1.68)	0.94 (0.61, 1.46)	0.72 (0.48, 1.08)	0.69 (0.46, 1.02)

ORs were calculated according to 30-min/day periods of sedentary time and physical activity intensity levels.

Age, gender, education level, smoking, alcohol use and comorbidity were included as covariates in the adjusted models.

Single model, examining the association of each intensity category (SB, LPA, and MVPA) individually with MetS.

Partition model, examining the association of each intensity category adjusted by time engaged in the rest of activity categories, with MetS.

In the isotemporal substitution model, the OR represents the estimated effects of substituting SB or LPA with an equal amount of time spent in LPA or MVPA.

Abbreviations: MetS, metabolic syndrome; SB, sedentary behavior; LPA, light-intensity physical activity; MVPA, moderate-to-vigorous physical activity; HDL-c, High density lipoprotein cholesterol

Table 3. Associations of behavioral categories with Metabolic Syndrome and Metabolic Syndrome components in older adults

	MetS	MetS components				
		Abdominal obesity	High blood pressure	Hypertriglyceridemia	Low HDL-c	High fasting glucose
Crude						
High SB and physically inactive	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Low SB and physically inactive	0.95 (0.55, 1.66)	0.74 (0.43, 1.30)	1.50 (0.69, 3.28)	0.81 (0.42, 1.55)	<b>0.40**</b> (0.22, 0.74)	1.08 (0.62, 1.89)
High SB and physically active	0.72 (0.44, 1.18)	<b>0.60*</b> (0.37, 0.99)	1.02 (0.54, 1.90)	0.84 (0.47, 1.49)	0.67 (0.41, 1.12)	0.62 (0.37, 1.04)
Low SB and physically active	<b>0.41*</b> (0.19, 0.90)	<b>0.29**</b> (0.14, 0.62)	2.61 (0.76, 8.92)	0.66 (0.28, 1.60)	<b>0.45*</b> (0.21, 0.97)	0.83 (0.40, 1.71)
Adjusted						
High SB and physically inactive	Ref.	Ref.	Ref.	Ref.	Ref.	Ref.
Low SB and physically inactive	0.97 (0.55, 1.71)	0.71 (0.39, 1.29)	1.47 (0.66, 3.29)	0.74 (0.38, 1.45)	<b>0.40**</b> (0.21, 0.74)	1.06 (0.60, 1.87)
High SB and physically active	0.87 (0.51, 1.50)	0.65 (0.37, 1.14)	1.03 (0.52, 2.05)	0.83 (0.45, 1.53)	0.79 (0.46, 1.37)	0.68 (0.39, 1.19)
Low SB and physically active	<b>0.43*</b> (0.19, 0.97)	<b>0.28**</b> (0.12, 0.63)	2.10 (0.59, 7.41)	0.57 (0.23, 1.42)	0.45 (0.20, 1.02)	0.81 (0.38, 1.73)

ORs were calculated according to 30-min periods of SB and distinct behavioral categories of physical activity.

Age, gender, education level, smoking, alcohol use and comorbidity were included as covariates in the adjusted models.

Low SB: Quartile 1 of the ratio between the average SB and the average LPA.

High SB: Quartiles 2, 3 or 4 of the ratio between the average SB and the average LPA.

Physically Active:  $\geq 150$  min of MVPA per week.

Physically Inactive:  $< 150$  min of MVPA per week.

High SB and physically inactive (n=214); Low SB and physically inactive (n=66), High SB and physically active (n=90); Low SB and physically active (n=66).

Abbreviations: MetS, metabolic syndrome; SB, sedentary behavior; High density lipoprotein cholesterol

Figure 1 - Isotemporal substitution of 30-min/day of SB and LPA with time in MVPA on standardized MetS components. Values shown are standardized  $\beta$  (95% CI). These represent the change in outcome variables (z-scores) when substituting 30 min per day of SB or LPA with time in MVPA according to different behavioral categories of physical activity. Age, gender, education level, smoking, alcohol use and comorbidity were included as covariates in the regression models.

High SB & PI (n=214), Quartile 1 of the ratio between the average SB and the average LPA and <150 min of MVPA per week; Low SB & PI (n=66), Quartiles 2, 3 or 4 of the ratio between the average SB and the average LPA and <150 min of MVPA per week; High SB & PA (n=90), Quartile 1 of the ratio between the average SB and the average LPA and  $\geq$ 150 min of MVPA per week; Low SB & PA (n=36), Quartiles 2, 3 or 4 of the ratio between the average SB and the average LPA and  $\geq$ 150 min of MVPA per week.

Abbreviations: SB, sedentary behavior; LPA, light physical activity; MVPA, moderate to vigorous physical activity; PI, physically inactive; PA, physically active; WC, waist circumference; DBP, diastolic blood pressure, SBP, systolic blood pressure; TG, triglycerides; HDL-c, high density lipoprotein cholesterol; FPG, fasting plasma glucose.