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Original article

Does light-intensity physical activity moderate the relationship between sitting time and adiposity markers in adolescents?

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Abstract

Background: While the relationship between sedentary time and adiposity markers may be independent of moderate-to-vigorous intensity physical activity (MVPA) among adolescents, little is known about the role of light-intensity physical activity (LIPA) in this relationship. The aim of this cross-sectional study was to examine whether device-measured LIPA and MVPA moderate the associations between objectively measured sitting time and adiposity markers (body mass index (BMI)) and waist circumference (WC)) among adolescents.

Methods: This study included accelerometer and inclinometer data obtained from 219 adolescents (age = 14.9 ± 1.6 years, mean ± SD), collected during 2014 and 2015 in Melbourne, Australia. ActiGraph GT3X accelerometers were used to determine time spent in total-LIPA (101 counts/min to 3.99 metabolic equivalents (METs)) was dichotomized into low-LIPA (101−799 counts/min) and high LIPA (800 counts/min to 3.99 METs), and MVPA (≥ 4 METs). The average time spent sitting was obtained from activPAL inclinometers. Anthropometric measures were assessed by trained staff. Interactions between sitting and total-LIPA, low-LIPA, high-LIPA, and MVPA on BMI *z*-score (*z*BMI) and WC *z*-score (*z*WC), respectively, were examined using linear regression, adjusting for age and sex; and moderation by total-LIPA, low-LIPA, high-LIPA, and MVPA were examined by adding interaction terms. Significant interaction effects were probed by comparing associations at the mean and at 1 SD below and above the mean.

Results: Total-LIPA significantly moderated the association between sitting time and *z*BMI, and low-LIPA significantly moderated the association between sitting time and *z*BMI and *z*WC. No other associations were found for total-LIPA, high-LIPA, or MVPA. Specifically, at high levels of total-LIPA (+1 SD), there is a negative association between sitting time and *z*BMI. In addition, at high levels of low-LIPA (+1 SD), there is a negative association between sitting time and *z*BMI and *z*WC.

Conclusion: Associations between sitting and adiposity depended on time spent in total-LIPA and low-LIPA, but not high-LIPA or MVPA. Results suggest that increasing time spent in LIPA may provide protection from the deleterious effects of sitting on adiposity markers among adolescents. Experimental evidence is needed to support these conclusions.

Keywords: Adolescents; Anthropometric measures; Obesity; Physical activity; Sedentary behavior; Sitting time

1. Introduction

Evidence suggests that excessive time spent in sedentary behaviors, characterized by low energy expenditure (i.e., <1.5 metabolic equivalents (METs)) while in a sitting, reclining, or lying posture during waking hours,[1] are associated with adverse health outcomes among adults.[2] While some evidence indicates that these relationships are contentious, sedentary time is pervasive and persistent, and the impact on health warrants further investigation. Despite adolescents' high proportion of time spent sedentary (>65% of waking hours),[3−5] the evidence on sedentary behaviors and health outcomes among this population group is mixed and, therefore, less conclusive. Cross-sectional and longitudinal studies have reported null associations between adolescents' overall sedentary time and health markers;[6−8]

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however, some studies have found that the total amount of accelerometer-measured sedentary time accumulated in a day is adversely associated with cardiovascular risk factors (i.e., elevated systolic blood pressure, triglycerides, and glucose levels[9]), cardiorespiratory fitness (in girls[10]), and adiposity/obesity markers.[11−14] While some of these relationships attenuated when accounting for moderate-to-vigorous intensity physical activity (MVPA),[7,14−17] this is not always the case.[12,13] Furthermore, the majority of the literature described has been based on accelerometry and may therefore have included standing time and other light-intensity physical activity (LIPA) within the assessment of the sedentary time exposure. Although small associations were found between sedentary time and health outcomes, these findings may have implications on adulthood health. A 2016 meta-analysis of prospective studies using self-reported measures indicated that a high volume of MVPA (i.e., 60−75 min/day) eliminated the mortality risk associated with increased sitting time in adults.[18] Although this finding looks promising, the majority of adolescents and adults do not achieve 60−75 min/day of MVPA.

Among Australian adolescents, 90% do not meet the minimum government recommendation of 60 min/day of MVPA, and sedentary behaviors are highly prevalent.[3,19] This observation has persisted for the past 2 decades.[20] Only 4%−5% of adolescents' waking hours are spent in MVPA,[3] which could potentially explain why not all studies have found that MVPA attenuates relationships between sedentary behaviors and health. A much greater proportion of their day is spent in lower intensity activity,[2] such as LIPA, for approximately 24%−38% of waking hours.[4,21] LIPA is defined as any activities involving energy expenditure between 1.6 and 4.0 METs,[22] such as standing and slow walking.[23,24] Decreasing sedentary/sitting time by increasing LIPA may provide a feasible "gateway" to enhancing overall daily physical activity participation.

Evidence of the health impact of objectively measured LIPA in children and adolescents is limited and inconclusive. Some studies suggest that LIPA may be beneficial,[21,25,26] while others have reported no association with adiposity and cardiometabolic risk markers.[17,27,28] Most of these studies consider LIPA (note: for the purpose of this study, it is labelled as total-LIPA) as 1 broad category of intensity (i.e., activities ranging from standing to slow walking (~1.6−4.0 METs)); however, there is evidence that there may be differing health benefits from participating in activities at the low (e.g., standing still) and high (e.g., light walking) ends of the LIPA spectrum.[7] Among adolescents, both low-LIPA and high-LIPA were associated with lower diastolic blood pressure, and high-LIPA was also associated with higher high-density lipoprotein cholesterol levels.[21] These studies suggest that, like MVPA, total-LIPA could also attenuate the adverse impact of sitting on health.

To date, most studies that explored the associations between the various intensities of physical activity, sedentary time, and health in children and adolescents have employed hip-mounted accelerometers.[16,29] A major disadvantage of accelerometers is their inability to differentiate between sitting and standing, which results in inaccurately capturing standing still as being in the sedentary range and overestimates sedentary time.[30,31] To our knowledge, no studies have used objective measures of sitting and standing (i.e., inclinometers) in combination with accelerometers to determine the potential role of total-LIPA in the relationship between sitting and health among adolescents. The aim of this study was to examine the associations between objectively measured sitting time and adiposity markers and the moderating effect of total-LIPA (low-LIPA and high-LIPA) and MVPA on this relationship.

2. Methods

For this study, cross-sectional data were extracted from the Neighbourhood Activity in Youth Project: The NEArbY Study. The Deakin University Human Ethics Advisory Group (HEAG-H 152_2013), the Department of Education and Training (2013_002182), and the Catholic Education Office (Project ID#1950) approved the study.

2.1. Recruitment

Participant recruitment has been published elsewhere.[32] In brief, secondary schools in Melbourne were recruited ($n = 18$ out of 137 approached; 14% response rate) and chose which year levels would be invited to participate in the study. A 15-min presentation was delivered to eligible students, and packs containing information about the study, consent forms for adolescents and their parents, and a parent survey (with its own consent form) were distributed. In total, parental consent and adolescents' assent were received for 528 participants.

Using iPads, adolescents completed an online survey at school and wore an ActiGraph accelerometer for 7 days. Optional assessments, including wearing an activPAL inclinometer for 1 week ($n = 357$) and having their stature, body mass, and waist circumference (WC) measured ($n = 473$), depended on additional parental permission on the consent form. Data collection occurred between 2014 and 2015.

2.2. Measures

2.2.1. Demographics

Adolescents self-reported their age and sex.

2.2.2. Sitting and physical activity

Participants wore an ActiGraph GT3X accelerometer (ActiGraph LLC, Pensacola, FL, USA) on a belt on their right hip and concurrently wore an activPAL3 inclinometer (PAL Technologies Ltd, Glasgow, UK) on the front of their right thigh (at the mid-point), attached via an elastic garter. Participants were instructed to wear both monitors during all waking hours except during water-based activities. All device-derived data were extracted using manufacturer software (ActivPAL Professional v7.2.29 (ActiGraph LLC) and ActiLife Version 6.11.8 (PAL Technologies Ltd.)) and processed using a customized Microsoft Excel macro in 15-s periods. Consecutive 0 counts for 60 min was used as non-wear time for both devices.[33] Monitor data were included in the analysis if participants had worn each monitor for ≥4 valid days. A valid day was defined as ≥8 h/day of wear time for weekdays and ≥7 h/day for weekend days. The average wear time for activPAL was 805 ± 50 min (mean ± SD) and for the ActiGraph was 776 ± 48.6 min during waking hours.

Average minutes per day spent in sitting were computed from the activPAL data. Average minutes per day from the ActiGraph data were computed as follows: total-LIPA (101 counts/min to 3.99 METs), which was dichotomized into the low-LIPA (101−799 counts/min) and high-LIPA (800 counts/min to 3.99 METs) groups. The high-LIPA cut-point of >800 counts/min was based on previous research as it captures static LIPA such as standing.[21,31] The count per minute thresholds for MVPA were calculated at ≥4 METs for those <18 years old, based on age-specific thresholds (i.e., a threshold of ≥4 METs for a 14-year-old is ≥1706 counts/min).[34] For 4 participants aged ≥18 years, the Freedson adult cut-point was used to determine MVPA (i.e., ≥4 METs is ≥2274 counts/min).[35]

2.2.3. Anthropometrics measures

Body mass was measured using a portable electronic scale (Tanita BC-351; Tanita, Tokyo, Japan), and stature was measured using a stadiometer (Seca 217; Seca GmbH, Hamburg, Germany) to the nearest 0.1 kg and 0.1 cm, respectively. Two measurements (averaged) were taken for stature and body mass. A third measure was taken, and averaged, when a difference of more than 0.5 cm or 0.5 kg was noted. All measurements were made with the participants wearing their school uniform, without shoes, and in privacy (e.g., in a spare classroom).

WC was measured using a flexible measuring tape. To allow the research staff to identify the umbilicus point in the mid-axillary plane, adolescents were asked to remove any bulky clothes. The average of the 3 measurements was used in analyses when there was a discrepancy greater than 1 cm in the first 2 measurements.

Body mass index *z*-score (*z*BMI) and WC *z*-score (*z*WC) were calculated from raw anthropometric data using Stata (StataCorp LP, College Station, TX, USA) functions with the US Centers for Disease Control and Prevention and UK growth charts, respectively.[36] BMI (kg/m^2) was calculated from body mass and stature and categorized according to the International Obesity Task Force definitions of healthy weight or overweight/obese.[37]

2.3. Data analysis

Statistical analyses were conducted using Stata 15.0 (StataCorp, College Station, TX, USA). Statistical significance was set at $p < 0.05$. Prior to analyses, all activPAL- and ActiGraph-derived outcome variables were standardized according to total wear time as follows: (duration of X within waking hours divided by wear time within waking hours) multiplied by 960 min, where X is the activity (i.e., sitting, total-LIPA, low-LIPA, high-LIPA, or MVPA) and waking hours are equivalent to 960 min (16 h). Multicollinearity was tested using Pearson's correlations prior to the analyses, confirming the absence of collinearity between the variables studied (i.e., the correlation between sitting (from activPAL) and each physical variable (from ActiGraph) varied between −0.16 and 0.38).

The main effect of sitting and physical activity (total-LIPA, low-LIPA, high-LIPA, and MVPA) on adiposity markers (*z*BMI and *z*WC) was examined using simple separated regression models. Moderation by total-LIPA, low-LIPA, high-LIPA, and MVPA were examined by adding interaction terms to the respective simple regression models. Significant interaction effects were probed by computing associations (i.e., *z*BMI and *z*WC differences with sitting time) at different point-estimates of each moderator at the mean, and at 1 SD below and above mean (using lincom postestimation command).The continuous moderator variables were centered around the mean.[38] All the models were adjusted for age and sex and accounted for potential clustering effects at the school level using the vce (cluster) function. Additionally, every regression model was adjusted for the specific activity covariate.

3. Results

3.1. Descriptive characteristics

Complete data (valid activPAL, ActiGraph, and anthropometric data) were obtained from 219 participants. Participants (age = 14.9 ± 1.6 years, 60% girls), spent an average of 67.6% (10.8 h) of their time sitting or lying, with 27.0% (4.3 h) in total-LIPA, 17.2% (2.8 h) in low-LIPA, 9.7% (1.6 h) in high-LIPA, and 5.3% (0.8 h) in MVPA during waking hours (Table 1).

3.2. Associations between sitting time and adiposity markers

As shown in Table 2, there were no associations between sitting time and *z*BMI or *z*WC. These associations remained nonsignificant after adjusting for specific physical activity variables.

3.3. Moderation analysis

It was found that total-LIPA moderated the association between sitting time and *z*BMI ($p = 0.002$). Additionally, low-LIPA moderated the association between sitting time and *z*BMI ($p = 0.005$) and *z*WC ($p = 0.038$). When the models were

Table 1
Participants' demographics, anthropometrics, sitting, and activity characteristics (mean ± SD or %).

	Overall
Age (year)	14.9 ± 1.6
Female (%)	58.6
BMI (kg/m^2)	22.2 ± 3.8
*z*BMI	0.59
BMI categories (%)	
Normal weight	72.1
Overweight/obese	27.8
WC (cm)	76.9 ± 9.9
*z*WC	1.4 ± 1.1
Sitting (min/day)[a]	649.3 ± 92.6
Total-LIPA (min/day)[b]	259.9 ± 55.2
Low-LIPA (min/day)[b]	165.9 ± 36.8
High-LIPA (min/day)[b]	93.9 ± 24.6
MVPA (min/day)[b]	50.9 ± 25.8

[a] Data derived from activPAL inclinometers.
[b] Data derived from ActiGraph accelerometers.
Abbreviations: high-LIPA= high light-intensity physical activity (800 counts/min to 3.99 metabolic equivalents (METs)); low-LIPA = low light-intensity physical activity (101−799 counts/min); MVPA = moderate-to-vigorous physical activity (i.e., 4 METs for a 14-year-old is ≥ 1706 counts/min); total-LIPA= total light-intensity physical activity; *z*BMI = body mass index z-score; *z*WC = waist circumference z-score.

Table 2
Associations between sitting time and *z*BMI and *z*WC, and adjustment for physical activity variables.

Dependent variable	*B* (95%CI)	*p*
*z*BMI		
Sitting time	−0.001 (−0.003 to 0.001)	0.312
Total-LIPA[a]	−0.000 (−0.003 to 0.001)	0.447
Low-LIPA[a]	−0.001 (−0.003 to 0.000)	0.198
High-LIPA[a]	−0.000 (−0.003 to 0.002)	0.845
MVPA[a]	−0.001 (−0.004 to 0.001)	0.188
*z*WC		
Sitting time	−0.000 (−0.002 to 0.001)	0.513
Total-LIPA[a]	−0.000 (−0.003 to 0.002)	0.513
Low-LIPA[a]	−0.001 (−0.003 to 0.001)	0.296
High-LIPA[a]	−0.000 (−0.002 to 0.002)	0.850
MVPA[a]	−0.000 (−0.002 to 0.001)	0.410

Note: All the models were adjusted for age and sex and accounted for clustering by school.
[a] These models were additionally adjusted for specific physical activity variable (e.g., total-LIPA[a] indicates that this model was adjusted for LIPA; MVPA[a] indicates that this model was adjusted for MVPA).
Abbreviations: 95%CI = 95% confidence interval; high-LIPA= high light-intensity physical activity (800 counts/min to 3.99 metabolic equivalents (METs)); low-LIPA = low light-intensity physical activity (101−799 counts/min); MVPA = moderate-to-vigorous physical activity (i.e., 4 METs for a 14-year-old is ≥ 1706 counts/min); total-LIPA= total light-intensity physical activity; *z*BMI = body mass index *z*-score; *z*WC = waist circumference *z*-score.

adjusted for MVPA, these associations remained very similar (data not shown). There were no moderating effects for any other intensity of physical activity: for *z*BMI: high-LIPA ($p = 0.099$) and MVPA ($p = 0.118$); and for *z*WC: total-LIPA ($p = 0.260$), high-LIPA ($p = 0.815$), and MVPA ($p = 0.075$).

Follow-up analyses depicted in Figs. 1, 2, and 3 show that at high levels of total-LIPA (+1 SD) there is a negative association between sitting time and *z*BMI (Fig. 1). In addition, at high levels of low-LIPA (+1 SD), there is a negative association between sitting time and *z*BMI (Fig. 2) and *z*WC (Fig. 3) for the models with and without adjustment for MVPA.

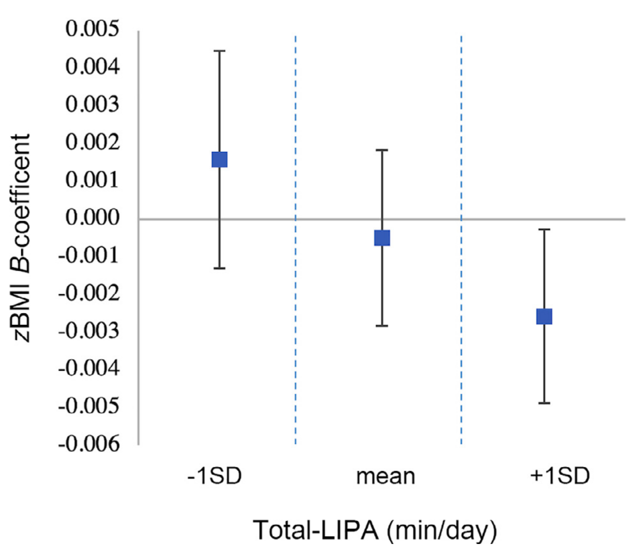

Fig. 1. Associations between *z*BMI and sitting time at different levels of total-LIPA. Model adjusted for sex and age, and accounted for clustering by school. LIPA = light-intensity physical activity; *z*BMI = body mass index *z*-score.

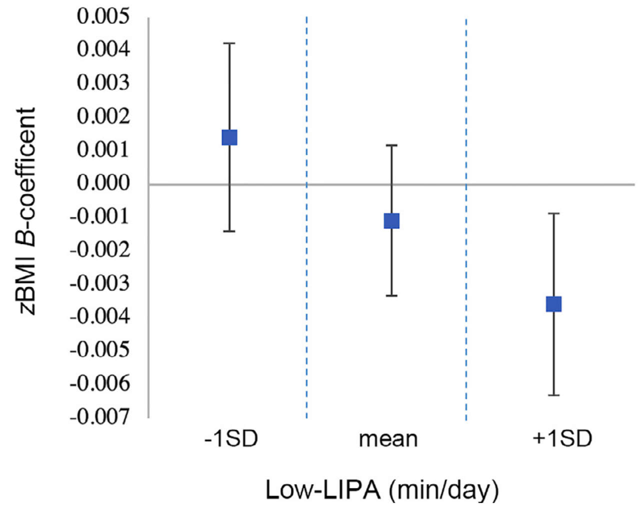

Fig. 2. Associations between *z*BMI and sitting time at different levels of low-LIPA. Model adjusted for sex and age, and accounted for clustering by school. low-LIPA = low-light-intensity physical activity; *z*BMI = body mass index *z*-score.

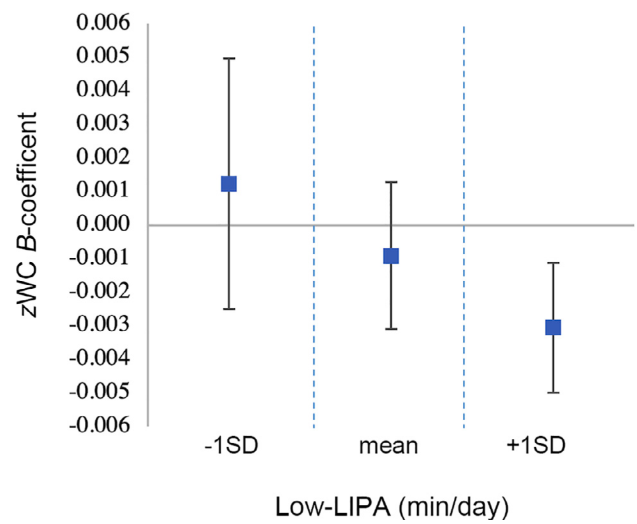

Fig. 3. Associations between *z*WC and sitting time at different levels of low-LIPA. Model adjusted for sex and age, and accounted for clustering by school. low-LIPA = low-light-intensity physical activity; *z*WC = waist circumference *z*-score.

4. Discussion

The aim of this study was to examine associations between objectively measured sitting time and adiposity markers (BMI and WC) and to determine the moderating effect of total-LIPA, low-LIPA and high-LIPA, and MVPA in these associations. Few previous studies have examined associations between objectively assessed sitting time in youth and adiposity markers. Additionally, this study was novel in that it examined the potential moderation effect of different intensities of physical activity (total-LIPA (low-LIPA and high-LIPA) and MVPA) on the association between sitting time and adiposity markers (BMI and WC). Total-LIPA moderated the association between sitting time and *z*BMI, and low-LIPA levels moderated the relationship between time spent sitting and zBMI and zWC. Those who sat proportionally more time during waking hours tended to have lower zBMI and zWC if they spent a high amount of time in total-LIPA and low-LIPA; however, the magnitudes were small.

MVPA did not moderate the association between sitting and adiposity markers. These findings are consistent with some evidence that indicates that the health impact of sitting is independent of MVPA.[12,13] This finding could be explained by the small amount of time that participants spent during daily waking hours in MVPA (in this sample, just 5%).

The overall amount of sitting time for the sample was high (67%, 10.8 h/day). Studies that have objectively measured sitting time also report similar sitting proportions accumulated across the day (52%−80%).[5,39–41] To be able to observe differences in adiposity or other health markers, the full physical activity spectrum (e.g., sitting, LIPA, and MVPA) should be used to classify individuals.[17] For example, a previous study found that higher skin fold thickness was found in a low-activity group (i.e., low standing time, LIPA, MVPA, and high sitting time) compared to the high-activity group (high standing time, LIPA, MVPA, and low sitting time),[41] suggesting that an integrative model could better reflect adolescents' health profiles.

Previous studies have reported negative associations between low-LIPA and high-LIPA and metabolic risk markers among adults[42] and adolescents.[21,43] In contrast to MVPA (5% of waking hours), adolescents spend a much higher amount of daily time in total-LIPA (approximately 27% of waking hours). Because LIPA consists of incidental activities such as slow walking and standing, there may be alternate practical opportunities to increase LIPA during waking hours for adolescents other than simply increasing MVPA. For example, research has shown that height-adjustable desks or active pedagogy in the school classroom can reduce and break up sitting and increase students' energy expenditure[44] and physical activity.[45,46] Increasing adolescents' MVPA to meet physical activity guidelines clearly should be the ultimate goal, but shifting young people along the activity spectrum from sitting to LIPA may be a practical way to help them achieve that goal.

The use of an objective measure of physical activity (accelerometers) in combination with the objective measure of sitting (activPAL inclinometers) is a key strength of this study. This approach helps to overcome the limitation of hip-worn accelerometers in differentiating between sitting and standing. Another strength is the analysis of LIPA according to 2 intensities (i.e., low-LIPA and high-LIPA), thereby distinguishing between static and dynamic intensities, which may have different health impacts.[7] Although these intensities were extracted via count-points from accelerometers (which could be a limitation), due the correlated nature of the standing variables (i.e., low-LIPA) and stepping variables (i.e., high-LIPA) these factors were unable to be included as moderators. The age group considered for this study is also a strength, because among adolescents very little is known about the relationship between sitting and health. However, it is not possible to generalize the results to other age groups.

The limitations of this study include the cross-sectional study design, which limits causality associations; the small sample size, which reduces the statistical power; and the lack of more objective measures of adiposity (e.g., dual-energy X-ray absorptiometry). In addition, these analyses did not account for dietary intake. Accounting for dietary intake as a covariate in the statistical models may have provided a more complete overview of energy balance and adiposity in this population.

Future research should be directed at testing associations between objectively measured sitting and health markers (including moderation by physical activity) using longitudinal and experimental study designs and larger sample sizes. In addition, more sophisticated analysis (e.g., compositional analysis) may be considered due to the complex relationship between the dependent and independent variables. It is necessary to determine if replacing sitting with LIPA may provide some protection from the deleterious effects of sitting on health among adolescents. This information could be useful in supporting the addition of LIPA-related recommendation sin current physical activity guidelines.

5. Conclusion

Time spent during waking hours in total-LIPA and low-LIPA, but not high-LIPA or MVPA, moderated the relationship between sitting and adiposity markers of BMI and WC. Findings suggest that increasing time spent in light-intensity activities may provide protection from the deleterious effects of sitting on adiposity markers among adolescents. While it is well-accepted that MVPA benefits adolescent health,[47] future longitudinal or experimental research should determine whether decreasing the time spent sitting in favor of increasing LIPA such as standing and light ambulation, may also have favorable effects on adiposity markers among adolescents.

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Authors' contributions

AMCA analyzed the data, interpreted the findings, and wrote the original manuscript; AT assisted in interpreting the results. All authors conceived and designed the study, were involved in writing the paper. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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