Obesity Prevention

Reallocating sedentary time to moderate-to-vigorous physical activity but not to light-intensity physical activity is effective to reduce adiposity among youths: a systematic review and meta-analysis


Introduction

Available evidence suggests that sedentary behaviour is associated with negative health outcomes and is defined as any sitting or lying time (≤1.5 metabolic equivalents during waking hours) (1), independent (2) or not of moderate-to-vigorous intensity physical activity (MVPA) (3). Because time is finite, and assuming sleep is constant, participating in one activity such as screen-based activities results in not participating in another (e.g. physical activity); therefore, a certain activity partaken at a certain time will have heterogeneous effects on an outcome depending on the other activities being displaced (4).
The isotemporal substitution paradigm has been developed as a statistical technique to model the impact of reallocating time spent in one activity with time spent in another activity in an equal time-exchange manner. Since the seminal study by Mekary et al. (4) in 2009, the number of publications in adults analysing the isotemporal association between physical activity of different intensities and different health outcomes has rapidly grown. Evidence has shown that replacing sedentary time with equivalent amounts of light-intensity physical activity (LIPA) or MVPA yielded associated health benefits on body composition (4), cardiometabolic parameters (5) or mortality (6) among adults. This information is relevant for physical activity promotion strategies providing a concrete example on the magnitude of theoretical improvement in an outcome for a given amount of physical activity at a specific intensity. For children and adolescents, few studies have applied isotemporal substitution analysis to examine the effects of time reallocation mainly analysing fatness parameters (7–11). Due to limited number of studies in this regard and contradictory results, it appears appropriate to take a first approach using the meta-analysis methodology in order to summarize the results found so far. Therefore, the aim of this study was to synthesize the evidence on adiposity of activity intensities (i.e. LIPA and MVPA) in children and adolescents by conducting a systematic review and meta-analysis of available evidence.

Methods

The study was undertaken in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement (12). The protocol was registered with the National Institute for Health Research International prospective register of systematic reviews (PROSPERO) under the registration number CRD42016037585.

Data sources

A search of the literature was performed using the electronic databases Cochrane Central Register of Controlled Trials (CENTRAL), EMBASE and MEDLINE. The last search was performed on 11 November 2016. No limit on the date of publication was imposed. The complete search strategy is shown in appendix 1. Also, the reference lists of included articles were examined to detect studies potentially eligible for inclusion. Non-English studies were not explored.

Eligibility criteria

Studies were included in the review if they met the following inclusion criteria: (i) included human participants aged <18 years; (ii) reported on the effects of replacing sedentary behaviour with LIPA and/or MVPA on at least one anthropometric or body composition parameter of interest; (iii) written in English; and (iv) were primary research articles.

Two independent reviewers carried out the screening and review (AG-H and RR-V), with a third reviewer (BP-C) sought in case of disagreement. Articles were first screened and selected for eligibility based on title and abstract. The full text was then reviewed, and after confirming eligibility to be included, data were extracted.

Data collection

Data were extracted from all articles that met selection criteria and deemed to be appropriated for detailed review by two authors, and differences were discussed. Information extracted was as follow: characteristics of the sample, objective measurement of activity technique, length of sedentary bout being replaced, outcomes of interest, analytical approach and main results from each of the studies. Also, data of interest to meta-analyse the results from the different studies (i.e. regression coefficient and 95% CI representing the effect of replacing sedentary behaviour with more active behaviour on the outcome of interest) were extracted.

Risk of bias

An assessment of the quality of the included studies was made using an adjusted format of the Newcastle–Ottawa quality assessment scale (13). This scale contains eight items categorized into three domains (selection, comparability and exposure). A star system is used to enable semi-quantitative assessment of study quality, such that the highest-quality studies are awarded a maximum of 1 star per item with the exception of the comparability domain, which allows allocating 2 stars. Thus, the maximum score for prospective and cross-sectional studies was 9 and 7, respectively. A score of 6 or more was deemed to be high quality (14).

Data synthesis and analytical approach

The a priori plan was to conduct a one-step individual participant data meta-analysis. All analyses were carried out using Comprehensive Meta-analysis Software (Biostat, Englewood, NJ, USA). To estimate effect sizes, we used each study’s standardized regression coefficient (β) and 95% CIs or standard errors (15,16). The random-effects model (DerSimonian–Laird approach) was used in all cases to summarize the pooled β. The likelihood approach with random effects was used to better account for the imprecision in the estimate of between-study variance (17).
The percentage of total variations across the studies due to heterogeneity (Cochran’s Q-statistic) was estimated using \( I^2 \). Values \( I^2 \) of <25%, 25–50% and >50% were considered as small, medium and large amounts of heterogeneity, respectively (18). Egger regression tests were performed to detect small study effects and possible publication bias (19). A sensitivity analysis was conducted to assess the robustness of the summary estimates in order to determine whether or not a particular study accounted for the heterogeneity. A series of analysis were therefore conducted by sequentially omitting one study at each turn. Finally, a stratified exploratory analysis was performed using the same procedures as the main analysis comparing the time blocks exchanged (15, 30 or 60 min).

**Results**

**Study selection**

The search strategy identified 252 articles (Fig. 1), and eight full articles were retrieved. Of these, three were rejected (not included isotemporal substitution model). Finally, only five studies were included in the systematic review and meta-analysis.

**Study characteristics**

The five studies included 7,351 youths. Sample sizes ranged from 353 to 5,607 participants (3,611 girls – 51.45%). The studies analysed preschoolers and children (11), only children (6–12 years) (8,10) or children and adolescents (6–18 years) combined (7,9).

All studies included in the current meta-analysis were cross-sectional (7,9,10) and/or prospective (8,10) observational in nature. Table 1 summarizes the characteristics of the studies. All included studies used accelerometers to assess sedentary behaviour and physical activity, except one which assessed sedentary behaviour (screen-based behaviour such as screen time, academic-related activities and other sedentary behaviours) with questionnaire (8). Sample size and sampling strategy varied from small convenience samples (7,8,10,11) to large representative samples (9). Isotemporal substitution paradigm was reported for BMI (\( n = 4 \)), central obesity (\( n = 3 \)) and body fat percentage (\( n = 3 \)), with time blocks exchanged ranging from 15 to 60 min.

**Risk of bias**

All of the three cross-sectional studies, and all of the prospective studies were deemed to be of high quality, with a Newcastle Ottawa Score \( \geq 6 \) (Supplementary table 1).
<table>
<thead>
<tr>
<th>Author (Study)</th>
<th>Design</th>
<th>Population</th>
<th>Sample size</th>
<th>Accelerometer (epoch)</th>
<th>SB (counts/min)</th>
<th>LIPA (counts/min)</th>
<th>MVPA (counts/min)</th>
<th>Length of bout being replaced (min)</th>
<th>Outcomes of interest</th>
<th>Confounders and covariates included in analysis</th>
<th>Main results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aggio et al. 2015</td>
<td>Cross-sectional</td>
<td>Children and adolescents</td>
<td>353</td>
<td>Actigraph wGT3X BT</td>
<td>&lt;100</td>
<td>—</td>
<td>≥3,000 counts min</td>
<td>60</td>
<td>Body composition: Total body fat, physical fitness: handgrip strength, horizontal jump, peak expiratory flow and flexibility</td>
<td>Age, sex, ethnicity, height and school deprivation</td>
<td>- Replacing 60 min of sedentary time with MVPA was favourably associated with body fat and horizontal jump distance</td>
</tr>
<tr>
<td>Collings et al. 2017</td>
<td>Cross-sectional</td>
<td>Preschoolers and children</td>
<td>333</td>
<td>Actigraph wGT3X BT (15 s)</td>
<td>&lt;8.20</td>
<td>820 to 3,907 counts min</td>
<td>≥3,908 counts min</td>
<td>20</td>
<td>Body composition: Body mass index, waist circumference and sum of skinfolds</td>
<td>Age, gender, ethnicity, index of multiple deprivation, monitor wear time and season of assessment</td>
<td>- Replacing 20 min of sedentary time with MVPA was favourably associated with sum of skinfolds</td>
</tr>
<tr>
<td>Huang et al. 2016</td>
<td>Cross-sectional and prospective</td>
<td>Children</td>
<td>672</td>
<td>ActiGraph</td>
<td>≥100</td>
<td>≥3,200 counts min</td>
<td>30</td>
<td>Body composition: Body mass index</td>
<td>Age, sex and snacking habit of the child, parental education, parental BMI and marital status</td>
<td>- Substitution of screen time or academic-related activities with other sedentary behaviours or MVPA was associated with lower BMI</td>
<td>- Replacing 60 min/day of sedentary behaviour with MVPA was associated with a reduced android, gynoid and total body</td>
</tr>
<tr>
<td>Loprinzi et al. 2015</td>
<td>Cross-sectional</td>
<td>Children and adolescents</td>
<td>5,607</td>
<td>ActiGraph 7164</td>
<td>&lt;100</td>
<td>—</td>
<td>≥3,200 counts min</td>
<td>60</td>
<td>Body composition: Body mass index, waist circumference, triceps skinfold, subscapular skinfold, android body fat (%)</td>
<td>Age, sex, race-ethnicity, cotinine, poverty-to-income ratio, accelerometer wear time and energy intake</td>
<td>- Replacing 60 min/day of LIPA with sedentary behaviour resulted in a non-significant results</td>
</tr>
</tbody>
</table>

(Continues)
Effects of replacing sedentary time with light-intensity physical activity and moderate-to-vigorous physical activity

The meta-analysis revealed that replacing sedentary time (15–60 min) with LIPA was not associated with changes in any anthropometric and body composition parameters, showing an overall small to medium heterogeneity ($I^2 = 0–33.1\%$).

Pooled analysis from cross-sectional studies revealed that reallocating sedentary time into MVPA time was negatively associated with body fat percentage ($\beta = -2.512$, 95% CI, $-4.165$ to $-0.860$; $p = 0.003$), showing large heterogeneity ($I^2 = 88.9\%$). Regarding subgroup analysis, the greatest magnitude of association was detected when 60 min of sedentary behaviour was reallocated to 60 min of MVPA ($\beta = -4.535$, 95% CI, $-5.887$ to $-3.182$; $p < 0.001$; $I^2 = 0\%$). No statistically significant associations were found when data from prospective studies were pooled (Table 2).

Publication bias and sensitivity analysis

Egger’s linear regression tests did not provide evidence for a potential publication bias (Table 2). Results from the sensitivity analysis performed revealed that no single study particularly contributed to the reported heterogeneity.

Discussion

Our meta-analysis suggests that (hypothetical) isotemporal substitution of sedentary behaviour with MVPA favours significant cross-sectional negative associations with body fat percentage. As expected, a greater magnitude of association was observed when longer bouts of sedentary time were reallocated to MVPA, i.e. 60 min in the case of body fat percentage. We did not observe any statistical significant associations when replacing sedentary time with LIPA nor in the single prospective study identified.

The lowest intensity that would confer health benefits among youths is still unclear (20). However, there is scientific evidence showing that high intensity physical activity (mainly vigorous physical activity and MVPA) has positive effects on health in youths (21). A systematic review conducted in children and adolescents suggests that, because most of the studies are focused on physical activity of at least moderate intensity, drawing conclusions around the potential health benefits of engaging in LIPA activities remains difficult and therefore warrants further research (22). Thus, our observations add to the existing knowledge suggesting that replacing sedentary time with LIPA does not affect any of the adiposity parameter examined, regardless of the study design or bout duration. Even when a 60-min block time of sedentary behaviour was reallocated to
Table 2  Pooled effect size for substitution sedentary time by LIPA and MVPA

<table>
<thead>
<tr>
<th></th>
<th>Replacing sedentary time with LIPA</th>
<th></th>
<th></th>
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<th>Egger test</th>
<th>Replacing sedentary time with MVPA</th>
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<th>Egger test</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>n</td>
<td>Effect size (β)</td>
<td>95% CI</td>
<td>p</td>
<td>I²</td>
<td>n</td>
<td>Effect size (β)</td>
<td>95% CI</td>
<td>p</td>
<td>I²</td>
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<tr>
<td>Cross-sectional</td>
<td></td>
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</tr>
<tr>
<td>Body mass index</td>
<td>4</td>
<td>-0.001</td>
<td>-0.036 to 0.036</td>
<td>0.989</td>
<td>0</td>
<td>0.713</td>
<td>4</td>
<td>-0.095</td>
<td>-0.291 to 0.101</td>
<td>0.343</td>
</tr>
<tr>
<td>Waist circumference</td>
<td>4</td>
<td>-0.029</td>
<td>-0.194 to 0.136</td>
<td>0.733</td>
<td>0</td>
<td>0.901</td>
<td>4</td>
<td>-1.425</td>
<td>-0.460 to 0.240</td>
<td>0.063</td>
</tr>
<tr>
<td>Body fat percentage</td>
<td>4</td>
<td>-0.198</td>
<td>-0.410 to 0.014</td>
<td>0.067</td>
<td>0</td>
<td>0.209</td>
<td>4</td>
<td>-2.512</td>
<td>-4.165 to -0.860</td>
<td>0.003</td>
</tr>
<tr>
<td>Subgroup analysis</td>
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<tr>
<td>BMI (30 min)</td>
<td>2</td>
<td>-0.015</td>
<td>-0.093 to 0.063</td>
<td>0.701</td>
<td>47.1</td>
<td>—</td>
<td>2</td>
<td>-0.234</td>
<td>-0.587 to 0.118</td>
<td>0.193</td>
</tr>
<tr>
<td>Body fat percentage (60 min)</td>
<td>2</td>
<td>-0.569</td>
<td>-1.294 to 0.155</td>
<td>0.124</td>
<td>0</td>
<td>—</td>
<td>2</td>
<td>-4.535</td>
<td>-5.887 to -3.182</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Prospective</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Body mass index</td>
<td>3</td>
<td>0.001</td>
<td>-0.047 to 0.048</td>
<td>0.992</td>
<td>33.1</td>
<td>0.867</td>
<td>3</td>
<td>-0.154</td>
<td>-0.344 to 0.037</td>
<td>0.113</td>
</tr>
</tbody>
</table>

LIPA, light-intensity physical activity; MVPA, moderate to vigorous physical activity.

60 min of LIPA, no favourable association was observed (β = -0.569; p = 0.124). Despite there are substantially more opportunities to increase LIPA in a given day, for example with light ambulatory movement, and may be more readily attainable and easier to promote than MVPA, this intensity seems unrelated to positive effects on adiposity markers. However, positive effects of LIPA may be more pronounced in less fit, inactive populations (7) and in overweight, obese or at-risk overweight children and adolescents (23). Therefore, among at-risk populations, LIPA may be a first step in the progression to achieve the recommended amount of MVPA (24). Despite the small number of studies and variety of adiposity outcomes analysed within the current study, our results seem to align with the current population health guidelines in young people (≤18 years) and other studies focusing on MVPA rather than LIPA for health benefits (25). However, it is impossible to infer causality or temporality from cross-sectional studies, and more prospective studies with longer duration of follow-up are required to confirm our observations.

Current evidence linking overall sedentary behaviour with adiposity in youth is fairly consistent suggesting no association when MVPA is accounted for (26,27). Similarly, a recent meta-analysis found very limited evidence showing that total sedentary time is associated with health and development in children and young people, particularly when accounting for MVPA (27). The findings of the current review suggest that isotemporal substitution of sedentary behaviour with MVPA (15 to 60 min) favours statistically significant negative associations with total percentage of body fat, with greater magnitude of associations depicted when only studies replacing 60 min of sedentary time by 60 min of MVPA were pooled.

According to our results, previous studies have shown a negative association between MVPA and a number of adiposity parameters in youth (28,29). Sardinha et al. (10) suggested that reducing sedentary time by reallocating the same amount of time into MVPA may positively influence on childhood adiposity. The same study (10) reported that as little as 15 min of MVPA may have some positive effects on adiposity among children. Given that lack of time is a barrier to physical activity (30) among this population group, 15 min bouts of MVPA could be a more realistic, achievable target to help preventing childhood obesity.

No statistical associations were found in prospective studies (8,10); however, pooled analysis shows a negative trend towards statistical significant associations of replacing sedentary behaviour with MVPA on BMI (β = -0.154, 95% CI, -0.344 to 0.037; p = 0.113; I² = 88.3%). The lack of significant association may be due to limited number of studies. Moreover, the mean duration of prospective studies included in this review may be to short (i.e. 20–24 months) to detect significant associations with adiposity parameters. However, some prospective studies have suggested a negative association between MVPA and adiposity indexes in youth (28,31). Therefore, further longer prospective studies are warranted.

The amount of sedentary time that might be harmful to health in young people remains unclear. Some evidence have suggested relationships between MVPA (negative) and accumulation of sitting time (positive) with the group of risk factors that comprise cardiovascular health (32), whereas sedentary time appears to be unrelated to these risk factors when adjusted for MVPA (2). While LIPA has been considered an alternative to MVPA intensity for special population groups (e.g. high-risk youth, older adults, cancer) (33,34), our results do not support such hypothesis. Therefore, these results beg the question whether or not LIPA could bring any health benefits in children and adolescents. In this context, we speculate that MVPA levels might induce additive improvement in the oxidative metabolism-dependent energy system, metabolic capacity, qualitative changes in skeletal muscle fibre type, muscle...
mass and fibre diameter (35). However, exercise training studies using a randomized design are needed to establish causality for a possible effect of LIPA on cardio-metabolic risk factors in youth.

Much of the sedentary time among youth occurs while at school (36). Therefore, efforts towards replacing sedentary activities with MVPA at schools are warranted. Despite academic-related activities potentially interfering with the aim of improving MVPA among children and adolescents (36,35), several strategies could be encouraged: (i) reducing the amount of time spend on screen time, i.e. computer, mobile phones or playing videogames; (ii) promoting organized sports appears to contribute to increased MVPA and the proportion of youth meeting PA recommendations (37); and (iii) promoting high-intensity activities bouts during school-based recess or physical education classes (38). In this regard, a recent meta-analysis has found that afterschool physical activity interventions to date have had mixed effectiveness on increasing MVPA levels (39).

This meta-analysis has limitations at study and review levels that need to be considered when interpreting the results. First, although two of the studies included in this review were prospective, the cross-sectional nature of the pooled observations of the remaining studies does not allow definitive conclusions to be drawn around the causal relationship between the variables of interest. Therefore, well-designed, prospective studies are warranted to further clarify the temporal and potentially causal associations between sedentary time, physical activity and adiposity in young people. Second, the isotemporal substitution modelling is limited as being a mathematical assumption, and substituting a large amount of sitting time with time spent in MVPA may not be feasible. Third, accelerometers may be inaccurate at distinguishing between sedentary and light activities increasing the risk for misclassification. Furthermore, these devices cannot capture activity during non-wear time; therefore, activities during these times are not accounted for. Fourth, despite the included studies using accelerometers, an objective method of free-living activity assessment, cut-points applied for sedentary, LIPA and MVPA time differed across the included studies. However, given the consistent results across studies, it is unlikely this affects the main conclusion of our analyses. At review level, statistical heterogeneity was high for some of the meta-analysed outcomes, and therefore results should be cautiously interpreted. Generalization of results may be further limited due to the low number of studies, difference in duration bouts and measures of sedentary time included in the analysis.

Conclusions

Replacing sedentary time with LIPA showed no significant associations with any adiposity-related outcomes; in contrast, replacing sedentary time with MVPA was associated with benefits to body fat percentage but not with BMI or waist circumference. However, additional prospective studies are needed to adequately address the impact of replacing sedentary behaviour with activity of different intensities and bout durations on adiposity-related outcomes among children and adolescents.

Acknowledgements

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Conflict of interest statement

No conflict of interest was declared.

Supporting information

Additional Supporting Information may be found online in the supporting information tab for this article. https://doi.org/10.1111/obr.12552

Supplementary file S1. Search strategy

Supplementary files S2. Methodological quality of the included studies – cross sectional and prospective associations

References

9. Loprinzi PD, Cardinal BJ, Lee H et al. Markers of adiposity among children and adolescents: implications of the isotemporal...


