2016

Objectively measured sedentary behaviour and health and development in children and adolescents: systematic review and meta-analysis

Dylan P. Cliff
University of Wollongong, dylanc@uow.edu.au

Kylie Hesketh
Deakin University, kylie.hesketh@deakin.edu.au

Stewart A. Vella
University of Wollongong, stvella@uow.edu.au

Trina Hinkley
Deakin University, thinkley@uow.edu.au

Margarita D. Tsiros
University of South Australia

See next page for additional authors

Publication Details

Cliff, D. P., Hesketh, K. D., Vella, S. A., Hinkley, T., Tsiros, M. D., Ridgers, N. D., Carver, A., Veitch, J., Parrish, A. -M., Hardy, L. L., Plotnikoff, R. C., Okely, A. D., Salmon, J. & Lubans, D. R. (2016). Objectively measured sedentary behaviour and health and development in children and adolescents: systematic review and meta-analysis. Obesity Reviews, 17 (4), 330-344.

Objectively measured sedentary behaviour and health and development in children and adolescents: systematic review and meta-analysis

Abstract

Sedentary behaviour has emerged as a unique determinant of health in adults. Studies in children and adolescents have been less consistent. We reviewed the evidence to determine if the total volume and patterns (i.e. breaks and bouts) of objectively measured sedentary behaviour were associated with adverse health outcomes in young people, independent of moderate-intensity to vigorous-intensity physical activity. Four electronic databases (EMBASE MEDLINE, Ovid EMBASE, PubMed and Scopus) were searched (up to 12 November 2015) to retrieve studies among 2- to 18-year-olds, which used cross-sectional, longitudinal or experimental designs, and examined associations with health outcomes (adiposity, cardio-metabolic, fitness, respiratory, bone/musculoskeletal, psychosocial, cognition/academic achievement, gross motor development and other outcomes). Based on 88 eligible observational studies, level of evidence grading and quantitative meta-analyses indicated that there is limited available evidence that the total volume or patterns of sedentary behaviour are associated with health in children and adolescents when accounting for moderate-intensity to vigorous-intensity physical activity or focusing on studies with low risk of bias. Quality evidence from studies with robust designs and methods, objective measures of sitting, examining associations for various health outcomes, is needed to better understand if the overall volume or patterns of sedentary behaviour are independent determinants of health in children and adolescents.

Keywords

measured, sedentary, behaviour, health, review, meta, analysis, development, children, adolescents, objectively, systematic

Disciplines

Education | Social and Behavioral Sciences

Publication Details

Cliff, D. P., Hesketh, K. D., Vella, S. A., Hinkley, T., Tsiros, M. D., Ridgers, N. D., Carver, A., Veitch, J., Parrish, A. -M., Hardy, L. L., Plotnikoff, R. C., Okely, A. D., Salmon, J. & Lubans, D. R. (2016). Objectively measured sedentary behaviour and health and development in children and adolescents: systematic review and meta-analysis. Obesity Reviews, 17 (4), 330-344.

Authors

Dylan P. Cliff, Kylie Hesketh, Stewart A. Vella, Trina Hinkley, Margarita D. Tsiros, Nicola D. Ridgers, Alison Carver, Jenny Veitch, Anne-Maree Parrish, Louise L. Hardy, Ronald Plotnikoff, Anthony D. Okely, Jo Salmon, and David R. Lubans

Objectively measured sedentary behaviour and health and development in children and adolescents: Systematic review and meta-analysis

Dylan P. Cliff[a], Kylie D. Hesketh[b], Stewart A. Vella[a], Trina Hinkley[b] , Margarita D. Tsiros[c], Nicola D. Ridgers[b] , Alison Carver[b], Jenny Veitch[b], Anne-Maree Parrish[a], Louise L. Hardy[e], Ronald C. Plotnikoff[d] , Anthony D. Okely[a], Jo Salmon[b], David R. Lubans[d]

Affiliations
[a]Early Start Research Institute, Faculty of Social Sciences, School of Education, and Illawarra Health and Medical Research Institute, University of Wollongong, Northfields Ave, Wollongong, NSW, Australia, 2522
[b]Centre for Physical Activity and Nutrition Research (C-PAN), Deakin University, 221 Burwood Highway, Burwood, Victoria 3125, Australia
[c] Alliance for Research in Exercise, Nutrition and Activity, Sansom Institute for Health Research, School of Health Sciences, University of South Australia, North Terrace, Adelaide, South Australia, Australia, 5000
[d]Priority Research Centre for Physical Activity and Nutrition, Faculty of Education and Arts, University of Newcastle, Newcastle, 2308, Australia
[e]Prevention research Collaboration, School of Public Health, University of Sydney, NSW Australia

Keywords: sedentary lifestyle; exercise; sitting; youth
Running head: Child sedentary behaviour and health
Financial Disclosures and Conflicts of Interests. This review was funded by the Australasian Child and Adolescent Obesity Research Network (ACAORN). The authors have no other conflicts of interest to declare.
Study Registration: PROSPERO: International prospective register of systematic reviews. 2014: CRD42014009084

Corresponding Author:
Dylan P. Cliff, PhD
Early Start Research Institute
Faculty of Social Sciences
University of Wollongong
Northfields Ave, Wollongong NSW 2522 Australia
Ph: +61 2 4221 5929 Fax: +61 2 4221 3892
E-mail: dylanc@uow.edu.au

Tables: 1
Figures: 1
Supplementary Files: 1

Abstract
Sedentary behaviour has emerged as a unique determinant of health in adults. Studies in children and adolescents have been less consistent. We reviewed the evidence to determine if the total volume and patterns (i.e., breaks and bouts) of objectively-measured sedentary behaviour were associated with adverse health outcomes in young people, independent of moderate- to vigorous-intensity physical activity (MVPA). Four electronic databases (EMBASE MEDLINE, Ovid EMBASE, PubMed, and Scopus) were searched (up to 12 November 2015) to retrieve studies among 2-18 year-olds, that used cross-sectional, longitudinal or experimental designs, and examined associations with health outcomes (adiposity, cardio-metabolic, fitness, respiratory, bone/musculoskeletal, psychosocial, cognition/academic achievement, gross motor development, and other outcomes). Based on 88 eligible observational studies, level of evidence grading and quantitative meta-analyses indicated that there is limited available evidence that the total volume or patterns of sedentary behaviour are associated with health in children and adolescents when accounting for MVPA or focusing on studies with low risk of bias. Quality evidence from studies with robust designs and methods, objective measures of sitting, examining associations for various health outcomes are needed to better understand if the overall volume or patterns of sedentary behaviour are independent determinants of health in children and adolescents.

Introduction

Sedentary behaviours are defined as any waking behaviours characterised by an energy expenditure ≤1.5 metabolic equivalents (METs; 1 MET = rest) while in a sitting or reclining posture (1). Independent of time spent in moderate- to vigorous-intensity physical activity (MVPA), both the total volume and pattern of sedentary behaviour have been shown to influence cardio-metabolic health (2-5) and all-cause mortality (6) in adults. Consequently, sedentary behaviour has emerged as a unique determinant of population health.

Among children and adolescents, television viewing or screen-based forms of entertainment are the most prevalent leisure-time sedentary behaviors (7, 8). However, time spent in screen-based entertainment is not necessarily indicative of young people's overall or total sedentary time (8), which also occurs in other contexts such as sitting during class time at school or during motorised transport (9, 10). Population data from North America (11, 12), the United Kingdom (13) and Europe (14) indicate that children and adolescents spend a substantial proportion of their day sedentary. In the United States, for example, 6-11 and 12-15 year-olds in the 2003-2004 National Health And Nutrition Examination Survey spent approximately 40% (6h) and >50% (7.5h) of their waking hours sedentary, respectively (12). Aside from adults aged ≥60 years, 16-19 year-old adolescent females were the next most sedentary age group (60% of waking hours; 8h).

Recent systematic reviews that have included studies of electronic media use and television viewing have concluded that this type of sedentary behaviour is associated with adverse health and developmental outcomes in preschoolers and school-aged children and adolescents (15-21). However, the mechanisms through which screen-based behaviours (22) and other sitting behaviours (23, 24) might influence health and development among children and adolescents may differ. For example, television viewing is associated with increased energy intake, unhealthy snacking and sugary-beverage consumption during and following exposure (22), which may not be consistent for other sedentary behaviours. A recent narrative review summarised evidence from studies examining the associations between volume and patterns of objectively measured sedentary behaviour and markers of cardio-metabolic risk in 6-19 year-olds (25). In contrast to previous reviews that included studies of screen-time, there was limited evidence supporting associations between volume or patterns of sedentary behaviour and individual or clustered cardio-metabolic risk when adjusted for MVPA. As young children (<6 years) were not included in the review, the consistency of the evidence in early childhood remains unclear. Likewise, studies of children and adolescents examining associations between volume and patterns of objectively measured sedentary behaviour and other important health and developmental outcomes, such as health-related fitness, bone health, or psychosocial, motor and cognitive development, have not been reviewed. Finally, previous reviews (16, 20, 21, 25) have not included meta-analyses quantifying the associations between objectively measured sedentary behaviour and health outcomes.

The purpose of this paper was to systematically review the expanding evidence base and, where possible, conduct meta-analyses to address the following questions among preschoolers, children and adolescents: i) is objectively-measured total sedentary behaviour associated with adverse health and developmental outcomes? ii) are patterns of sedentary behaviour associated with adverse health and developmental outcomes? iii) are associations independent of MVPA?, and iv) what are moderators of the associations (i.e., age group or ROB in studies)?

Methods

Study inclusion criteria

This review aimed to identify all studies published in peer-reviewed journals that examined associations between objectively measured sedentary behaviour or patterns of sedentary behaviour and health outcomes in children and adolescents (2-18 years). The review was registered with PROSPERO (CRD42014009084) and reported using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) (26). The search was not delimited by date restrictions but only included studies published in English. Studies were included if they met the following criteria:

Population – participants were aged between 2-18 years (i.e., mean age was within age limit at baseline and follow-up/post-test for longitudinal and experimental studies) and apparently healthy (with no diagnosed disease or disability besides overweight or obesity).

Intervention/exposure – for observational studies, habitual daily/weekly total sedentary time or patterns of sedentary behaviour were measured objectively (e.g., using wearable monitors/accelerometers but not direct observation or heart rate monitoring). Studies that only used subjective or objective measures of television viewing or electronic media use were not included. Likewise, studies only assessing specific periods of sedentary behaviour, such as during school recess, were excluded. For experimental studies, the intervention was required to incorporate a component designed to decrease sedentary behaviour, and could not include strategies targeting other behaviours, such as physical activity or diet, that may have influenced the health outcome of interest. The control condition could not include strategies designed to reduce sedentary behaviour or modify other behaviours that may have improved the targeted health outcome. Pre-test and post-test values for the overall volume or pattern of sedentary behaviour must have been measured objectively and reported for both groups.

Outcomes - for observational studies, associations between the exposure and an identified health outcome (see below) were reported, and for experimental studies, the pre-test and post-test values or treatment effect for an identified health outcome were reported.

Study design – the study was either observational or a controlled experiment (e.g., randomised or non-randomised controlled trials).

After consulting previous reviews (16, 27-29), health outcomes were chosen to capture a broad range of potential effects. These included: i) adiposity (e.g., body mass index (BMI), percentage body fat (BF%)), ii) cardio-metabolic health (e.g., insulin, cholesterol), iii) health-related fitness (e.g., cardiorespiratory fitness, muscular strength), iv) respiratory health (e.g., asthma), v) bone and musculoskeletal health (e.g., bone density), vi) psychosocial health (e.g., anxiety, self-esteem, behavioural conduct, quality of life), vii) cognition and academic achievement (e.g., attention, school performance), viii) gross motor skills, and ix) other outcomes.

Search Strategy

Four electronic databases were searched for relevant studies up to 12 November 2015: Ovid MEDLINE (from 1950), Ovid EMBASE (from 1946), PubMed (from 1809), and Scopus (from 1960). An example search strategy can be found in Table S1. Articles were extracted and imported into Endnote X7 (Thomson Reuters, San Francisco, CA) where duplicates were removed. Titles and abstracts of potentially relevant articles were screened by two independent reviewers (a research assistant and one of JV, AC, or DC), and full text articles were retrieved for all studies meeting initial screening by at least one reviewer. Two independent reviewers screened all full text articles for eligibility (a research assistant and one of JV, AC, or DC) and any discrepancies were discussed to reach consensus. To supplement the electronic database search, international researchers were contacted via the Sedentary Behaviour Research Network (http://www.sedentarybehaviour.org/) listserv and asked to identify any additional published or accepted papers.

Data extraction

Data were extracted by a research assistant and checked by one of six reviewers (AP, NR, AO, SV, RP or LH). We extracted descriptive information on the study sample (size, percentage of girls, percentage with complete data, age, percentage of sample overweight or obese, BMI and/or BMI *z*-score, and cultural background), study design (and duration of follow-up for longitudinal studies), exposure measurement (activity monitor type, cut-point to define sedentary behaviour, inclusion criteria for activity monitor wear time, non-wear criteria, and average wear time), variables (e.g., total sedentary time, or breaks in sedentary behaviour), outcomes examined, covariates included in the analyses, and study findings. Where available, we extracted relevant model statistics for each outcome variable, with preference placed on standardised regression or correlation coefficients from fully adjusted models that could be synthesised via meta-analysis.

Risk of bias assessment

Information on the ROB for individual studies was extracted by one of two reviewers (TH or MT). Items were as follows: i) was representative sampling/random selection used to select participants?, ii) did an adequate percentage of participants have complete data? (cross-sectional: ≥ 70%; longitudinal ≥ 60%), iii) was the measure of sedentary behaviour valid (i.e., Does the device and/or cut-point for sedentary behaviour have established validity in children or adolescents? – Actigraph: ≤ 50 to ≤ 150cpm; Actical: ≤ 24 to ≤ 100cpm), and iv) was MVPA included as a covariate in analyses or was an analysis presented that accounted for MVPA? (e.g., by stratifying for quartiles of MVPA). To determine the range of sedentary behaviour cut-points considered valid for each activity monitor, we consulted relevant studies and reviews for the most common devices such as the Actigraph (30-33) or Actical (11, 31, 34-36), or examined supporting evidence cited in each study. Items were coded as present ("1") or absent/unclear ("0"), and low ROB was classified as the presence of ≥3/4 items. Prior to extracting data, reviewers demonstrated > 95% agreement with criterion assessments conducted on 12 randomly selected studies (48 items).

Categorisation of levels of evidence and meta-analyses

Results were coded using the approach first employed by Sallis et al. (37) and subsequently applied to observational studies examining associations with health outcomes (38). The result was classified as no association (0) if 0-33% of studies reported a significant association. If 34-59% of studies reported a significant association, or if fewer than 5 studies reported on the outcome, the result was classified as being inconsistent/uncertain (?). If ≥60% of studies found a significant association, the result was classified as positive (+) or negative (-), depending on the direction of the association. To understand if these findings were influenced by study ROB or adjustment for MVPA, such coding was performed only among studies: i) with low ROB, or ii) that adjusted for MVPA.

Quantitative meta-analyses were conducted using random effects models in Comprehensive Meta-Analysis (Version 2.2). Heterogeneity was determined by Cochran's Q statistic and I^2 values (values of 25, 50, and 75 were considered to indicate low, moderate and high heterogeneity, respectively) (39). Publication bias was analysed using Rosenthal's classic fail-safe N and Duval and Tweedie's trim and fill procedure (40). Planned sub-analyses examined if effects were moderated by sex, age group (pre-schoolers: 2-4y, school-age children: 5-12y, adolescents: 13-18y), adjustment for MVPA, and overall ROB (≥3/4 ROB items vs <3/4). However, due to limited number of studies, moderating effects for sex were not tested. Meta-analyses were conducted where there were at least 5 studies investigating the same exposure (e.g., total sedentary time) and over-arching outcome (e.g., adiposity) or sub-outcome (e.g., cholesterol), using the same design (e.g., cross-sectional), and reporting correlation or standardised regression coefficients. Where coefficients were not available from fully adjusted models, coefficients for partially or unadjusted models were used. To avoid duplication, only one coefficient was included for each over-arching or sub-outcome and participant group in each study. For adiposity, one coefficient was selected from each study using the following hierarchy: i) BF% measured by dual energy x-ray absorptiometry, ii) BF% measured by skinfolds, iii) BF% measured by bioelectrical impedance analysis, iv) waist circumference, v) BMI. For cardio-metabolic outcomes, separate meta-analyses were conducted on the following sub-outcomes based on the available data: HDL cholesterol, glucose/insulin, systolic blood pressure and diastolic blood pressure. Due to a limited number of studies for health-related fitness, a meta-analysis was conducted for the sub-outcome of cardio-respiratory fitness only.

Results

Following the removal of duplicates, 7,533 studies were retrieved (Figure 1). After full-text screening, 88 studies were included in the review. Of the included studies, 73 were cross-sectional, 8 were longitudinal, and 7 reported both cross-sectional and longitudinal results. No experimental studies were deemed eligible for the review. One study used the thigh-mounted activPAL to assess sedentary behaviour (41); all others used activity monitors placed on the waist, hip or wrist.

Adiposity

A description of the 50 studies (pre-schoolers = 3, children = 37, adolescents = 10) that investigated associations between total volume or pattern of sedentary behaviour and adiposity is provided in Table S2. Forty-eight studies reported associations for total volume of sedentary behaviour (cross-sectional = 35, longitudinal = 9, both = 4). Of the 48 studies that examined associations for total sedentary behaviour, 17 (35%) used representative sampling, 24 (50%) had minimal missing data, 35 (73%) used a valid measure of sedentary behaviour, and 29 (60%) adjusted for MVPA (Table S3). Subsequently, 22 (46%) had ≥3/4 ROB items.

A summary of the associations between the total volume of sedentary behaviour and each health or developmental outcome, including adiposity, can be found in Table 1. Although 11 studies reported a significant positive association between sedentary behaviour and adiposity, overall the level of evidence classification was "no association" (11/48). This classification was consistent for studies with low ROB (3/22) and those that adjusted for MVPA (2/29).

The meta-analysis examining the cross-sectional association between overall sedentary time and adiposity outcomes included 27 studies and 7,160 participants. Using a random effects model, the pooled effect size indicated a weak but statistically significant positive association ($r = 0.07$, 95% CI 0.00 to 0.13, $p = 0.024$) (Figure S1). However, high levels of heterogeneity were observed; $Q = 142.72$ 26, $p < 0.001$ and $I^2 = 81.78$. With respect to risk of publication bias, Rosenthal's fail-safe N indicated that 124 studies with an effect size of zero would be needed for the association to not be statistically significant. Both ROB ($p < 0.001$) and adjustment for MVPA ($p < 0.001$) emerged as significant effect moderators. Among studies with a low ROB (n = 6) the association was not statistically significant ($r = -0.03$, 95% CI 0.07 to 0.02, $p = 0.223$), whereas it was for the remaining studies ($r = 0.11$, 95% CI 0.03 to 0.19, $p = 0.01$). Likewise, the association was not statistically significant for studies (n = 6) that adjusted for MVPA ($r = -0.00$, 95% CI -0.07 to 0.076, $p = 0.98$), but was for those that didn't ($r = 0.10$, 95% CI 0.02 to 0.18, $p = 0.018$). Age group was not a significant effect moderator ($p = 0.498$).

When focusing on the 13 studies that reported longitudinal associations between total sedentary time and adiposity (42-50), 3 (23%) used representative sampling, 8 (62%) had minimal missing data, 10 (77%) used a valid measure of sedentary behaviour, and 9 (69%) adjusted for MVPA (Table S3). Subsequently, 6 (46%) had ≥3/4 ROB items. Overall, the level of evidence classification was "no association" (4/13), which was consistent for studies with low ROB (1/6) or that adjusted for MVPA (2/9).

Of the 6 studies that reported cross-sectional associations between patterns of sedentary behaviour and adiposity (46, 51-55), 3 (50%) used representative sampling, 2 (33%) had minimal missing data, 6 (100%) used a valid measure of sedentary behaviour, and 4 (67%) adjusted for MVPA (Table S3). Subsequently, 4 (67%) had ≥3/4 ROB items. All 6 studies examined associations for breaks in sedentary behaviour, and 4 also investigated bouts of sedentary behaviour (51-54). Five of the 6 studies reported that the number of sedentary breaks were not statistically significantly associated with adiposity outcomes. One study with low ROB found that the number of breaks in sedentary time were significantly negatively associated with BMI *z*-score in 9 year-old children (n = 522) who had at least one biological parent with obesity (51). Of the 4 studies that examined associations for bouts of sedentary behaviour, 3 studies with low ROB reported at least one significant association (51-53).

Cardio-metabolic outcomes

A description of the 29 studies (children = 22, adolescents = 7) that investigated associations between total volume or pattern of sedentary behaviour and cardio-metabolic outcomes is provided in Table S4. Twenty-eight studies examined associations for total sedentary behaviour volume; 27 were cross-sectional, one was longitudinal (56) and one study reported both cross-sectional and longitudinal associations (44). Of these 28 studies, 8 (29%), 10 (36%), 22 (79%), and 16 (57%) used representative sampling, had minimal missing data, used a valid measure of sedentary behaviour, and adjusted for MVPA, respectively (Table S5). Subsequently, 8 (29%) had ≥3/4 ROB items.

A summary of the associations between the total volume of sedentary behaviour and cardio-metabolic outcomes can be found in Table 1. Eight studies reported at least one significant association; however, the level of evidence classification was "no association" (8/28). Likewise, the level of evidence was classified as "no association" for studies with a low ROB (1/8) or that adjusted for MVPA (2/16).

The meta-analysis examining the cross-sectional associations between overall sedentary time and glucose/insulin included 5 studies and 3,133 participants. Using a random effects model, the pooled effect size indicated a weak but statistically significant positive association ($r = 0.07$, 95% CI 0.01 to 0.13, $p = 0.030$) (Figure S2). However, moderate levels of heterogeneity were observed; Q (X) = 9.61X, $p = 0.087$ and $I^2 = 47.97$), and there was a risk of publication bias as Rosenthal's fail-safe N indicated that 10 studies with an effect size of zero would be required for the association to not be statistically significant. Likewise, both ROB ($p = 0.031$) and adjustment for MVPA ($p = 0.031$) emerged as significant effect moderators. In the study with low ROB that adjusted for MVPA, the association was not statistically significant ($r = -0.12$, 95% CI -0.29 to 0.06, $p = 0.192$), whereas it was for the remaining studies ($r = 0.09$, 95% CI 0.04 to 0.13, $p < 0.001$). Age was not a significant effect moderator for the association between sedentary time and glucose/insulin ($p = 0.775$). The pooled effect size from the 5 studies (n = 2,236) that examined associations between sedentary behaviour and HDL cholesterol was not statistically significant ($r = -0.02$, 95% CI -0.13 to 0.09, $p = 0.705$) (Figure S3). ROB ($p = 0.001$) and MVPA adjustment ($p = 0.001$); however, were significant moderators of the association. In the study with low ROB that adjusted for MVPA the association was statistically significant ($r = -0.29$, 95% CI -0.45 to -0.12, $p = 0.001$), whereas it wasn't for the remaining studies. Age was not a significant moderator of the association between sedentary time and HDL cholesterol ($p = 0.217$). Based on the findings from 6 (n = 2,347) and 5 (n = 2,145) studies, respectively, associations between sedentary behaviour and systolic ($r = 0.02$, 95% CI -0.08 to 0.12, $p = 0.732$) (Figure S4) and diastolic blood pressure ($r = 0.02$, 95% CI -0.09 to 0.13, $p = 0.732$) (Figure S5) were not statistically significant, and ROB, adjustment for MVPA, and age were not significant effect moderators (all $p > 0.05$).

One low ROB study examined longitudinal associations between total sedentary time and cardio-metabolic outcomes in 10 year-old children over a 200-day period (44). After adjustment for MVPA, a significant negative association was evident between change in sedentary behaviour and change in HDL cholesterol, however, change in total sedentary time was not associated with change in clustered metabolic syndrome score or other individual components. Another longitudinal study found that total sedentary time was not associated with individual or clustered cardio-metabolic risk in 11-12 year-old children (56).

Of the 4 studies that investigated cross-sectional associations between patterns of sedentary behaviour and cardio-metabolic health (51, 53, 54, 57), 2 (50%) used representative sampling, 2 (50%) had minimal missing data, 4 (100%) used a valid measure of sedentary behaviour, and 4 (100%) adjusted for MVPA (Table S5). Subsequently, all 4 (100%) had ≥3/4 ROB items. All 4 studies examined associations for bouts of sedentary behaviour, and 3 also investigated breaks in sedentary behaviour. Two of the 4 studies found no associations between bouts of, or breaks in, sedentary time in large national samples of children and adolescents in the United States (54) and Canada (53). Saunders et al. (51) found that the number of breaks in sedentary time and 1-4min bouts of sedentary behaviour were significantly negatively associated with a clustered cardio-metabolic risk score in 522 children (aged 9 years) who had at least one biological parent with obesity. Additionally, significant positive associations were reported between 10-14min sedentary bouts and fasting glucose among girls. Another study among overweight and obese children (n = 120) found that those in the highest quartile of 30min sedentary bouts exhibited significantly lower HDL cholesterol compared to children in the lowest quartile (57).

Health-related fitness

A description of the 12 studies (children = 7, adolescents = 5) that investigated associations between total volume of sedentary behaviour and health-related fitness is provided in Table S6. Of these, 7 (58%) used representative sampling, 9 (75%) had minimal missing data, 8 (67%) used a valid measure of sedentary behaviour, and 6 (50%) adjusted for MVPA, respectively (Table S7). Subsequently, 6 (50%) had ≥3/4 ROB items.

A summary of the associations between the total volume of sedentary behaviour and health-related fitness outcomes can be found in Table 1. Three studies reported significant associations between sedentary behaviour and a health related fitness outcome, although the level of evidence was classified as "no association" (3/12). This was consistent for studies with low ROB (2/6) or that adjusted for MVPA (2/6).

The meta-analysis examining the cross-sectional association between overall sedentary time and cardio-respiratory fitness included 9 studies and 4,499 participants. The random effects model indicated that the association was not statistically significant (r = -0.04, 95% CI -0.09 to 0.01, p = 0.130) (Figure S6) with moderate levels of heterogeneity Q = 21.47, p = 0.029 and I^2 = 48.79. Age group was the only significant moderator of the association (p = 0.047). Higher levels of sedentary behaviour were significantly associated with lower cardio-respiratory fitness in studies (n = 8) among school-age children (r = -0.06, 95% CI -0.14 to -0.00, p = 0.037), whereas the association was not significant in studies (n = 4) among adolescents (r = 0.02, 95% CI -0.07 to 0.11, p = 0.717). With respect to patterns of sedentary behaviour, one study in children and adolescents (n = 135) that was not classified as low ROB found that the number of breaks in sedentary time and the length of sedentary bouts did not differ by tertiles of cardio-respiratory fitness (58).

Bone and musculoskeletal outcomes

A description of the 8 studies (children = 6, adolescents = 2) that investigated associations between the total volume or pattern of sedentary behaviour and bone and musculoskeletal outcomes is provided in Supplementary File 2, Table S8. Of the 8 studies, 3 (38%) used representative sampling, 3 (38%) had minimal missing data, 8 (100%) used a valid measure of sedentary behaviour, and 4 (50%) adjusted for MVPA (Table S9). Subsequently, 3 (38%) had ≥3/4 ROB items.

A summary of the associations between the total volume of sedentary behaviour and bone outcomes can be found in Table 1. The association was classified as "inconsistent/ uncertain" for all studies (4/8), low ROB studies (1/3) and those that adjusted for MVPA (1/4). One longitudinal study that was not classified as low ROB reported that total sedentary time was negatively associated with bone mineral content and density of the femoral neck over 12-months in 11-13 year-olds (n=169) (59). Another study that was not classified as low ROB found that breaks in bouts of sedentary time were not significantly associated with bone outcomes in children and adolescents aged 9-20 years (n = 206) (60).

Psychosocial outcomes

A description of the 5 studies (children = 4, adolescents = 1) that investigated associations between total volume or patterns of sedentary behaviour and psychosocial outcomes is provided in Table S10. Of these, 0 (0%) used representative sampling, 1 (20%) had minimal missing data, 4 (80%) used a valid measure of sedentary behaviour, and 3 (60%) adjusted for MVPA (Table S11). Subsequently, 1 (20%) had ≥3/4 ROB items.

A summary of the associations between the total volume of sedentary behaviour and psychosocial outcomes can be found in Table 1. The evidence was classified as "no association" for all studies (1/5), and "inconsistent/uncertain" for the 1 low ROB study (0/1), and for studies that adjusted for MVPA (1/3). One study that was not classified as low ROB found that breaks in sedentary time and bouts of sedentary behaviour were not associated with global self-esteem and physical self-worth in 11 year-old children (n = 787) (61).

Gross motor skills

A description of the 3 studies (pre-schoolers = 2, children = 1) that investigated associations between the total volume of sedentary behaviour and gross motor skills is provided in Table S12. Of the 3 studies, 2 (67%) used representative sampling, 0 (0%) had minimal missing data, 2 (67%) used a valid measure of sedentary behaviour, and 1 adjusted for MVPA (33%) (Table S13). Subsequently, 1 (33%) had ≥3/4 ROB items.

A summary of the associations between the total volume of sedentary behaviour and gross motor skills can be found in Table 1. Because of small numbers, the evidence was classified as "inconsistent/uncertain" for all studies (1/3), and the 1 low ROB study (1/1).

Cognitive outcomes

A description of the 3 studies that investigated associations between the total volume of sedentary behaviour and cognitive outcomes in children is provided in Table S14. Of the 3 studies, 0 (0%) used representative sampling, 3 (100%) had minimal missing data, 3 (100%) used a valid measure of sedentary behaviour, and 1 adjusted for MVPA (33%) (Table S15). Subsequently, 1 (33%) had ≥3/4 ROB items.

A summary of the associations between the total volume of sedentary behaviour and cognitive outcomes can be found in Table 1. Because of small numbers, the evidence was classified as "inconsistent/uncertain" for all studies (1/3), and the 1 low ROB study that adjusted for MVPA (0/1).

Other outcomes

Two studies investigated associations between the total volume of sedentary behaviour and liver enzymes (Table S16). Ruiz et al.'s (62) study was classified as low ROB and found no significant associations between overall sedentary behaviour and liver enzymes among 12-18 year-old adolescents (n = 718). In contrast, another study that was not classified as low ROB and that did not adjust for MVPA found that total sedentary time was detrimentally associated with liver enzymes in 7-15 year-olds (63).

Discussion

Based on summative syntheses via level of evidence grading and quantitative meta-analyses, this review found limited available evidence demonstrating that total sedentary time is associated with health and development in children and young people, particularly when accounting for MVPA or when focusing on studies with low ROB. With respect to the level of evidence grading for adiposity and cardio-metabolic outcomes, these conclusions were drawn from a reasonably large number of studies (n = 8-29) that were classified as low ROB or that adjusted for MVPA. For adiposity, these conclusions were also consistent when based on evidence from longitudinal studies (n = 13). However, due to the small number of studies that adjusted for MVPA and examined associations between total sedentary time and health-related fitness, bone and musculoskeletal health, psychosocial development, gross motor skills, and cognitive outcomes, or examined associations for patterns of sedentary time, further evidence is needed before confident conclusions can be made.

These findings are consistent with those from a recent narrative review examining associations between objectively measured sedentary behaviour and cardio-metabolic risk in 6-19 year-olds (25). Froberg and Raustorp (25) summarised findings from 45 studies and found little evidence to support volumes or patterns of sedentary behaviour being associated with individual or clustered cardio-metabolic risk in young people, after accounting for MVPA. In contrast, several recent reviews that included measures of electronic media use have concluded that screen-based sedentary behaviours, particularly television viewing, are detrimentally associated with health and developmental outcomes in preschoolers (16, 17), and school-age children and adolescents (18, 19, 64). While the contrasting findings in this review may be accounted for by methodological differences between studies relying on self- report versus objective assessment they may equally be attributed to qualitative differences between total sedentary behaviour (from objective assessment) and the specific sedentary behaviours examined in other studies included in these reviews. For the most part, the evidence in previous reviews comes from studies examining television viewing as the sedentary behaviour exposure. Although children and young people engage in a number of different types of sedentary behaviours in various contexts – such as education, transportation, and leisure (10) – television viewing and electronic media use for entertainment appear to have a particularly potent influence on young people's health and development. This may be for a number of reasons, including increased sitting time and decreased energy expenditure (23). However, it may also be because of increased energy intake from unhealthy snacking and sugary-beverage consumption during and following exposure, exposure to advertising, the displacement of opportunities for social and educational development, exposure to content that promotes socially undesirable behaviour, the development of biological processes of dependence, the interference of cognitive processes, and the displacement of MVPA (22). As such, there may be unique mechanistic pathways through which television viewing and electronic media use influence health and development in young people, some of which might not be common to all sedentary behaviours, and this may in part explain the contrasting findings in this review.

Considering the evidence from numerous studies among adults indicating that overall sedentary time (3, 4, 6, 65) and patterns of sedentary behaviour (2, 3, 5) are adversely associated with health outcomes, particularly cardio-metabolic health, explaining the contrasting findings among studies in children and adolescents is challenging. There are a number of measurement issues to consider when objectively measuring sedentary behaviour (66-69), which could influence the ability to detect associations. Specifically, the validity of cut-point based approaches to estimate sedentary time from hip-mounted accelerometers is limited because of the potential to misclassify standing still as sedentary behaviour (69, 70). However, associations have been detected among adults despite these measurement limitations. Only one study included in this review used a posture-based activity monitor to assess sedentary behaviour (41); total sitting time, bouts of sitting, and MVPA were not cross-sectionally associated with adiposity in 13-18 year-old females, but higher levels of light physical activity (excluding standing time) and more breaks in sitting time were associated with lower levels of adiposity. Another important issue when investigating independent associations between sedentary behaviour and health and developmental outcomes is the potential co-dependence of sedentary behaviour and MVPA. Although associations between sedentary behaviour and MVPA appear to be weak (71), they combine with light physical activity to constitute a composite whole because waking hours are finite (72). Therefore, these behaviours are intrinsically co-dependent. Traditional analysis approaches do not take this into account and so alternatives, such as compositional analyses (72), may be needed to more clearly understand if there is an optimal balance between sedentary behavior, light physical activity, MVPA, and also sleep, to maximise health and developmental potential during different stages of childhood and adolescence.

Interestingly, a laboratory-based study in youth found that a day of prolonged sitting did not have acute adverse effects on cardio-metabolic biomarkers, relative to a day where sedentary behaviour was broken-up with light physical activity (73), which is inconsistent with mechanistic studies among adults (2, 5, 74). Relative to adults, these contrasting findings in children and adolescents might be due to lower levels or shorter life-time exposure to sedentary behaviour, higher levels of physical activity or more time spent in MVPA, or generally healthier profiles for the cardio-metabolic outcomes that have been investigated. A small amount of evidence suggests that adverse associations between sedentary behaviour volume or patterns and adiposity or cardio-metabolic outcomes might be apparent in overweight, obese or at-risk of overweight samples of children and adolescents (51, 57, 75-77). These findings among overweight/obese young people require confirmation in further studies, but may be due to i) unhealthier cardio-metabolic profiles (78) allowing detection earlier in life relative to non-overweight samples, ii) greater sedentary behaviour exposure (79), or iii) because of a lower MVPA volume (79), compared to their non-overweight peers.

Although experimental studies are underway (80), none were retrieved that met the inclusion criteria for this review, which required sedentary behaviour to be measured objectively. Nonetheless, some experimental evidence indicates that the use of stand-biased desks in classrooms, which are likely to decrease sedentary time, might result in increased energy expenditure among school-age children compared with traditional seated-desks (81), without impeding classroom engagement (82). Much sedentary time among youth occurs while at school (54). Therefore, experimental research in this setting has important implications for the translation of intervention strategies if it can be demonstrated that educational and development goals can be achieved, while also addressing public health targets such as increased energy expenditure, and obesity and chronic disease prevention. Although this review does not demonstrate that objectively measured sedentary time is adversely associated with health and developmental outcomes in young people, without further experimental evidence testing subtle shifts from sitting to standing or light physical activity, it is premature to conclude that excessive sedentary behaviour does not adversely impact on health and development in children and adolescents. Further, given the evidence of adverse effects among adults, and some evidence of tracking of sedentary behaviours across the life course, continuing to encourage children and young people to limit their time spent sedentary is prudent.

Strengths and limitations

Although several reviews on the health consequences of sedentary behaviour among children and adolescents are available (15, 16, 18, 20, 25, 83), only more recent reviews include the proliferation of studies which objectively measure sedentary behaviour. To our knowledge this is the first systematic review to focus on objectively measured sedentary behaviour volume and patterns and: i) include a wide range of health outcomes, ii) synthesise studies to categorise the level of evidence for each outcome, and iii) conduct a quantitative meta-analysis. Furthermore the interpretation of the findings were enhanced by an examination of the potential moderating effects on associations of adjustment for MVPA and ROB.

The review findings are influenced by limitations of the evidence base, which should be considered. For each of the outcomes, <50% of studies examining associations for overall sedentary time were classified as low ROB, which impacts the strength of the conclusions. Nevertheless, other than the meta-analysis results for adiposity where associations differed by ROB categories, findings were relatively consistent across ROB categories for both qualitative and quantitative analyses. This suggests that current evidence is either inconsistent or does not indicate that objectively measured sedentary time is negatively associated with health or developmental outcomes in children and adolescents, particularly after adjustment for MVPA. Other than for adiposity where a number of longitudinal studies were retrieved, the conclusions from the review are largely based on cross-sectional evidence, and further longitudinal and experimental evidence is required. As there were few studies for some outcomes, designs (i.e., longitudinal), and age groups (i.e., preschoolers and adolescents), and because of differences in definitions of breaks and bouts for sedentary behaviour patterns, meta-analyses could not be conducted to test all associations examined and moderator analyses testing sub-groups were limited. Excluding one study (41), all others used activity monitors placed on the hip or wrist and used thresholds to define epochs of data as sedentary behaviour. Differentiating between sitting and standing still using such methods is problematic (69, 70), likely resulting in sedentary time being over-estimated, and influencing the apparent associations with health outcomes.

A number of limitations of the review should also be taken into account when interpreting the findings. Because of differences in analyses and reporting, and too few studies for some outcomes, not all studies that contributed to the level of evidence grades were included in the meta-analyses. Authors were not contacted to provide additional study data, and this is acknowledged as a limitation. However, after accounting for study ROB and adjustment for MVPA, findings from level of evidence summaries and meta-analyses were consistent. For cardio-metabolic outcomes, some studies reported multiple outcomes and this might have increased the likelihood of concluding that a significant association was observed in the level of evidence summary. However, because the overall classification for cardio-metabolic outcomes was “no association”, this does not appear to have influenced the final conclusion. Although efforts were made to consider if study findings were at risk of bias by evaluating key methodological components, some criteria could be considered lenient (e.g., <30% and <40% missing data for cross-sectional and longitudinal studies, respectively). Likewise, other methodological aspects that were not assessed could also potentially influence study results. For example, the validity of outcome measures (a post hoc examination indicated that all studies used measures that appeared to be valid except one which investigated associations for psycho-social outcomes and did not provide validity information but used a measure with adequate face validity (84)). All others used measures that appeared to be valid), sedentary behaviour data reduction protocols such as definitions of non-wear time and number of days of monitoring required, and, for the level of evidence summaries, study power, could impact reported associations. However, evidence to reach consensus on sedentary behaviour data reduction protocols is currently lacking, and study power would not have influenced pooled meta-analysis findings.

Conclusion

Our findings indicate that there is limited available evidence demonstrating that the overall volume or patterns of sedentary behaviour are associated with health and development in children and young people, particularly from studies with low ROB that adjust for MVPA. Quality evidence from studies using experimental or longitudinal designs, using direct measures of sitting posture, and examining associations for a variety of health and developmental outcomes among different age groups, is needed to better understand if the overall volume or patterns of sedentary behaviour are unique determinants of health in children and adolescents, independent of MVPA.

Conflict of Interest Statement

The authors declare that there are no conflicts of interest

Acknowledgements

This review was funded by the Australasian Child and Adolescent Obesity Research Network (ACAORN). DPC was funded by a National Heart Foundation of Australia Postdoctoral Research Fellowship (PH 11S 6025) and an Australian Research Council (ARC) Discovery Early Career Researcher Award (DE140101588). KDH is supported by an ARC Future Fellowship (FT130100637) and an Honorary National Heart Foundation of Australia Future Leader Fellowship (100370). TH is funded by a National Health and Medical Research Council (NHMRC) Early Career Fellowship (APP1070571). NDR is funded by an Australian Research Council Discovery Early Career Researcher Award (DE120101173). JV is funded by a NHMRC Early Career Fellowship (APP1053426). RCP is funded by an NHMRC Senior Research Fellowship. ADO is supported by a National Heart Foundation of Australia Career Development Fellowship (CR11S 6099). JS is supported by a NHMRC Principal Research Fellowship (APP1026216). DR is supported by an ARC Future Fellowship (FT140100399). We thank Katherine Downing, Yvonne Ellis and Sanne Veldman for their contribution as research assistants.

References

1. Sedentary Behaviour Research Network. Letter to the Editor: Standardized use of the terms ,"sedentary", and ,"sedentary behaviours". Appl Physiol Nutr Metab 2012;**37**:540-2.
2. Dunstan DW, Kingwell BA, Larsen R et al. Breaking up prolonged sitting reduces postprandial glucose and insulin responses. Diabetes Care 2012;**35**:976-83.
3. Healy GN, Matthews CE, Dunstan DW, Winkler EAH, Owen N. Sedentary time and cardio-metabolic biomarkers in US adults: NHANES 2003-06. Eur Heart J 2011;**32**:590.
4. Helmerhorst HJF, Wijndaele K, Brage S, Wareham NJ, Ekelund U. Objectively measured sedentary time may predict insulin resistance independent of moderate-and vigorous-intensity physical activity. Diabetes 2009;**58**:1776.
5. Peddie MC, Bone JL, Rehrer NJ, Skeaff CM, Gray AR, Perry TL. Breaking prolonged sitting reduces postprandial glycemia in healthy, normal-weight adults: a randomized crossover trial. Am J Clin Nutr 2013;**98**:358-66.
6. van der Ploeg HP, Chey T, Korda RJ, Banks E, Bauman A. Sitting time and all-cause mortality risk in 222 497 Australian adults. Arch Intern Med 2012;**172**:494.
7. Australian Bureau of Statistics. Australian health survey: Physical Activity, 2011-12. Canberra2013. Report No.: 4364.0.55.004.
8. Biddle SJH, Gorely T, Marshall SJ, Cameron N. The prevalence of sedentary behavior and physical activity in leisure time: A study of Scottish adolescents using ecological momentary assessment. Prev Med 2009;**48**:151-5.
9. Salmon J, Tremblay MS, Marshall SJ, Hume C. Health risks, correlates, and interventions to reduce sedentary behavior in young people. Am J Prev Med 2011;**41**:197-206.
10. Hardy LL, Hills AP, Timperio A et al. A hitchhiker's guide to assessing sedentary behaviour among young people: Deciding what method to use. J Sci Med Sport 2013;**16**:28-35.
11. Colley RC, Wong SL, Garriguet D, Janssen I, Connor Gorber S, Tremblay MS. Physical activity, sedentary behaviour and sleep in Canadian children: parent-report versus direct measures and relative associations with health risk. Health Rep 2012;**23**:45-52.
12. Matthews CE, Chen KY, Freedson PS et al. Amount of time spent in sedentary behaviors in the United States, 2003-2004. Am J Epidemiol 2008;**167**:875.
13. Steele RM, Van Sluijs E, Sharp SJ, Landsbaugh JR, Ekelund U, Griffin SJ. An investigation of patterns of children's sedentary and vigorous physical activity throughout the week. Int J Behav Nutr Phys Act 2010;**7**:88.
14. Ruiz JR, Ortega FB, Martinez-Gomez D et al. Objectively measured physical activity and sedentary time in European adolescents: the HELENA study. Am J Epidemiol 2011;**174**:173-84.
15. de Rezende LFM, Lopes MR, Rey-López JP, Matsudo VKR, do Carmo Luiz O. Sedentary behavior and health outcomes: an overview of systematic reviews. PLoS ONE 2014;**9**:e105620.
16. LeBlanc AG, Spence JC, Carson V et al. Systematic review of sedentary behaviour and health indicators in the early years (aged 0–4 years). Appl Physiol Nutr Metab 2012;**37**:753-72.
17. Hinkley T, Teychenne M, Downing KL, Ball K, Salmon J, Hesketh KD. Early childhood physical activity, sedentary behaviors and psychosocial well-being: A systematic review. Prev Med 2014;**62**:182-92.
18. Tremblay MS, LeBlanc AG, Kho ME et al. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. Int J Behav Nutr Phys Act 2011;**8**:98.
19. Biddle SJ, Asare M. Physical activity and mental health in children and adolescents: a review of reviews. Br J Sports Med 2011;**45**:886-95.
20. Chinapaw MJM, Proper KI, Brug J, van Mechelen W, Singh AS. Relationship between young peoples' sedentary behaviour and biomedical health indicators: a systematic review of prospective studies. Obes Rev 2011;**12**:e621-32.
21. Kolle E, Ekelund U. Is Sitting Time a Strong Predictor of Weight Gain? Curr Obes Rep 2013;**2**:77-85.
22. Sigman A. Time for a view on screen time. Arch Dis Child 2012;**97**:935-42.

23. Hamilton MT, Hamilton DG, Zderic TW. Role of low energy expenditure and sitting in obesity, metabolic syndrome, type 2 diabetes, and cardiovascular disease. Diabetes 2007;**56**:2655.
24. Voss MW, Carr LJ, Clark R, Weng T. Revenge of the "sit" II: does lifestyle impact neuronal and cognitive health through distinct mechanisms associated with sedentary behavior and physical activity? Ment Health Phys Activ 2014;**7**:9-24.
25. Fröberg A, Raustorp A. Objectively measured sedentary behaviour and cardio-metabolic risk in youth: a review of evidence. Eur J Pediatr 2014;**173**:845-60.
26. Liberati A, Altman DG, Tetzlaff J et al. The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. Ann Intern Med 2009;**151**:W-65-W-94.
27. Janssen I, LeBlanc AG. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. Int J Behav Nutr Phys Act 2010;**7**:40.
28. Timmons BW, LeBlanc AG, Carson V et al. Systematic review of physical activity and health in the early years (aged 0-4 years). Appl Physiol Nutr Metab 2012;**37**:773-92.
29. Tremblay MS, Colley RC, Saunders TJ, Healy GN, Owen N. Physiological and health implications of a sedentary lifestyle. Appl Physiol Nutr Metab 2010;**35**:725-40.
30. Janssen X, Cliff DP, Reilly JJ et al. Predictive validity and classification accuracy of ActiGraph energy expenditure equations and cut-points in young children. PLoS ONE 2013;**8**:e79124.
31. Lubans DR, Hesketh K, Cliff D et al. A systematic review of the validity and reliability of sedentary behaviour measures used with children and adolescents. Obes Rev 2011;**12**:781-99.
32. Ridgers ND, Salmon J, Ridley K et al. Agreement between activPAL and ActiGraph for assessing children's sedentary time. Int J Behav Nutr Phys Act 2012;**9**:15.
33. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. Med Sci Sports Exerc 2011;**43**:1360.
34. Janssen X, Cliff D, Reilly J et al. Evaluation of Actical equations and thresholds to predict physical activity intensity in young children. J Sports Sci 2015;**33**:498-506.
35. Evenson K, Catellier D, Gill K, Ondrak K, McMurray R. Calibration of two objective measures of physical activity for children. J Sports Sci 2008;**26**:1557-65.
36. Wong S, Colley R, Connor Gorber S, Tremblay M. Actical accelerometer sedentary activity thresholds for adults. J Phys Activity Health 2011;**8**:587-91.
37. Sallis J, Prochaska JJ, Taylor CB. A review of correlates of physical activity of children and adolescents. Med Sci Sports Exerc 2000;**32**:963-75.
38. Lubans DR, Morgan PJ, Cliff DP, Barnett LM, Okely AD. Fundamental movement skill competency in youth: review of associated health benefits. Sports Med 2010;**40**:1019-35.
39. Higgins JP, Thompson SG, Deeks JJ, Altman DG. Measuring inconsistency in meta-analyses. BMJ 2003;**327**:557.
40. Rosenthal R. The file drawer problem and tolerance for null results. Psychol Bull 1979;**86**:638.
41. Dowd KP, Harrington DM, Hannigan A, Donnelly AE. Light intensity physical activity is associated with adiposity in adolescent females. Med Sci Sports Exerc 2014;**46**:2295-300.
42. Basterfield L, Pearce MS, Adamson AJ et al. Physical activity, sedentary behavior, and adiposity in English children. Am J Prev Med 2012;**42**:445-51.
43. Fisher A, Hill C, Webber L, Purslow L, Wardle J. MVPA is associated with lower weight gain in 8–10 year old children: a prospective study with 1 year follow-up. PLoS ONE 2011;**6**:e18576.
44. Hjorth MF, Chaput J-P, Damsgaard CT et al. Low physical activity level and short sleep duration are associated with an increased cardio-metabolic risk profile: A longitudinal study in 8-11 year old Danish children. PLoS ONE 2014;**9**:e104677.
45. Hjorth MF, Chaput JP, Ritz C et al. Fatness predicts decreased physical activity and increased sedentary time, but not vice versa: support from a longitudinal study in 8- to 11-year-old children. Int J Obes 2014;**38**:959-65.
46. Kwon S, Burns TL, Levy SM, Janz KF. Which contributes more to childhood adiposity-high levels of sedentarism or low levels of moderate-through-vigorous physical activity? The Iowa Bone Development Study. J Pediatr 2013;**162**:1169-74.

47. Trinh A, Campbell M, Ukoumunne OC, Gerner B, Wake M. Physical activity and 3-year BMI change in overweight and obese children. Pediatrics 2013;**131**:e470-e7.
48. Butte NF, Cai G, Cole SA et al. Metabolic and behavioral predictors of weight gain in Hispanic children: the Viva la Familia Study. Am J Clin Nutr 2007;**85**:1478-85.
49. Mitchell JA, Pate RR, Beets MW, Nader PR. Time spent in sedentary behavior and changes in childhood BMI: a longitudinal study from ages 9 to 15 years. Int J Obes 2013;**37**:54-60.
50. Treuth MS, Baggett CD, Pratt CA et al. A longitudinal study of sedentary behavior and overweight in adolescent girls. Obesity 2009;**17**:1003-8.
51. Saunders TJ, Tremblay MS, Mathieu ME et al. Associations of sedentary behavior, sedentary bouts and breaks in sedentary time with cardiometabolic risk in children with a family history of obesity. PLoS ONE 2013;**8**:e79143.
52. Carson V, Stone M, Faulkner G. Patterns of sedentary behavior and weight status among children. Pediatr Exerc Sci 2013;**26**:95-102.
53. Colley RC, Garriguet D, Janssen I et al. The association between accelerometer-measured patterns of sedentary time and health risk in children and youth: results from the Canadian Health Measures Survey. BMC Pub Health 2013;**13**:200.
54. Carson V, Janssen I. Volume, patterns, and types of sedentary behavior and cardio-metabolic health in children and adolescents: a cross-sectional study. BMC Pub Health 2011;**11**:274.
55. Oliver M, Schluter PJ, Healy GN, Tautolo E-S, Schofield G, Rush E. Associations between breaks in sedentary time and body size in pacific mothers and their children: findings from the pacific islands families study. J Phys Activity Health 2013;**10**:1166-74.
56. Stamatakis E, Coombs N, Tiling K et al. Sedentary time in late childhood and cardiometabolic risk in adolescence. Pediatrics 2015;**135**:e1432-41.
57. Cliff DP, Jones RA, Burrows TL et al. Volumes and bouts of sedentary behavior and physical activity: associations with cardiometabolic health in obese children. Obesity 2014;**22**:E112-E8.
58. Denton SJ, Trenell MI, Plotz T, Savory LA, Bailey DP, Kerr CJ. Cardiorespiratory fitness is associated with hard and light intensity physical activity but not time spent sedentary in 10-14 year old schoolchildren: the HAPPY study. PLoS ONE 2013;**8**:e61073.
59. Ivuskans A, Maestu J, Jurimae T et al. Sedentary time has a negative influence on bone mineral parameters in peripubertal boys: a 1-year prospective study. J Bone Miner Metab 2015;**33**:85-92.
60. Gabel L, McKay HA, Nettlefold L, Race D, Macdonald HM. Bone architecture and strength in the growing skeleton: The role of sedentary time. Med Sci Sports Exerc 2014;**47**:363-72.
61. Faulkner G, Carson V, Stone M. Objectively measured sedentary behaviour and self-esteem among children. Ment Health Phys Activ 2014;**7**:25-9.
62. Ruiz JR, Labayen I, Ortega FB et al. Physical activity, sedentary time, and liver enzymes in adolescents: the HELENA study. Pediatr Res 2014;**75**:798-802.
63. Martins C, Aires L, Junior IF et al. Physical Activity is Related to Fatty Liver Marker in Obese Youth, Independently of Central Obesity or Cardiorespiratory Fitness. Journal of sports science & medicine 2015;**14**:103-9.
64. Chinapaw MJ, Yildirim M, Altenburg TM et al. Objective and self-rated sedentary time and indicators of metabolic health in Dutch and Hungarian 10-12 year olds: the ENERGY-Project. PLoS ONE 2012;**7**:e36657.
65. Koster A, Caserotti P, Patel KV et al. Association of sedentary time with mortality independent of moderate to vigorous physical activity. PLoS ONE 2012;**7**:e37696.
66. Atkin AJ, Ekelund U, Moller NC et al. Sedentary time in children: influence of accelerometer processing on health relations. Med Sci Sports Exerc 2013;**45**:1097-104.
67. Atkin AJ, Gorely T, Clemes SA et al. Methods of measurement in epidemiology: sedentary behaviour. Int J Epidemiol 2012;**41**:1460-71.
68. Chinapaw MJ, de Niet M, Verloigne M, De Bourdeaudhuij I, Brug J, Altenburg TM. From sedentary time to sedentary patterns: accelerometer data reduction decisions in youth. PLoS ONE 2014;**9**:e111205.

69. Janssen X, Cliff D. Issues related to measuring and interpreting objectively measured sedentary behavior data. Measure Phys Ed Exerc Sci 2015;**19**:116-24.
70. Dowd KP, Harrington DM, Donnelly AE. Criterion and concurrent validity of the activPAL™ professional physical activity monitor in adolescent females. PLoS ONE 2012;**7**:e47633.
71. Pearson N, Braithwaite R, Biddle S, Sluijs E, Atkin A. Associations between sedentary behaviour and physical activity in children and adolescents: a meta‐analysis. Obes Rev 2014;**15**:666-75.
72. Chastin SF, Palarea-Albaladejo J, Dontje ML, Skelton DA. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and combinedardio-metabolic health markers: A novel compositional data analysis approach. PLoS ONE 2015;**10**:e0139984.
73. Saunders TJ, Chaput J-P, Goldfield GS et al. Prolonged sitting and markers of cardiometabolic disease risk in children and youth: A randomized crossover study. Metabolism 2013;**62**:1423-8.
74. Altenburg TM, Rotteveel J, Dunstan DW, Salmon J, Chinapaw MJ. The effect of interrupting prolonged sitting time with short, hourly, moderate-intensity cycling bouts on cardiometabolic risk factors in healthy, young adults. J Appl Physiol 2013;**115**:1751-6.
75. Mitchell J, Pate R, Beets M, Nader P. Time spent in sedentary behavior and changes in childhood BMI: a longitudinal study from ages 9 to 15 years. Int J Obes 2012;**37**:54-60.
76. Henderson M, Gray-Donald K, Mathieu M-E et al. How are physical activity, fitness, and sedentary behavior associated with insulin sensitivity in children? Diabetes Care 2012;**35**:1272-8.
77. Cliff DP, Okely AD, Burrows TL et al. Objectively measured sedentary behavior, physical activity, and plasma lipids in overweight and obese children. Obesity 2013;**21**:382-5.
78. Weiss R, Dziura J, Burgert TS et al. Obesity and the metabolic syndrome in children and adolescents. The New England Journal of Medicine 2004;**350**:2362-74.
79. Cooper AR, Goodman A, Page AS et al. Objectively measured physical activity and sedentary time in youth: the International children's accelerometry database (ICAD). Int J Behav Nutr Phys Act 2015;**12**:113.
80. Salmon J, Arundell L, Hume C et al. A cluster-randomized controlled trial to reduce sedentary behavior and promote physical activity and health of 8-9 year olds: The Transform-Us! Study. BMC Pub Health 2011;**11**:759.
81. Benden ME, Blake JJ, Wendel ML, Huber Jr JC. The impact of stand-biased desks in classrooms on calorie expenditure in children. Am J Public Health 2011;**101**:1433-6.
82. Dornhecker M, Blake JJ, Benden M, Zhao H, Wendel M. The effect of stand-biased desks on academic engagement: an exploratory study. Int J Health Prom Ed 2015:1-10.
83. Saunders TJ, Chaput J-P, Tremblay MS. Sedentary behaviour as an emerging risk factor for cardiometabolic diseases in children and youth. Can J Diabetes 2014;**38**:53-61.
84. Herman KM, Sabiston CM, Tremblay A, Paradis G. Self-Rated Health in Children at Risk for Obesity: Associations Of Physical Activity, Sedentary Behaviour and BMI. J Phys Activity Health 2014;**11**:543-52.
85. Butte NF, Puyau MR, Adolph AL, Vohra FA, Zakeri I. Physical activity in nonoverweight and overweight Hispanic children and adolescents. Med Sci Sports Exerc 2007;**39**:1257-66.
86. De Bourdeaudhuij I, Verloigne M, Maes L et al. Associations of physical activity and sedentary time with weight and weight status among 10- to 12-year-old boys and girls in Europe: a cluster analysis within the ENERGY project. Pediatr Obes 2013;**8**:367-75.
87. Espana-Romero V, Mitchell JA, Dowda M, O'Neill JR, Pate RR. Objectively measured sedentary time, physical activity and markers of body fat in preschool children. Pediatr Exerc Sci 2013;**25**:154-63.
88. Hussey J, Bell C, Bennett K, O'Dwyer J, Gormley J. Relationship between the intensity of physical activity, inactivity, cardiorespiratory fitness and body composition in 7-10-year-old Dublin children. Br J Sports Med 2007;**41**:311-6.
89. Kennedy K, Shepherd S, Williams JE, Ahmed SF, Wells JC, Fewtrell M. Activity, body composition and bone health in children. Arch Dis Child 2013;**98**:204-7.

90. Machado-Rodrigues AM, Coelho-e-Silva MJ, Mota J et al. Cardiorespiratory fitness, weight status and objectively measured sedentary behaviour and physical activity in rural and urban Portuguese adolescents. J Child Health Care 2012;**16**:166-77.
91. Treuth MS, Hou N, Young DR, Maynard LM. Accelerometry-measured activity or sedentary time and overweight in rural boys and girls. Obes Res 2005;**13**:1606-14.
92. Marques A, Minderico C, Martins S, Palmeira A, Ekelund U, Sardinha LB. Cross-sectional and prospective associations between moderate to vigorous physical activity and sedentary time with adiposity in children. Int J Obes 2015.
93. Hsu YW, Belcher BR, Ventura EE et al. Physical activity, sedentary behavior, and the metabolic syndrome in minority youth. Med Sci Sports Exerc 2012;**43**:2307.
94. Oliver M, Schluter PJ, Rush E, Schofield GM, Paterson J. Physical activity, sedentariness, and body fatness in a sample of 6-year-old Pacific children. Int J Pediatr Obes 2011;**6**:e565-e73.
95. Melo X, Santa-Clara H, Pimenta NM et al. Intima-media thickness in 11-13 Years-old children: Variation attributed to sedentary behavior, physical activity, cardiorespiratory fitness and waist circumference. J Phys Activity Health 2015;**12**:610-7.
96. Ekelund U, Luan J, Sherar LB, Esliger DW, Griew P, Cooper A. Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. JAMA 2012;**307**:704-12.
97. Mitchell JA, Mattocks C, Ness AR et al. Sedentary behavior and obesity in a large cohort of children. Obesity 2009;**17**:1596-602.
98. Marques A, Santos R, Ekelund U, Sardinha LB. Association between physical activity, sedentary time and healthy fitness in youth. Med Sci Sports Exerc 2015;**47**:575-80.
99. Aires L, Silva P, Silva G, Santos MP, Ribeiro JC, Mota J. Intensity of physical activity, cardiorespiratory fitness, and body mass index in youth. J Phys Activity Health 2010;**7**:54.
100. Martinez-Gomez D, Eisenmann JC, Gomez-Martinez S, Veses A, Marcos A, Veiga OL. Sedentary behavior, adiposity and cardiovascular risk factors in adolescents. The AFINOS study. Rev Esp Cardiol 2010;**63**:277-85.
101. Grydeland M, Bergh IH, Bjelland M et al. Correlates of weight status among Norwegian 11-year-olds: The HEIA study. BMC Pub Health 2012;**12**:1053.
102. Bailey DP, Boddy LM, Savory LA, Denton SJ, Kerr CJ. Associations between cardiorespiratory fitness, physical activity and clustered cardiometabolic risk in children and adolescents: the HAPPY study. Eur J Pediatr 2012;**171**:1317-23.
103. Byun W, Liu J, Pate RR. Association between objectively measured sedentary behavior and body mass index in preschool children. Int J Obes 2013;**37**:961-5.
104. Casazza K, Dulin-Keita A, Gower BA, Fernandez JR. Differential influence of diet and physical activity on components of metabolic syndrome in a multiethnic sample of children. J Am Diet Assoc 2009;**109**:236-44.
105. Chaput JP, Lambert M, Mathieu ME, Tremblay MS, J OL, Tremblay A. Physical activity vs. sedentary time: independent associations with adiposity in children. Pediatr Obes 2012;**7**:251-8.
106. Chaput JP, Leduc G, Boyer C et al. Objectively measured physical activity, sedentary time and sleep duration: independent and combined associations with adiposity in canadian children. Nutr Diabetes 2014;**4**:e117.
107. Chaput JP, Saunders TJ, Mathieu ME et al. Combined associations between moderate to vigorous physical activity and sedentary behaviour with cardiometabolic risk factors in children. Appl Physiol Nutr Metab 2013;**38**:477-83.
108. Collings PJ, Brage S, Ridgway CL et al. Physical activity intensity, sedentary time, and body composition in preschoolers. Am J Clin Nutr 2013;**97**:1020-8.
109. Deforche B, De Bourdeaudhuij I, D'Hondt E, Cardon G. Objectively measured physical activity, physical activity related personality and body mass index in 6- to 10-yr-old children: a cross-sectional study. Int J Behav Nutr Phys Act 2009;**6**:25.
110. Purslow LR, Hill C, Saxton J, Corder K, Wardle J. Differences in physical activity and sedentary time in relation to weight in 8-9 year old children. Int J Behav Nutr Phys Act 2008;**5**:67-.

111. Steele RM, van Sluijs EM, Cassidy A, Griffin SJ, Ekelund U. Targeting sedentary time or moderate- and vigorous-intensity activity: independent relations with adiposity in a population-based sample of 10-y-old British children. Am J Clin Nutr 2009;**90**:1185-92.
112. Fenton SA, Duda JL, Barrett T. Inter-participant variability in daily physical activity and sedentary time among male youth sport footballers: independent associations with indicators of adiposity and cardiorespiratory fitness. J Sports Sci 2015:1-13.
113. Katzmarzyk PT, Barreira TV, Broyles ST et al. Physical activity, sedentary time, and obesity in an international sample of children. Med Sci Sports Exerc 2015;**47**:2062-9.
114. Latt E, Maestu J, Ortega FB, Raask T, Jurimae T, Jurimae J. Vigorous physical activity rather than sedentary behaviour predicts overweight and obesity in pubertal boys: a 2-year follow-up study. Scand J Public Health 2015;**43**:276-82.
115. Loprinzi PD, Cardinal BJ, Lee H, Tudor-Locke C. Markers of adiposity among children and adolescents: implications of the isotemporal substitution paradigm with sedentary behavior and physical activity patterns. Journal of diabetes and metabolic disorders 2015;**14**:46.
116. Gaya AR, Alves A, Aires L, Martins CL, Ribeiro JC, Mota J. Association between time spent in sedentary, moderate to vigorous physical activity, body mass index, cardiorespiratory fitness and blood pressure. Ann Hum Biol 2009;**36**:379-87.
117. Sardinha LB, Andersen LB, Anderssen SA et al. Objectively measured time spent sedentary is associated with insulin resistance independent of overall and central body fat in 9- to 10-year-old Portuguese children. Diabetes Care 2008;**31**:569-75.
118. Ekelund U, Anderssen SA, Froberg K, Sardinha LB, Andersen LB, Brage S. Independent associations of physical activity and cardiorespiratory fitness with metabolic risk factors in children: the European youth heart study. Diabetologia 2007;**50**:1832-40.
119. Hopkins N, Stratton G, Ridgers ND, Graves LE, Cable NT, Green DJ. Lack of relationship between sedentary behaviour and vascular function in children. Eur J Appl Physiol 2012;**112**:617-22.
120. Martinez-Gomez D, Eisenmann JC, Healy GN et al. Sedentary behaviors and emerging cardiometabolic biomarkers in adolescents. J Pediatr 2012;**160**:104-10.e2.
121. Martinez-Gomez D, Tucker J, Heelan KA, Welk GJ, Eisenmann JC. Associations between sedentary behavior and blood pressure in young children. Arch Pediatr Adolesc Med 2009;**163**:724-30.
122. Nettlefold L, McKay HA, Naylor PJ, Bredin SS, Warburton DE. The relationship between objectively measured physical activity, sedentary time, and vascular health in children. Am J Hypertens 2012;**25**:914-9.
123. de Moraes AC, Carvalho HB, Rey-Lopez JP et al. Independent and combined effects of physical activity and sedentary behavior on blood pressure in adolescents: gender differences in two cross-sectional studies. PLoS ONE 2013;**8**:e62006.
124. Gabel L, Ridgers ND, Della Gatta PA et al. Associations of sedentary time patterns and TV viewing time with inflammatory and endothelial function biomarkers in children. Pediatr Obes 2015.
125. Henderson M, Gray-Donald K, Rabasa-Lhoret R et al. Insulin secretion and its association with physical activity, fitness and screen time in children. Obesity 2014;**22**:504-11.
126. Moore JB, Beets MW, Barr-Anderson DJ, Evenson KR. Sedentary time and vigorous physical activity are independently associated with cardiorespiratory fitness in middle school youth. J Sports Sci 2013;**31**:1520-5.
127. Santos R, Mota J, Okely AD et al. The independent associations of sedentary behaviour and physical activity on cardiorespiratory fitness. Br J Sports Med 2014;**48**:1508-12.
128. Hjorth MF, Chaput JP, Michaelsen K, Astrup A, Tetens I, Sjodin A. Seasonal variation in objectively measured physical activity, sedentary time, cardio-respiratory fitness and sleep duration among 8-11 year-old Danish children: a repeated-measures study. BMC Pub Health 2013;**13**:808.

129. Martinez-Gomez D, Ortega FB, Ruiz JR et al. Excessive sedentary time and low cardiorespiratory fitness in European adolescents: the HELENA study. Arch Dis Child 2011;**96**:240-6.
130. De Smet S, Michels N, Polfliet C et al. The influence of dairy consumption and physical activity on ultrasound bone measurements in Flemish children. J Bone Miner Metab 2014.
131. Herrmann D, Buck C, Sioen I et al. Impact of physical activity, sedentary behaviour and muscle strength on bone stiffness in 2-10-year-old children-cross-sectional results from the IDEFICS study. Int J Behav Nutr Phys Act 2015;**12**:112.
132. Heidemann M, Molgaard C, Husby S et al. The intensity of physical activity influences bone mineral accrual in childhood: the childhood health, activity and motor performance school (the CHAMPS) study, Denmark. BMC Pediatr 2013;**13**:32.
133. Chastin SF, Mandrichenko O, Skelton DA. The frequency of osteogenic activities and the pattern of intermittence between periods of physical activity and sedentary behaviour affects bone mineral content: the cross-sectional NHANES study. BMC Pub Health 2014;**14**.
134. Martikainen S, Pesonen A-K, Lahti J et al. Physical activity and hypothalamic-pituitary-adrenocortical axis function in adolescents. Psychoneuroendocrinology 2014;**49**:96-105.
135. Page AS, Cooper AR, Griew P, Jago R. Children's screen viewing is related to psychological difficulties irrespective of physical activity. Pediatrics 2010;**126**:e1011-e7.
136. Hume C, Timperio A, Veitch J, Salmon J, Crawford D, Ball K. Physical activity, sedentary behavior, and depressive symptoms among adolescents. J Phys Activity Health 2011;**8**:152-6.
137. Lopes L, Santos R, Pereira B, Lopes VP. Associations between sedentary behavior and motor coordination in children. Am J Hum Bio 2012;**24**:746-52.
138. Cliff DP, Okely AD, Smith LM, McKeen K. Relationships between fundamental movement skills and objectively measured physical activity in preschool children. Pediatr Exerc Sci 2009;**21**:436-49.
139. Williams H, Pfeiffer K, O'Neill J et al. Motor skill performance and physical activity in preschool children. Obesity 2008;**16**:1421-6.
140. van der Niet AG, Smith J, Scherder EJ, Oosterlaan J, Hartman E, Visscher C. Associations between daily physical activity and executive functioning in primary school-aged children. J Sci Med Sport 2015;**18**:673-7.
141. Syvaoja HJ, Kantomaa MT, Ahonen T, Hakonen H, Kankaanpaa A, Tammelin TH. Physical activity, sedentary behavior, and academic performance in Finnish children. Med Sci Sports Exerc 2013;**45**:2098-104.
142. Syvaoja HJ, Tammelin TH, Ahonen T, Kankaanpaa A, Kantomaa MT. The associations of objectively measured physical activity and sedentary time with cognitive functions in school-aged children. PLoS ONE 2014;**9**:e103559.

Objectively measured sedentary behaviour and health outcomes in children and adolescents: Systematic review and meta-analysis. Cliff DP, et al. Early Start Research Institute, University of Wollongong, Northfields Ave, Wollongong, NSW, Australia 2522. +61 2 4221 5929. dylanc@uow.edu.au

Table S1: Search Strategy

#	**Search Terms**	**Date Limit**
1	Sedentar* OR sitting	Nil
2	Cardiometabolic OR insulin OR glucose OR metabolic OR cholesterol OR blood pressure OR triglyceride OR lipid	
3	Adiposity OR obes* OR overweight OR body fat OR body composition OR waist circumference OR skin?fold OR body mass index OR weight	Nil
4	Bone OR skeletal	Nil
5	Fitness OR cardiorespiratory OR musc* OR strength OR endurance OR conditioning	Nil
6	Asthma OR wheez* OR bronchitis OR respiratory	Nil
7	Anxiety OR depression OR Mental health OR self?esteem OR psychosocial OR quality of life OR social OR emotion*	Nil
8	Academic OR education* OR grade OR school OR cogniti* OR attention OR concentration OR executive function OR memory OR language OR intelligence	Nil
9	Skill* OR motor OR coordination	Nil
10	2 OR 3 OR 4 OR 5 OR 6 OR 7 OR 8 OR 9	Nil
11	1 AND 10	Nil
12	Child* OR adolescen* OR school OR youth OR juvenile OR teen* OR young person	Nil
13	Acceleromet* OR monitor OR inclinometer OR objective*	
14	11 AND 12 AND 13	Nil

Table S2: Characteristics of studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and adiposity outcomes** in children and adolescents

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Preschool (2-4y)									
Byun, 2013, (103), USA, CHAMPS & EDPAPC	CHAMPS: n=263 (51% girls; 62%) EDPAPC: n=155 (49.1% girls; 59%)	CHAMPS: 4.2 ± 0.6y; 3-5y EDPAPC: 4.0 ± 0.7y; 3-5y	CHAMPS: NR, 16.3 ± 1.6 kg/m^2 EDPAPC: NR, 15.9 ± 1.7 kg/m^2	Cross-sectional	Actigraph; ≤37.5 c/15s; ≥60 min; ≥1dNR, ≥360min/d; CHAMPS: 7.5d, 786min/d EDPAC: 7.5d, 456min/d	Total SB	BMI z-score	Age, gender, race, parent education levels, MVPA	NS
Collings, 2013, (108), USA, South-hampton Women's Survey	n=398 (49% girls; 39%)	4.10 ± 0.08y; 4y	20.1%, 16.3 kg/m^2	Cross-sectional	Actiheart; ≤30 c/15s; ≥ 100 min; ≥1d, ≥600min/d; 5.2d, 1425.6min/d	Total SB	Fat Mass Lean Mass Trunk fat mass %Body fat	Age, sex, birth weight, maternal education, maternal BMI, smoking during pregnancy, sleep duration, MVPA	NS for all
Espana-Romero, 2013, (87), USA, SHAPES	n=357 (49% girls; NR)	Boys: 4.5 ± 0.4y 3-5y Girls: 4.6 ± 0.3y; 3-5y	Boys: 27.9%, 16.3 kg/m^2 Girls: 28.7%, 16.3 kg/m^2	Cross-sectional	Actigraph; ≤200c/15s; NR; ≥2d, ≥360min/d; NR	Total SB	BMI z-score WC	Ethnicity/race, parental education	WC: Sig (+) for girls at 90th percentile. NS for boys and other percentiles.

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Children (5-12y)									
Bailey, 2012, (102), England, HAPPY	N=100 (59% girls, NR)	11.76 ± 1.33y; 10-14y	15%, z-score = -0.19	Cross-sectional	RT3; <288cpm; ≥10 min, ≥3d, ≥540min/d (weekdays), ≥480min/d (weekend days); 764.2 min/d	Total SB	WC	Age, sex, ethnicity, SES	NS
Basterfield, 2012, (42), England, Gateshead Millennium Study	n=403 (51% girls;79%)	7.4-9.4y	BL: 24.6% FU: 32.5% NR	Longitudinal	Actigraph; <1100cpm; NR; ≥3d, 360min/d; BA: 6.4d, 666 min/day FU: 6.1d, 678min/d	Total SB	FMI BMI Z-score	BL FMI, BL BMI z-score, sex, SES, MVPA	NS for all
Butte, 2007, (48) USA, Viva La Familia Study	n=798 (49% girls; 90.1%)	NR 4-19y	52% overweight Boys NOW: 0.10 z-score OW: -0.0.1 z-score Girls: NOW: 0.14 z-score OW: -0.001 z-score	Longitudinal	Actiwatch; <50 cpm; NR; NR; NR	SB	FMI BMI	Sex, age, age squared, Tanner stage	NS for all

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Butte, 2007, (85), USA, Viva La Familia Study	n= 897 (51% girls; 87%)	10.8 ± 3.8y; 4-19y	NOW boys: 19.7 ± 3.6 kg/m^2 OW boys: 30.5 ± 7.2 kg/m^2 NOW girls: 19.7 ± 3.8 kg/m^2 OW girls: 29.6 ± 6.4 kg/m^2	Cross-sectional	Actiwatch; NR; NR, ≥1000/ 1440min/d; NR, 1410min/d	Total SB	WC %FM	Age, gender, %FM	WC: Sig (+) %FM: Sig (+)
Carson, 2014, (52), Canada, Project BEAT	n=787 (54% girls; 46.2%)	11.1 ± 0.7y	37%, NR	Cross-sectional	Actigraph; ≤100cpm; ≥60 min; ≥4d (including 1 weekend day), ≥600min/d; ≥7d, 863min/d	Total SB SB breaks SB bouts (1-4 min; 5-9 min; 10-19 min; 20-29 min; ≥30 min)	BMI z-score	Age, sex, SES, MVPA	Total SB: NS SB breaks: NS SB bouts: 5-9 and 10-19 min bouts for total days: Sig (+) for low MVPA group only. 1-4 min SB bouts on weekends: Sig (+) for high MVPA group only.

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Casazza, 2009, (104), USA, NR	N=202 (47% girls; NR)	Whole sample: 9.63 ± 0.1y	Whole sample: 18.58 ± 0.2 kg/m^2	Cross-sectional	Actigraph; NR; NR; NR; NR	Total SB	WC	Total body fat, age, sex, SES	NS
Chaput, 2012, (105), Canada, QUALITY	n=550 (46% girls; 87%)	9.6 ± 0.9y; 8-10y	41%; NR	Cross-sectional	Actigraph; ≤100cpm; ≥60min; ≥4d, ≥600min/d; NR	Total SB	BF% Waist/height ratio	MVPA, age, sex, sleep duration, energy intake, sexual maturation (Tanner stage), parental socioeconomic status, parental BMI	NS
Chaput, 2013, (107), Canada, QUALITY	n=536 (46% girls; 87%)	9.6 ± 0.9y; 8-10y	41%; NR	Cross-sectional	Actigraph; ≤100cpm ≥60 min; ≥4d (including 1 weekend d), ≥600min/d; 6.5d, NR	Total SB	WC	Age, sex, sleep duration, energy intake, sexual maturation (Tanner stage), parental socioeconomic status, and parental BMI, MVPA	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Chaput, 2014, (106), Canada, ISCOLE	N=507 (59% girls; 89%)	10.0 ± 0.4y; 9-11y	NR 18.3 kg/m^2	Cross-sectional	Actigraph; ≤100cpm; NR; ≥4d (including 1 weekend d), ≥600min; NR	Total SB	Body fat WHtR	Age, sex, ethnicity, maturity offset, fast food consumption annual household income, highest level of parental education, sleep, MVPA	NS for all
Chinapaw, 2012, (64), Hungary & The Netherlands, ENERGY	N=142 (51% girls; 68%)	12.2 ± 0.6y; 10-13y	28% 19.8 kg/m^2	Cross-sectional	Actigraph; ≤100cpm; ≥20 min; ≥4d (including 1 weekend d), ≥600min/d on weekdays, ≥480 min/d weekend; NR	Total SB	WC	Sex, country, number of sedentary bouts, MVPA	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Colley, 2012, (11) Canada, CHMS	n=878 (48% girls; 45.8%)	8.7y NR; 6-11y	23%, 17.8kg/m^2	Cross-sectional	Actical; ≤100cpm; ≥60 min; ≥4d, ≥600min/d; NR	Total SB	BMI WC	Age, sex, MVPA, sleep, screen-time	NS for all
Colley, 2013, (108) Canada, CHMS	n=1608 (50% girls; 40.8%)	Boys: 8.2 – 17 yr Girls: 8.1 – 16.9 yr; 6-19y	Boys: 17.8-23.4 kg/m^2 Girls: 17.0-22.6 kg/m^2	Cross-sectional	Actical; ≤100cpm; ≥ 60 min; ≥4d (including 1 weekend d), ≥600min/d; NR	Total SB SB weekdays after 3pm SB weekends SB breaks SB bouts (20, 40, 60, 80, 100, 120 min)	BMI WC	Age, MVPA	WC: Number of breaks on weekdays after 3pm sig (-) in boys 11-14 yr; BMI & WC: 80 min bouts on weekdays after 3pm sig (+) in boys 11-14 yr; NS for all others

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
De Bourdeaudhuij, 2012, (86)Hungary, Belgium, the Netherlands, Greece, Switzerland, ENERGY	N=766 (53% girls; NR)	11.5 ± 0.8y 10 -12 y	BMI 18.8 kg/m^2	Cross-sectional	Actigraph; ≤100 cpm; ≥20 min; ≥3d, ≥600min on weekday, ≥480 min weekend; NR	Total SB	BMI WC	Age	Girls: Cluster with low SB and high MVPA had lower BMI and WC than others. Boys: NS
Deforche, 2009, (109) Belgium, NR	N=97 (53% girls; 49%)	8.6 ± 1.4y 6-10y	49%; 24.2 ± 4.8 kg/m^2	Cross-sectional	CSA/MTI accelerometers; <500 cpm; ≥60 min; ≥3d, ≥600 min/d; NR	Total SB	BMI z-score	Parents BMI	NS
Ekelund, 2007, (118) Denmark, Estonia, Portugal, EYHS	n=1709 (53% girls; 89%)	9.7 ± 0.4y; 15.5 ± 0.5y; 9-15y	17.3 kg/m^2 20.8 kg/m^2	Cross-sectional	Actigraph; <500cpm; ≥10 min; ≥4d, NR; NR	Total SB	WC BMI	Sex, age, study location, analysis birthweight, sexual maturity, smoking status, BMI, parental socioeconomic status, CRF	NS for all

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Ekelund, 2012, (96) International, ICAD	Cross-sectional: n=20,871 (52% girls; NR) Longitudinal: n=6,413	11.3 ± 2.8y; 4-18y	25.1%, 19.3 kg/m^2	Cross-sectional (BL) and longitudinal (2.1y)	Actigraph; ≤100cpm; ≥60 min; ≥1d, ≥500min/d; 5.2d, 835 min/d	Total SB	WC	Age, sex, monitor wear time, MVPA	NS for all
Fenton, 2015, (112), England, PAPA	n=118 (100% boys; 79%)	11.7 ± 1.6y; 9-15y	18.6 ± 3.2 kg/m^2	Cross-sectional	Actigraph; ≤100cpm; ≥30 min; ≥4d, ≥480min/d; NA, 768 min/d	Total SB	%Body fat, WC, BMI z-score	Age, ethnicity, season, monitor wear time, MVPA	NS for all
Fisher, 2011, (43), UK, PEACHES	N=280 (49% girls; 53%)	BA: 8.8 ± 0.37y FU: 9.7 ± 0.37y	BA: 16.94 FU: 17.52	Longitudinal (1y)	Actigraph; ≤100cpm; ≥10 min; ≥3d, ≥600min; NR	Total SB	BMI FMI WC	BL BMI, SES, sex, ethnicity, MVPA	NS for all
Grydeland, 2012, (101), Norway, HEIA	n=1103 (50% girls; 70%)	11.2 ± 0.3y;11y	13%, 17.9 kg/m^2	Cross-sectional	Actigraph; ≤100cpm; ≥20 min; ≥3d, ≥480 min/d; NR, 784 min/d	Total SB	BMI	Gender, pubertal status, parental education, breakfast consumption, TV, computer game, MVPA	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Hjorth 2014, (45), Denmark, OPUS	N= 785 (52% boys, NR)	Boys: 10.0 ± 0.6y Girls: 9.9 ± 0.7y 8-11y	13.4% , boys 0.19 z-score, girls 0.06 z-score	Cross-sectional and longitudinal	Actigraph; ≤100cpm; ≥15 min ≥ 4d; ≥10h/d; NR	Total SB	BMI z-score, FMI, Fat free mass, BF	BL age, sex, year, pubertal status, no. parents born in Denmark, parent highest education, weight, height, PA, MVPA, sleep duration, diet	NS for all
Hjorth, 2014, (44), Denmark, OPUS	N=723 (48% girls; 76%)	10.06 ± 0.6y; 8-11y	13.4%, BMI z-score[2] 0.146	Cross-sectional and longitudinal	Actigraph; ≤100cpm; ≥60 min; 4d, ≥ 600 min; NR	Total SB	WC	BL age, sex, pubertal status, sex-pubertal status interaction, days of follow up, BL SB, BL cardio metabolic risk component, MVPA, sleep duration, FMI	BL: Sig (+) FU: Sig (+)
Hussey, 2007, (88), UK, NR	n=152 (66% girls; 68%)	NR 7-10y	Boys: 28.5% Girls: 25.7% NR	Cross-sectional	RT3 accelerometer; 100-970cpm; NR; ≥4d, NR;	Total SB	BMI z-score WC	Age, gender, BMI z-score WC	WC: Sig (+) in boys. NS for all others

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Katzmarzyk, 2015, (113), International, ISCOLE	n=6,539 (54% girls, 89%)	10.4 ± 0.6y; 9-11y	12.4% obese; 18.4 kg/m^2	Cross-sectional	Actigraph; ≤100cpm; 20min; ≥4d, ≥600min/d 888min/d	Total SB	BMI z-score	Sex, wear time, clustering, MVPA	NS
Kennedy, 2012, (89), Scotland, NR	n=36 (44% girls; NR)	6.7 ± 0.6y; 6-7y	NR 0.33	Cross-sectional	Actigraph; ≤100cpm; NR; ≥3d, ≥600min/d;	Total SB	BMI Z-score FMI LMI	Size, age, weight, height	LMI: Sig (+) NS for all others
Kwon, 2013, (46), USA, IBDS	n=554 (50% girls; 93%)	BA: 8.8y FU: 15.4y; 8-15y	NR BA: Boys: 18.3 kg/m^2 Girls: 17.8 kg/m^2 FU: Boys: 22.7 Girls: 22.9 kg/m^2	Longitudinal (9y)	Actigraph; ≤100cpm; NR; ≥3d, ≥600min/d; NR	Total SB Breaks SB	Body fat mass	Age, body size, physical maturity	NS
Latt, 2015, (114), Estonia	n=136 (100% boys; 43%)	11.9 ± 0.7; NR	33.8% 20.4 kg/m^2	Longitudinal (2y)	Actigraph; ≤100cpm; 10min; ≥3d, ≥480min/d, NR	Total SB	BMI	Age, tanner stage	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Marques, 2015, (98), Portugal	n=2506 (53% girls; 79%)	13.2 ± 2.3y	30.9% NR	Cross-sectional	Actigraph; NR; ≥3d; ≥600min/d; NR	Total SB	BMI	MVPA, health-related fitness	NS
Marques, 2015, (92), Portugal	n=510 (49% girls; 49%)	10.1 ± 0.8y	33% NR	Cross-sectional & Longitudinal (1.7y)	Actigraph; ≤100cpm; 60min; ≥3d; ≥600min/d; NR	Total SB	BFM TFM FMI	Age, sex, maturity status, follow-up duration, outcome at baseline, MVPA	FMI: Longitudinal = Sig (-). NS for all others
Mitchell, 2009, (97), England, ALSPAC	n=5434 (52% girls; NR)	11.8 ± 0.2y 0-11y	30.3% 19.0 kg/m^2	Cross-sectional	Actigraph; <199cpm; NR; ≥3d, ≥600min/d; 437min/d	Total SB	BMI	MVPA, gender, social factors, early life sleep and TV habits, pubertal status	NS
Oliver, 2011, (94), NZ, PIF:PAC	n=102 (56% girls; 39%)	6.0y	99% NR	Cross-sectional	Actical; NR; ≥3d, ≥420min/d; NR	Total SB	BMI Fat Free mass	Maternal body size, child weight at birth, sleep time, socio-economic status	NS for all
Oliver, 2013, (55), NZ, PIF:PAC	n=126 children (59%; NR)	5.9y 5.8-6.7y	NR	Cross-sectional	Actical; ≤100cpm; NR ≥3d, ≥420min/d; 84.8min/d	Total SB Breaks/h Breaks duration	WC		NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Purslow, 2008, UK, (110), PEACHES	n=301(49% girls; 88%)	8.6 ± 0.4y;8-9y	20%, BMI SDS=0.15 (1.32)	Cross-sectional	Actigraph; ≤100cpm; NR; ≥3d, ≥600min/d; NR	Total SB	BMI WC	Age, sex, ethnicity, SES	NS for all
Saunders, 2013, (51), Canada, QUALITY	N=522 (45% girls; 83%)	9.2y 9.0-9.3y	NR	Cross-sectional	Actigraph; <100cpm; 60 min; ≥4d, ≥10h/d; 6.5d, 13.7h/d	Total SB Breaks in SB SB bouts	BMIz WC	Age, LPA, MVPA, SB (for breaks/bouts), BMIz, sexual maturation, parental education and income	BMIz: Sig (-) for breaks & bouts (1-4 min) for all. Sig (+) for bouts (10-14 min) for boys. WC: Sig (-) for bouts (5-9 min) for girls.

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Stamatakis, 2015, (56), England, ALSPAC	n=4,639 (53% girls, 46%)	11.8 ± 0.2y 11-12y	21.4 kg/m^2	Longitudinal (4y)	Actigraph; <199cpm; 10min; ≥3d, ≥600min/d; 4539.6min/d	Total SB	BMIz, WC, BF%, LBM%	Gender, wear time, age at measurement of outcome, time between measurements, paternal social class, birth weight, maternal BMI, Tanner stage (11y), age at measurement of Tanner stage, energy intake (10y), MVPA (11 y), baseline outcome (11y)	NS
Steele, 2009, (111), UK, SPEEDY	n=1,862 (56% girls;90%)	Boys: 10.2 ± 0.03y Girls: 10.3 ± 0.03y; 10y	23%, Boys: 17.9±2.9 kg/m^2 Girls: 18.4±3.3 kg/m^2	Cross-sectional	Actigraph; ≤100cpm; ≥10 min;≥3d, ≥500min/d; NR	Total SB	WC FMI BMI	Age, gender, school, SES, birth weight, maternal BMI, sleep duration, height, nutritional intake, MVPA	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Treuth, 2005, (91), USA, NR	n=229 (57% girls; 98%)	Boys: Elementary: 9.3 ± 1.0y Middle: 12.3 ± 1.2y High: 15.9 ± 1.4y Girls: Elementary: 9.2 ± 0.8 Middle: 11.8 ± 1.0y High: 15.9 ± 1.2y. 7-19y	Boys: Elementary: 51%, 19.9 kg/m^2 Middle: 38%, 21.8 kg/m^2 High: 20%, 22.6 kg/m^2 Girls: 39%, Elementary: 19.8 kg/m^2 Middle: 48%, 23.0 kg/m^2 High: 32%, 24.2 kg/m^2	Cross-sectional	Actiwatch ≤100cpm; NR; ≥4d (2 weekend d), ≥1000min; NR	Total SB	BMI Body fat		BMI & BF: Sig (+) for girls, NS for boys
Trinh, 2013, (47), Australia, LEAP2	n=126 (61% girls; 48.8%)	7.3 ±1.4y; 5-10y	100%, 1.8 BMI z-score	Longitudinal (3y)	Actical; ≤100cpm; ≥20 min; ≥5d, ≥600 min; NR	Total SB	BMI	Initial PA, intervention status, gender, age, SEIFA, maternal BMI, maternal education	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Adolescents (13-18y)									
Aires, 2010, (99), Portugal, NR	n=111 (56% girls; 9%)	14.5 ± 1.6y; 11-18y	Girls: 27.4% Boys: 38.8%, 22.2 ± 3.5 kg/m^2	Cross-sectional	MTI accelerometer; <500cpm; 10 min; ≥5d (4 weekdays, 1 weekend d), ≥600 min/d	Total SB (min/day)	BMI	Age, gender	NS
Atkin, 2013, (66), Europe, EYHS	n=1031 (53% girls; 48%)	9-10y Girls: 9.6±0.4y Boys: 9.7±0.4y 15-16y Girls: 15.6±0.5y Boys: 15.6±0.4y	17.1 kg/m^2	Cross-sectional	Actigraph; <800cpm; >100min; ≥1d, ≥500min/d; NR	Total SB	Sum of skinfolds	Age, age group, sex, study location, sexual maturity, day of the week, season, wear time, adiposity, average activity intensity (cpm)	Sig (+) for 100cpm cut-point and 10min and 20min non-wear criteria. NS for all others

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Carson, 2011, (54), USA, NHANES	n=2527 (49% girls; 39%)	13y; 10-16y	NR	Cross-sectional	Actigraph; ≤100cpm; >20 min; ≥4d (≥1 weekend day), ≥600min/d; 834 min/d	Total SB SB breaks SB bouts	WC	Age, gender, ethnicity, SES, smoking, total fat, saturated fat, dietary cholesterol, sodium, MVPA, SB (for breaks and bouts)	NS for all
Dowd, 2014, (41), UK, NR	n=195 (100% girls; 90%)	15.7 ± 0.9y; 13.1-18.7y	27.7%, 21.7 kg/m^2	Cross-sectional	ActivPal; ≥60 min; 240min non-wear time/d; ≥4d (≥1 weekend day): NR	Total SB	BMI Skinfolds	Age, school, MVPA,	NS for all
Hsu, 2012, (93), USA, NR	n=105 (75% girls; 56.1%)	13.1 ± 3.0y; NR	NR, BMI% = 90.6±16.9	Cross-sectional	Actigraph; ≤100cpm; ≥60 min; ≥4d, ≥600min/d; NR	Total SB	BMI WC	Age, gender, ethnicity, pubertal Tanner stage, fat mass and lean mass, MVPA	NS for all

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Loprinzi, 2015, (115), USA, NHANES	n=2,644 (NR; 47%)	Children: 6-11y Adolescents: 12-17y	NR	Cross-sectional	Actigraph; ≤100cpm; ≥60 min; ≥4d, ≥600min/d; 13.6 (children) & 14.2 (adolescents) min/d	Total SB	BMI, BMI%, WC, tricep SF, Subscap-ularis SF, Android BF%, Gynoid BF%, Total BF%	Age, gender, race-ethnicity, cotinine, poverty-to-income ratio, accelerometer wear time, energy intake, LPA, MVPA	NS for all
Machado-Rodrigues, 2012, (90), Portugal, MALS	n=362 (54% girls; 74%)	NR 13-16y	22%; Boys Rural: 20.5 kg/m^2 Urban: 19.6 kg/m^2 Girls Rural: 21.3 kg/m^2 Urban: 20.7 kg/m^2	Cross-sectional	Actigraph; ≤100cpm; 20 min; ≥5d, ≥600min/d; NR	Total SB, Weekday SB, Weekend SB	BMI	Age, gender, wear time	Urban: Sig (+) for SB weekday SB, weekend SB, and total SB. Rural: Sig (+) for SB weekday. NS for all others

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score)	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Martinez-Gomez, 2010, (100), Spain, AFINOS	n=201(99% girls; 87%)	Boys: 14.7 ± 1.2y Girls: 14.9± 1.3y 13-17y	NR Girls: 21.8 kg/m^2 Boys: 22.2 kg/m^2	Cross-sectional	Actigraph; <100cpm; ≥10 min; ≥4d (≥1 weekend d), ≥600min/d; NR	Total SB	Sum of skinfolds WC	Age, sex, developmental stage, tobacco intake,	NS for all
Mitchell, 2013, (49), USA, Study of Early Child Care and Youth Development	n=740 (51% girls; 55%)	NR 9-15y	NR	Longitudinal (6 y)	Actigraph; <100cpm; ≥60 min; ≥600 min/d, ≥3d; ≥2296 min/day	Total SB	BMI	MVPA, gender, race, maternal education, hours of sleep and healthy eating index	Sig (+) at 90th, 75th & 50th percentiles. NS for others.
Treuth, 2009, (50), USA, TAAG	n=1968 (100% girls; 38%)	6th Grade: 11.9 ± 0.4y 8th Grade: 13.9 ± 0.4y	6th Grades: 33%, 20.7 kg/m^2 8th Grades: 35%, 22.6 kg/m^2	Longitudinal (3y)	Actigraph; <50c/30s; NR; ≥1d, ≥360min/d	Total SB	BMI Body fat	PA, race, grade, field center, school within field center, student within school within field center	Body fat: Sig (-) BMI: NS

Abbreviations: ALSPAC, The Avon Longitudinal Study of Parents and Children; BEAT, Built Environment and Active Transport; BF, body fat; BMI, body mass index; BMIz, BMI z-score; BL, baseline; CHAMPS, The Children's Activity and Movement in Preschool Study; CHMS, The Canadian Health Measures Survey; CRF, cardio respiratory fitness; CS, cross-sectional; EDPAPC, Environmental Determinants of Physical Activity in Preschool Children; ENERGY, European Energy Balance Research; EYHS, European Youth Heart Study; FMI, fat mass index; FU, follow-up; HEIA, The Health in Adolescents Study; IBDS, The Iowa Bone Development Study; ISCOLE, The International Study of Childhood Obesity, Lifestyle and the Environment; ICAD, The International Children's Accelerometry Database; LBM%, lean body mass percent, LEAP, Live Eat and Play; MALS, Midlands Adolescent Lifestyle Study; MVPA, moderate-to-vigorous physical activity; NHANES, Nutrition Health and Nutrition Examination Survey; NR, not reported; NS, not significant; OPUS, Optimal well-being, development and health for Danish children through a healthy New Nordic Diet; Sig, significant; PIF:PAC, The Pacific Islands Families: Child and Parental Physical Activity and

Body Size; PEACHES, Physical Exercise and Appetite in Children Study, QUALITY: QUebec Adiposity and Lifestyle Investigation in Youth; SB, sedentary behavior; SEIFA, Socioeconomic Indexes for Area; SF, skin-folds; SHAPES, Study of Health and Activity in Preschool Environments; SPEEDY: Sport, Physical Activity and Eating behavior, Environmental Determinants in Young people; TAAG, Trial of Activity for Adolescent Girls; WC, waist circumference; (-), negative association; (+), positive association; [a] Consecutive 0 counts

Table S3: Risk of Bias scores for studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and adiposity** in children and adolescents

Adiposity outcomes				
Study Name (Author, year)	Representative Sampling (Yes/No)	Minimal Missing data (Yes/No)	Valid measure of SB (Yes/No)	Adjusted for MVPA (Yes/No)
Preschool				
Byun, 2013 (103)	1	0	1	1
Collings, 2013 (108)	0	0	1	1
Espana-Romero, 2013 (87)	0	0	0	0
Children				
Bailey, 2012 (102)	0	0	0	0
Basterfield, 2012 (42)	1	1	0	1
Butte, 2007 (48)	0	1	0	0
Butte, 2007 (85)	0	1	0	0
Carson, 2014 (52)	0	1	1	1
Casazza, 2009 (104)	0	0	0	0
Chaput, 2012 (105)	0	1	1	1
Chaput, 2013 (107)	0	1	1	1
Chaput, 2014 (106)	1	1	1	1
Chinapaw, 2012 (64)	1	0	1	1
Colley, 2012 (11)	1	0	1	1
Colley, 2013 (108)	1	0	1	1
De Bourdeaudhuij, 2012 (86)	1	0	1	1
Deforche, 2009 (109)	1	1	0	0
Ekelund, 2007 (118)	1	1	0	0
Ekelund, 2012 (96)	0	0	1	1
Fenton, 2015 (112)	0	1	1	1
Fisher, 2011 (43)	0	1	1	1
Grydeland, 2012 (101)	0	1	1	1
Hjorth, 2014 (cross-sectional) (45)	0	0	1	1
Hjorth, 2014 (longitudinal) (45)	0	1	1	1
Hjorth, 2014 (cross-sectional) (44)	0	0	1	1
Hjorth, 2014 (longitudinal) (44)	0	1	1	1
Hussey, 2007 (88)	1	0	1	0
Katzmarzyk, 2015 (113)	0	1	1	1
Kennedy, 2013 (89)	0	0	1	0
Kwon, 2013 (46)	0	1	1	0
Latt, 2015 (114)	0	0	1	0
Marques, 2015 (92)	0	0	1	1
Marques, 2015 (98)	1	1	1	1
Mitchell, 2009 (97)	1	0	0	1

Oliver, 2011 (94)	0	0	1	0
Oliver, 2013 (55)	0	0	1	0
Purslow, 2008 (110)	0	1	1	0
Saunders, 2013 (51)	0	1	1	1
Stamatakis, 2015 (56)	1	1	0	1
Treuth, 2005 (91)	0	1	0	0
Trinh, 2013 (47)	0	0	1	0
Steele, 2009 (111)	0	1	1	1
Adolescents				
Aires, 2010 (99)	0	0	0	0
Atkin, 2013 (66)	1	0	1	0
Carson, 2011 (54)	1	0	1	1
Dowd, 2014 (41)	0	1	1	1
Hsu, 2012 (93)	0	0	1	1
Loprinzi, 2015 (115)	1	0	1	1
Machado-Rodrigues, 2012 (90)	1	1	0	1
Martinez-Gomez, 2010 (100)	0	1	1	0
Mitchell, 2013 (49)	1	0	1	1
Treuth, 2009 (50)	0	1	1	0

1= present; 0 = absent/unclear

 Early Start Research Institute, University of Wollongong, Northfields Ave, Wollongong, NSW, Australia 2522. +61 2 4221 5929. dylanc@uow.edu.au

Table S4: Characteristics of studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and cardio-metabolic outcomes** in children and adolescents

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Children (5-12y)									
Bailey, 2012, (102), England, HAPPY	N=100 (59% girls, NR)	11.76 ± 1.33y; 10-14y	OW: 9%, OB: 6%, z-score -0.19	Cross-sectional	RT3; <288cpm; NR; ≥3d, ≥560min/d (weekdays), ≥480min/d (weekend days); NR	Total SB	BP, TC, HDL, TG, glucose	Age, sex, ethnicity and SES	NS for all
Butte, 2007, (85), USA, Viva La Familia Study	n= 897 (51% girls; 87%)	10.8 ± 3.8y; 4-19y	NOW boys: 19.7 ± 3.6 kg/m^2 OW boys: 30.5 ± 7.2 kg/m^2 NOW girls: 19.7 ± 3.8 kg/m^2 OW girls: 29.6 ± 6.4 kg/m^2	Cross-sectional	Actiwatch; <50 cpm; ≥20 min; NR, ≥1000/ 1440min/d; NR	Total SB	HDL, Insulin, Glucose, TC	Age, gender, BMI z-score, FM%	Insulin: Sig (+)

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Casazza, 2009, (104), USA, NR	n=202 (47% girls, NR)	9.63 ± 0.1y	18.58 ± 0.2 kg/m^2	Cross-sectional	Actigraph; NR; ≥7d, NR; NR	Total SB	SBP, Triglyceride level, HDL, Glucose level	Total body fat, age, sex, SES	Glucose: Sig (-) in Whites & Hispanics
Chaput, 2013, (107), Canada, QUALITY	n=536 (46% girls; 85%)	9.6 ± 0.9y 8-10y	41% NR	Cross-sectional	Actigraph; <100cpm; ≥60 min; ≥4d, ≥600min/d; 6.5d, NR	Total SB	Glucose, TG, HDL, SBP, DBP	Age, sex, MVPA, sleep duration, energy intake, sexual maturation, parental socioeconomic status, parental education, and parental BMI	NS for all
Chinapaw, 2012, (64), Netherlands & Hungary, ENERGY	n=142 (51% girls; 68%)	12.2± 0.6y 10-13y	28%, 19.8kg/m^2	Cross-sectional	Actigraph; <100cpm; ≥20min; ≥4d, ≥600min/d weekdays; ≥480min/d weekend, NR	Total SB	Glucose, HDL, LDL, TG, C-peptide, Metabolic risk	Gender, Country, Number of Sedentary bouts, MVPA, WC	NS for all

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Cliff, 2013, (77), Australia, HIKCUPS	n=126 (60% girls; 76%)	8.3 ± 1.1y 5.5-9y	100%, 24.7 kg/m^2, 2.8 z-score	Cross-sectional	Actigraph; 100 cpm; ≥20min; ≥3d, ≥600min/d; 7d, 756 min/d	Total SB	LDL, TC	Age, sex, adiposity (WC z-score or BMI z-score), and diet (energy intake or diet quality)	NS for all
Cliff, 2014, (57), Australia, HIKCUPS	n=120 (62% girls; 73%)	8.3 ± 1.1y 5.5-9y	100%, 24.7 kg/m^2, 2.8 z-score	Cross-sectional	Actigraph; 100 cpm; ≥20min; ≥3d, ≥600min/d; 7d, 756 min/d	Total SB SB bouts	TG, HDL, SBP, DBP, Insulin, Glucose, Clustered Metabolic Risk	Age, sex, WC z-score, energy intake, % energy from saturated fat, fiber intake, screen time, MVPA, monitor wear time and total SB (for bouts)	Total SB HDL: Sig (-) NS for all others 30min SB bouts HDL: Sig (-)
Colley, 2012, (11) Canada, CHMS	n=878 (48% girls; 45.8%)	8.7y NR; 6-11y	23%, 17.8kg/m^2	Cross-sectional	Actical; ≤100cpm; ≥60 min; ≥4d, ≥600min/d; NR	Total SB	DBP, non-HDL cholesterol	Age, sex, MVPA, sleep, screen-time	NS for all

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Colley, 2013, (108) Canada, CHMS	n=1608 (49% girls; 40.8%)	NR; 6-19y	Boys: 17.8-23.4 kg/m^2 Girls: 17.0-22.6 kg/m^2	Cross-sectional	Actical; <100cpm; >60min; ≥4d, ≥600min/d; NR	Total SB SB breaks Prolonged bouts SB	BP, Non-HDL	Age, MVPA, Wear time	NS for all
Ekelund, 2007, (118), Denmark, Estonia, Portugal, EYHS	n=1709 (53.1%girls; 89%)	9.7 ± 0.4y; 15.5 ± 0.5y; 9-15y	17.3 kg/m^2 20.8 kg/m^2	Cross-sectional	Actigraph; <500cpm; ≥10min; >4d, NR; NR	Total SB	BP, Glucose, Triacylglycerol, HDL	Sex, age, study location, analysis birth weight, sexual maturity, smoking status, BMI, parental socioeconomic status, CRF	NS for all
Ekelund, 2012, (96), International, ICAD	Cross-sectional: n=20,871 (52% girls; NR) Longitudinal: n=6,413	11.3 ± 2.8y; 4-18y	25.1%, 19.3 kg/m^2	Cross-sectional and longitudinal (2.1y)	Actigraph; <100cpm; ≥60min; ≥1d, ≥500min/d; 5.2d, 835 min/d	Total SB	SBP, Insulin, TG, HDL	Age, sex, monitor wear time, WC, MVPA	CS: NS FU: NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Gabel, 2015, (124), Australia, Transform-Us!	n=164 (53% girls; 27%)	8.7 ± 0.4y; 7-10y	22.2%, 17.4 kg/m²	Cross-sectional	Actigraph; <100cpm; ≥20min; ≥3d, ≥480min/d; NA, 717 min/d	Total SB SB breaks Frequency /Duration of 5-10min & >10min SB bouts	CRP, HOMA-IR, IL-2, IL-6, IL-8, IL-10, BDNF, PAI, sE-selectin, sICAM, sVCAM, TNF-α	Sex, WC, MVPA, diet density, clustering	NS for all
Henderson, 2012, (76), Canada, QUALITY	n=424 (48% girls; 67%)	9.7 ± 0.9y 8 – 10y	Girls: 43.5%,19.9 kg/m^2 Boys: 41.5%,19.3 kg/m^2	Cross-sectional	Actigraph; <100cpm; ≥60 min; ≥4d, ≥600min/d	Total SB	HOMA-IR, fasting insulin, Matsuda-ISI	Age, Sex, Pubertal development, % Body fat, Season, MVPA	NS
Henderson, 2014, (125), Canada, QUALITY	n=423 (48% girls; 67%)	9.7 ± 0.9y 8 – 10y	Girls: 43.7%,20.0 kg/m^2 , 0.8 z score Boys: 41.5%,19.3 kg/m^2 ,0.7 z-score	Cross-sectional	Actigraph; <100cpm; ≥60 min; ≥4d, ≥600min/d	Total SB	Insulin secretion - HOMA2-%B, AUC I/Gt30min, AUC I/Gt120min	Age, Sex, Pubertal development, % Body fat, Season, MVPA, HOMA2-IS or Matsuda-ISI	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Hjorth, 2014, (44), Denmark, OPUS	n=564 (48% girls; 76%)	10.06 ± 0.6y; 8-11y	13.4%, BMI z-score[2] 0.146	Cross-sectional and longitudinal	Actigraph; ≤100cpm; ≥60 min; 4d, ≥ 600 min; NR	Total SB	MAP $HOMA_{IR}$ TG HDL MetS-Score	Baseline age, sex, pubertal status, sex-pubertal status interaction, days of follow up, particular baseline movement behavior, baseline cardio metabolic risk component, MVPA, sleep duration, fat mass index	Baseline: $HOMA_{IR}$ & TG Sig (-) NS for others FU: $HOMA_{IR}$ & HDL-C Sig (-) NS for others
Hopkins, 2012, (119), UK, SportsLINX	n=116 (60% girls; 80%)	10.7 ± 0.3 10-11 y	19 kg/m^2	Cross-sectional & longitudinal (6 months)	Actigraph; <100cpm; >20min; ≥ 3d, ≥540 min/d; NR, 714.7 min/d	Total SB Changes in SB	Endoth-elial function	Maturation, gender, BMI, Total PA, High intensity PA	CS: NS FU: NS
Martinez-Gomez, 2009, (121), US, AFINOS	n=111 (49% girls; NR)	6.2 ± 1.5y 3-8y	NR; 15.87 kg/m^2	Cross-sectional	Actigraph; <100cpm; 3x20min; ≥3d, 600 min/d; NR, 299.9(84.2) min/d	Total SB	BP	Age, Sex, Height, Body, fat/adiposity	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Melo, 2015, (95), Portugal,	n=265 (50.9%girls; NR)	11.4 ± 0.5y 11-13y	29.4%, 19.6 ±3.4	Cross-sectional	Actigraph; <100cpm;≥60 min; >3d, >600min/d; NR	Total SB	HR rest, SBP, DBP, DIAM, IMT	Age, sex, maturity, PP	NS for all
Nettlefold, 2012, (122), Canada, Action Schools	n=102 (58% girls, 41%)	9.9 ± 0.6y 8-11y	NR; 17.5 kg/m^2	Cross-sectional	Actigraph; <100cpm; ≥30 min; ≥3d, ≥600min/d; NR	Total SB	Large or small arterial complianc e	Body Surface Area, BMI, SBP, Sex	NS
Sardinha, 2008, (117), Portugal, European Heart Study	n=308 (48% girls; 58%)	9.8 ± 0.3y	18.5% overweight 8.8% obese 18.0 kg/m^2	Cross-sectional	Actigraph; <500cpm; ≥10 min, >3d; >600min/d;	Total SB	Total and central FM Insulin	Sex, Sexual maturity, birth weight, total fat mass, central fat mass, MVPA, wear time	Insulin Sig NS for others
Saunders, 2013, (51), Canada, QUALITY	n=522 (45% girls; 83%)	9.2y 9.0-9.3y	NR	Cross-sectional	Actigraph; <100cpm; 60 min; ≥4d, ≥10h/d; 6.5d, 13.7h/d	Total SB Breaks in SB SB bouts	Insulin, Glucose, TG, HDL, hs-CRP, cMet	Age, LPA, MVPA, SB (for breaks/bouts), BMIz, sexual maturation, parental education and income	cMet risk: Sig (-) for breaks & bouts (1-4 min) for all. Glucose: Sig (+) for bouts (10-14 min) for girls. NS for others

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Stamatakis, 2015, (56), England, ALSPAC	n=2,963 (53% girls, 46%)	11.8 ± 0.2y 11-12y	21.4 kg/m^2	Longitudinal (4y)	Actigraph; <199cpm; 10min; ≥3d, ≥600min/d; 4539.6min/d	Total SB	Insulin, Glucose, TG, HDL, LDL, TC, CRP, cMet, SBP, DBP	Gender, wear time, age at measurement of outcome, time between measurements, paternal social class, birth weight, maternal BMI, Tanner stage (11y), age at measurement of Tanner stage, energy intake (10y), MVPA (11 y), baseline outcome (11y), BMI	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Adolescents (13-18y)									
Atkin, 2013, (66), Europe, EYHS	n=1031 (53% girls; 48%)	9-10y Girls: 9.6±0.4y Boys: 9.7±0.4y 15-16y Girls: 15.6±0.5y Boys: 15.6±0.4y	17.1 kg/m^2	Cross-sectional	Actigraph; <800cpm; >100min; ≥1d, ≥500min/d; NR	Total SB	Clustered metabolic risk	Age, age group, sex, study location, sexual maturity, day of the week, season, wear time, adiposity, average activity intensity (cpm)	Sig (+) for all cut-point and non-wear combinations except for 100 cpm and 60min or 100min non-wear
Carson, 2011, (54), USA, NHANES	n=2527 (49% girls; 39%)	13y 10-16y	NR	Cross-sectional	Actigraph; <100cpm; NR; ≥4d, ≥600min/d; NR, 834 min/d	Total SB SB breaks SB bouts	WC	Age, gender, ethnicity, SES, smoking, total fat, saturated fat, dietary cholesterol, sodium, MVPA, SB (for breaks and bouts)	NS for all
de Moraes, 2013, (123), Europe (Helena) & Brazil (BRACAH)	Helena- 3,308 (NR) BRACAH-991 (NR)	Helena- (NR) 12.5-17.5y BRACAH- (NR) 14-17.5y	NR	Cross-sectional	Actigraph; <100cpm; NR; ≥3d, ≥480min/d; NR	Total SB	SBP DBP	Age, SES, parental education, smoking, BMI, WC, and clustering	NS for all

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Gaya, 2009, (116), Portugal, NR	n=163 (60% girls; 31%)	Girls 14.0±1.7y Boys 13.9±1.7y; 11-17yrs	Girls: 21.21 kg/ m^2 Boys 21.68 kg/ m^2	Cross-sectional	Actigraph; <500cpm;NR; ≥4 days, ≥480min/d NR	Total SB	SBP DBP	Height, weight, gender, age	SBP: Sig (+) NS for DBP
Hsu, 2012, (93), USA, NR	n=105 (75% girls; 56%)	13.1 ± 3.0y 10-16y	17%; BMI percentile 90.55(±16.89)	Cross-sectional	Actigraph; <100cpm; ≥60 min; ≥4d, ≥600min/d; NR	Total SB	MetS, TG, HDL, Glucose, SBP, DBP	Age, gender, ethnicity, fat & lean mass, pubertal tanner stage,	NS for all
Martínez-Gómez, 2010, (100), Spain, AFINOS	n=201 (49% girls, 87%)	Boys 14.7 ± 1.2y Girls 14.9 ± 1.3y 13-17y	NR Girls 21.8 kg/ m^2 Boys 22.2 kg/ m^2	Cross-sectional	Actigraph; GTIM <100cpm;≥10min; ≥4 days incl. 1 weekend d, ≥600min/d; NR	Total SB	SBP, DBP, MBP, CT, TG, HDL-C, LDL-C, Glucose, Apo- A-1, Apo-B-100	Age, Sex, Developmental stage, Tobacco intake	SBP, TG, Glucose: Sig (+). NS for others

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Martínez-Gómez, 2012, (120), Spain, AFINOS	n=183 (48% girls, 79%)	14.8 ± 1.3y 13-17y	24.6%, 21.6 kg/m^2 1.2 z-score	Cross-sectional	Actigraph; GTIM <100cpm;≥10min; ≥4 days, ≥600min/d; NR	Total SB	WBC, CRP, C3 and C4, IL-6, adiponectin, leptin, CAM-1, VCAM-1, E-selectin, L-selectin, PAI-1	Age, Pubertal status, BMI, MVPA	NS for all

Abbreviations: AFINOS: Physical Activity as a Preventive Measure for Overweight, Obesity, Infection, Allergies and Cardiovascular Risk Factors in Adolescent; AUC I/Gt30min, area under the curve insulin/glucose t30min; AUC I/Gt120min, area under the curve insulin/glucose t120min; BMI, Body Mass Index; BRACAH, Brazilian Cardiovascular Adolescent Health; BDNF, brain-derived neurotrophic factor; C3, complement factor 3; C4, complement factor 4; CHMS, Canadian Health Measures Survey; cMet risk, cardio-metabolic risk; CRP, C-reactive protein; CS, cross-sectional; DBP, Diastolic Blood Pressure; DIAM: diameter of the common carotid artery; ENERGY, European Energy Balance Research; EYHS, European Youth Heart Study; FU, follow-up; The HAPPY study, the Healt and Physical Activity Promotion in Youth; HeLENA, Healthy Lifestyle in Europe by Nutrition in Adolescence; HDL, High-Density-*lipoprotein;* HIKCUPS, Hunter Illawarra Kids Challenge Using Parents Support; $HOMA_{IR,}$ Homeostatic model assessment of insulin resistance; HOMA2-IS, homeostatic model assessment version 2 index of insulin sensitivity; ICAD, The International Children's Accelerometry Database; IL, interleukin; ICAM-1 Intercellular adhesion molecule 1; IMT: intima-thickness of the common carotid artery; MAP, Mean Arterial bloodpressure; Matsuda-ISI, Matsuda-insulin sensitivity index; MetS, Metabolic syndrome; MR, Metabolic Risk; MVPA, moderate-to-vigorous physical activity; NR, not reported; NS, not significant; OPUS, Optimal well-being, development and health for Danish children through a healthy New Nordic Diet; NHANES, Nutrition Health and Nutrition Examination Survey; PAI, plasminogen activator inhibitor; QUALITY: Quebec Adiposity and Lifestyle Investigation in Youth; SB, sedentary behavior; SBP, Systolic Blood Pressure; SES, Socioeconomic Status; sE-selectin, soluble E-selectin, sICAM, soluble intracellular adhesion molecule; Sig, significant; sVCAM, soluble vascular adhesion molecule; TC, total cholesterol; TG, triglyceride; TNF-α, tumour necrosis factor; VCAM Vascular cell adhesion molecule; WBC, white blood cells; WC, waist circumference; (-), negative association; (+), positive association; [a] Consecutive 0 counts

Table S5: Risk of Bias scores for studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and cardio-metabolic outcomes** in children and adolescents

Cardio-metabolic outcomes				
Study Name (Author, year)	Representative Sampling (Yes/No)	Minimal Missing data (Yes/No)	Valid measure of SB (Yes/No)	Adjusted for MVPA (Yes/No)
Children				
Bailey, 2012 (102)	0	0	0	0
Butte, 2007 (85)	0	1	0	0
Casazza, 2009 (104)	0	0	0	0
Chaput, 2013 (107)	0	1	1	1
Chinapaw, 2012 (64)	1	0	1	1
Colley, 2012 (11)	1	0	1	1
Colley, 2013 (108)	1	0	1	1
Cliff, 2013 (77)	0	1	1	1
Cliff, 2014 (57)	0	1	1	1
Ekelund, 2007 (118)	1	1	0	0
Ekelund, 2012 (96)	0	0	1	1
Gabel, 2015 (124)	0	0	1	1
Henderson, 2012 (76)	0	0	1	1
Henderson, 2014 (125)	0	0	1	1
Hjorth, 2014 (cross-sectional) (44)	0	0	1	1
Hjorth, 2014 (longitudinal) (44)	0	1	1	1
Hopkins, 2012 (119)	0	1	1	0
Martinez-Gomez, 2009 (121)	0	0	1	0
Melo, 2015 (95)	0	0	1	1
Nettlefold, 2012 (122)	0	0	1	0
Sardinha, 2008 (117)	1	0	0	0
Saunders, 2013 (51)	0	1	1	1
Stamatakis, 2015 (56)	1	0	0	1
Adolescents				
Atkin, 2013 (66)	1	0	1	0
Carson, 2011 (54)	1	0	1	1
De Moraes, 2013 (123)	1		1	0
Hsu, 2012 (93)	0	0	1	1
Gaya, 2009 (116)	0	0	0	0
Martinez-Gomez, 2010 (100)	0	1	1	0
Martinez-Gomez, 2012 (120)	0	1	1	1

1= present; 0 = absent/unclear

Table S6: Characteristics of studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and fitness** in children and adolescents

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Children (5-12y)									
Butte, 2007, (85), USA, Viva La Familia Study	n= 897 (51% girls; 87%)	10.8 ± 3.8yr; 4-19y	NOW boys: 19.7 ± 3.6 kg/m^2 OW boys: 30.5 ± 7.2 kg/m^2 NOW girls: 19.7 ± 3.8 kg/m^2 OW girls: 29.6 ± 6.4 kg/m^2	Cross-sectional	Actiwatch; <50 cpm; ≥20 min; NR, ≥1000 min/d; NR, 1410min/d	Total SB	VO_2 peak	Age, gender, FMI	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Denton, 2013, (58), UK, HAPPY	n=135 (60% girls, 54%)	12 ± 1y 10-14y	NR BMI z-score = -0.3 ± 1.4	Cross-sectional	RT3 accelerometer <288cpm; ≥10 min; ≥3d, ≥540 min weekday, ≥600 min weekend day; 736 min/d	Total SB	CRF	Sex, age, ethnicity, SES, wear time	NS
Ekelund, 2007, (118), Europe, EYHS	n=1709 (53% girls; 89%)	9.7 ± 0.4y; 15.5 ± 0.5y; 9-15y	17.3 kg/m^2 20.8 kg/m^2	Cross-sectional	Actigraph <500cpm; ≥10 min; ≥4d, ≥NR; NR	Total SB	CRF	Sex, age, study location	Sig (-)
Fenton, 2015, (112), England, PAPA	n=118 (100% boys; 79%)	11.7 ± 1.6y; 9-15y	18.6 ± 3.2 kg/m^2	Cross-sectional	Actigraph; ≤100cpm; ≥30 min; ≥4d, ≥480min/d; NA, 768 min/d	Total SB	CRF	Age, ethnicity, season, monitor wear time, MVPA	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Hjorth, 2013, (128), Denmark, OPUS	n=635 (49% girls;76.1%)	10.06 ± 0.6y 8-11y	13.3% overweight/obese BMI z-score 0.13 ± 1.08	Cross-sectional	Actigraph <100cpm; ≥15 min; >7d, NR; NR	Total SB	CRF	MVPA age. Gender. Pubertal status	NS
Hussey, 2007, (88), UK, NR	n=152 (66% girls; 68%)	NR 7-10	Boys: 28.5% Girls: 25.7% NR	Cross-sectional	RT3 accelerometer; 100-970cpm; NR; ≥4d, NR;	Total SB	CRF	Age, gender, BMI z-score WC	NS
Moore, 2013, (126), USA, NR	n=285 (60% girls, 59%)	Middle school youth	48% overweight/obese> BMI percentile 85%	Cross-sectional	Actigraph <100cpm; ≥30min; ≥7d, ≥480min/d; NR	Total SB	CRF	Demographic characteristics and MVPA	Sig (-)
Adolescents (13-18y)									
Aires, 2010, (99), Portugal, NR	n=111 (56% girls; 11%)	14.5 ± 1.6y; 11-18y	Girls: 27.4% Boys: 38.8%, 22.2 ± 3.5 kg/m^2	Cross-sectional	MTI accelerometer <500cpm; ≥10 min; ≥5d, ≥600 min/d; NR	Total SB	CRF	Age, gender	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Machado-Rodrigues, 2012, (90), Portugal, MALS	n=362 (54% girls, 74%)	Male Rural: 14.3±1.1y Urban 14.1 ± 1.0y Female Rural 14.3 ±1.0y Urban 13.9 ± 1.0y 10-18y	21.9%overweight/obese Male Rural: 20.52 kg/m^2 Urban 53.5kg/m^2 Female Rural 53.4kg/m^2 Urban 13.9kg/m^2	Cross-sectional	Actigraph <NR; 20min; ≥5d, ≥600min/d; NR	Total SB	CRF	Age, gender, weartime	NS
Marques, 2015, (98), Portugal, NR	n=2506 (53% girls, 79%)	13.2 ± 2.3y 10-18y	23.1% overweight/obese NR	Cross-sectional	Actigraph <100cpm; ≥60min; ≥3d, ≥600 m/d; NR	Total SB	Fitness	Age, sex, weartime, MVPA	NS
Martinez-Gomez 2011, (129), Europe, HELENA-CSS	n=1808 (53% girls, 47%)	Low CRF 14.7 ± 1.2y High CRF 14.6±1.2y	Low CRF:22.5 kg/m^2 High CRF:20.2 kg/m^2	Cross-sectional	Actigraph <100cpm; 20min; ≥3d, ≥480min/d; NR	Total SB	CRF	Centre, age, BMI, weartime, MVPA	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Santos, 2014, (127), Portugal, NR	n=2506 (53% girls, 79%)	10-18y	23% overweight/obese NR	Cross-sectional	Actigraph <100cpm; ≥60min; >3d, ≥600 m/d;	Total SB	CRF	Age, gender, BMI, weartime, (participants were grouped by high/low SB and meeting/not meeting PA guidelines)	Sig (-)

CRF, Cardio-respiratory fitness; CS, cross-sectional; EYHS, European Youth Heart Study; FMI, fat mass index; FU, follow-up; HELENA-CSS, Healthy Lifestyle in Europe by Nutrition in Adolescence-Cross-Sectional Study; MALS, Midlands Adolescent Lifestyle Study; MVPA, moderate-to-vigorous physical activity; NR, not reported; NS, not significant; OPUS, Optimal well-being, development and health for Danish children through a healthy New Nordic Diet; SB, sedentary behavior; SES, socio-economic status, Sig, significant; The HAPPY study, The Health And Physical activity Promotion in Youth study; WC, waist circumference; (-), negative association, [a] Consecutive 0 counts

Objectively measured sedentary behaviour and health outcomes in children and adolescents: Systematic review and meta-analysis. Cliff DP, et al. Early Start Research Institute, University of Wollongong, Northfields Ave, Wollongong, NSW, Australia 2522. +61 2 4221 5929. dylanc@uow.edu.au

Table S7: Risk of Bias scores for studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and fitness outcomes** in children and adolescents

Fitness outcomes				
Study Name (Author, year)	Representative Sampling (Yes/No)	Minimal Missing data (Yes/No)	Valid measure of SB (Yes/No)	Adjusted for MVPA (Yes/No)
Children				
Butte, 2007 (85)	0	1	0	0
Denton, 2013 (58)	0	1	1	0
Ekelund, 2007 (118)	1	1	0	0
Fenton 2015 (112)	0	1	1	1
Hjorth, 2013 (128)	1	1	1	1
Hussey, 2007 (88)	1	0	1	0
Moore, 2013 (126)	0	1	1	1
Adolescents				
Aires, 2010 (99)	0	0	0	0
Machado-Rodriques, 2012 (90)	1	1	0	0
Marques, 2015 (98)	1	1	1	1
Martinez-Gomez, 2011 (129)	1	0	1	1
Santos, 2012 (127)	1	1	1	1

1= present; 0 = absent/unclear

Table S8: Characteristics of studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and bone and musculoskeletal outcomes** in children and adolescents

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	Variable	Variable		
Children (5-12y)									
De Smet, 2014, (130), Belgium, ChiBS	n=234 (49% girls; 76%)	9.8 ± 1.5y 6-12y	NR	Cross-sectional	Actigraph <100cpm; ≥20 min; ≥3d, ≥480 min/d; NR	Total SB	SOS, BUA, SI	Age, sex, fat mass (all outcome variables), ISCED-level (SOS only)	BUA & SI: Sig (-) SOS: NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	Variable	Variable		
Heidemann, 2013, (132), Denmark, CHAMPS	n=602 (51% girls, 81%)	11.5 ± 0.9y 9.7- 13.9y	NR	Longitudinal study (2 y)	Actigraph <100cpm; ≥20 min; ≥4d, ≥600 m/d; NR	Total SB	BMC BMD BA	Height, weight, age, puberty, baseline bone outcome, school, class,	BMC: Sig (+) NS for others
Herrmann, 2015, (131), Belgium, Estonia, Germany, Hungary, Italy, Spain, Sweden, and Cyprus, IDEFICS	Preschool: n=1,512 (47% girls; 24%) School-aged: n=2,953 (53% girls; 24%)	Preschool: 4.4 ± 0.9; 6-10y School-aged: 8.1 ± 1.2; 2- <6y	NR	Cross-sectional	Actigraph/Acti Trainer <100cpm; ≥20 min; ≥3d, ≥360 min/d; NR	Total SB	Bone stiffness index	Age, sex, country, fat free mass, milk & diary consumption, daylight duration, wear time, MVPA School-aged only: Also muscle strength	Preschool: NS School-aged: Sig (-)

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	Variable	Variable		
Ivuskans, 2015, (59), Estonia	n=169 (100% boys, NR)	12.1 ± 0.7y; 11-13y	NR, 19.8 kg/m^2	Longitudinal (12 months)	Actigraph <100cpm; 10min; ≥3d, ≥480min/d; 822.7 (baseline) and 759.1 (follow-up) min/day	Total SB	BMC, BMD, BA for TB, LS, FN	baseline SB, body mass, & pubertal stage; changes in age, pubertal stage, and body mass, VPA (for FN BMD only)	FN BMD & FN BMC: Sig (-) NS for others
Kennedy, 2013, (89), Scotland, NR	n=36 (44% girls, NR)	6.7 ± 0.6y NR	NR, *z* = 0.33 ± 1.18	Longitudinal study (6 yr)	Actigraph <100cpm; NR ≥3d, ≥600min; NR	Total SB	BMC & BMD for whole body, hip, & spine. Total hip bone area, Spine area, & BMAD z-score	Gender, age	Whole body BMD, total hip bone area & total hip BMC: Sig (-). NS for others

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	Variable	Variable		
Sardinha, 2008, (117), Portugal, EYHS	n=293 (49% girls, 55%)	9.7 ± 0.3y NR	NR, 18.1 kg/m^2	Cross-sectional	CSA (Actigraph) <100cpm; NR; ≥3d, ≥600min; NR	Total SB	TB BMC, LS BMC, FN BMC, Fyn compressive, FN bending, FN impact	Bone area, height, weight, fat-free mass, age	NS for all
Adolescents (13-18y)									
Chastin, 2015, (133), USA, NHANES	n=1,348 (50% girls, 49%)	13.8y 8-22y	NR, 22.3 kg/m^2	Cross-sectional	Actigraph <100cpm; ≥60 min; ≥5d, ≥600min; NR	Total SB, SB bout duration distribution	Femoral BMC Spinal BMC	Age, smoking, BMI, ethnicity + (if Sig) vitamin D, calcium intake, parental history of osteoporosis, alcohol intake (last 12mth), strength or vigorous exercise (girls) birth control and age of 1st menstruation	NS for all

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	Variable	Variable		
Gabel, 2015, (60), Canada, Healthy Bones III Study	n=206 (57% girls, 62.8%)	Males: 15.6y Females: 14.6y; 9-20y	NR	Cross-sectional	Actigraph <100cpm; ≥60 min; ≥3d, ≥600min; Males: 844.7min/d Females: 823.37min/d	Total SB, SB breaks	Bone architect-ure, Bone mineral density, Bone strength	Muscle cross-sectional area, limb length, maturity ethnicity, dietary calcium, PA	NS for all

BA, bone area; BMC, bone mineral content; BMD, bone mineral density; BUA, broadband ultrasound attenuation; CHAMPS, The Children's Activity and Movement in Preschool Study; ChiBS: Children's body composition and stress; CS, cross-sectional; EYHS, European Youth Heart Study; FN, Femoral Neck; FU, follow-up; ISCED, International Standard Classification of Education; LS, lumbar spine; MVPA, moderate-to-vigorous physical activity; NR, not reported; NS, not significant; PA, physical activity SB, sedentary behavior; SI, stiffness index; Sig, significant; SOS, speed of sound; TB, total body; VPA, vigorous physical activity; WC, waist circumference; (-), negative association; [a] Consecutive 0 counts

Table S9: Risk of Bias scores for studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and bone and musculoskeletal outcomes** in children and adolescents

Bone health outcomes				
Study Name (Author, year)	Representative Sampling (Yes/No)	Minimal Missing data (Yes/No)	Valid measure of SB (Yes/No)	Adjusted for MVPA (Yes/No)
Children				
De Smet, 2014 (130)	1	1	1	0
Heidemann, 2013 (132)	0	1	1	1
Herrman, 2015, (131)	0	0	1	1
Ivuskans, 2015, (59)	0	0	1	0
Kennedy, 2013 (89)	0	1	1	0
Sardinha, 2008 (117)	1	0	1	0
Adolescents				
Chastin, 2014 (133)	1	0	1	1
Gabel, 2015 (60)	0	0	1	1

1= present; 0 = absent/unclear

Table S10: Characteristics of studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and psychosocial outcomes** in children and adolescents

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Children (5-12y)									
Faulkner, (61), 2013, Canada, BEAT	n=787 (54% girls; 76.6%)	11.1 ± 0.6y; NR	29%	Cross-sectional study	ActiGraph <100cpm; ≥60min; ≥4d, ≥600min/d; 861.1 min/d	Total SB	Self-esteem, Self-worth	Sex, age, weight status, SES, accel weartime, school	NS for all
Herman, 2014, (84), Canada, QUALITY	n=527 (46% girls; 84%)	Boys: 9.64±1.0y Girls: 9.59±1.0y; 8-10y	40%	Cross-sectional	ActiGraph <100cpm; ≥60min; ≥4d, ≥600min/d; NR, 816min/d	Total SB	Self-rated health	Age, Tanner stage, BMI, MVPA	NS

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Martikainen, 2014, (134), Finland	n=283 (53% girls; 63%)	12.4 ± 0.5y; 11-13y	NR, 19.5 kg/m^2	Cross-sectional	Actiwatch <320cpm; ≥10min; NR, ≥600min/d; 8.4d	Total SB	Salivary cortisol: i) Upon awakening, ii) Awakening AUC, iii) At bed time, iv) In response to DST suppression	Time at awakening the day of, before and after sample, time difference, age, BMI, pubertal status, sleep duration, maternal occupation, maternal licorice consumption during pregnancy.	Girls: Awakening AUC – Sig (+) Boys: In response to DST suppression – Sig (+). NS for all others
Page, 2010, (135), UK, PEACH	n=1013 (51% girls, 75.6%)	10.9 ± 0.4y 10-11y	Male: BMI: 0.37 ± 1.1 kg/m^2 Female: BMI: 0.30 ± 1.2 kg/m^2	Cross-sectional	Actigraph <100cpm; 60 min; ≥3d, ≥600min/d; NR	Total SB	SDQ	MVPA, age, gender, level of deprivation, pubertal status, TV, computer use	Sig (-)

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Adolescents (13-18y)									
Hume, 2011, (136), Australia, CLAN	n=155 (60% girls; 38%)	14.5 ± 0.6y; 13-15y at baseline	2004 Wave 1 Boys: 26% Girls: 22% 2006 wave 2 Boys: 21% Girls: 28%	Cross-sectional and longitudinal (3y)	ActiGraph >50cpm; NR; ≥4d, days with <10,000cpm or > 20million counts or ≥360min of VPA were excluded; NR	Total SB	Depressive symptoms	MVPA, VPA, organized sport, TV viewing	NS

AUC, Area Under Curve; BEAT, Built Environment and Active Transport; BMI, body mass index; CLAN, Children Living in Active Neighborhoods; DST, dexamethasone suppression test; MVPA, Moderate- to vigorous-intensity physical activity; PEACH, Personal and Environmental Associations with Children's Health project; QUALITY, QUebec Adipose and Lifestyle InvesTigation in Youth; SDQ, Strength and Difficulties Questionnaires; SES, socioeconomic status; VPA, vigorous physical activity; [a]Consecutive 0 counts; (-), negative association; (+), positive association

Table S11: Risk of Bias scores for studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and psychosocial outcomes** in children and adolescents

Psychosocial outcomes				
Study Name (Author, year)	Representative Sampling (Yes/No)	Minimal Missing data (Yes/No)	Valid measure of SB (Yes/No)	Adjusted for MVPA (Yes/No)
Children				
Faulkner, 2014 (61)	0	0	1	1
Herman, 2014 (84)	0	1	1	1
Martikainen, 2014 (134)	0	0	0	0
Page, 2010 (135)	0	0	1	1
Adolescents				
Hume, 2011 (136)	0	0	1	0

1= present; 0 = absent/unclear

 Early Start Research Institute, University of Wollongong, Northfields Ave, Wollongong, NSW, Australia 2522. +61 2 4221 5929. dylanc@uow.edu.au

Table S12: Characteristics of studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and gross motor skill outcomes** in children and adolescents

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Preschool (2-4y)									
Cliff, 2009, (138), Australia, PANDA	n=46 (46% girls; 32%)	4.3 ± 0.7y 3-5y	NR 15.9 kg/m^2	Cross-sectional	ActiGraph <1100cpm; 20min; ≥3d, ≥360 min/d; 4.1d, 641 min/d;	Total SB	GMQ, Locomotor, Object control	Age, SES child, z-BMI	NS for all

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Williams, 2008, (139), USA, CHAMPS	n=198 (49.5% girls; 50%)	4.2 ± 0.5y 3-4y	NR 16.2	Cross-sectional	Actigraph; <37.5 c/15s; ≥60min; ≥3d, <300min, >1080min; NR	Total SB	Locomotor, Object control, Total skills	BMI, race, sex, parent education, age, preschool	NS for all
Children (5-12y)									
Lopes, 2012, (137), Portugal, The Bracara Study	n= 213 (52% girls, 36%)	9.46 ± 0.43y; 9-10y	NR	Cross-sectional	Actigraph <100cpm; ≥60min[a]; ≥3d, ≥600min/d; NR, 791 min/d	Total SB	MC	MVPA, wear time, WHtR, mothers education level	Sig

CS, cross-sectional; CHAMPS, Children's Health and Activity Monitoring for Schools; cpm, counts per minute; FMS, Fundamental Movement Skills; FU, follow-up; MC, Motor Coordination; MVPA, moderate-to-vigorous physical activity; NR, not reported; NS, not significant; PA, Physical Activity; PANDA, Preschool Activity 'N' Dietary Adiposity; SB, sedentary behavior; Sig, significant; WC, waist circumference; WHtR, Waist-to-Height Ratio; [a] Consecutive 0 count

Table 13: Risk of Bias scores for studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and gross motor skill outcomes** in children and adolescents

Gross motor skill outcomes				
Study Name (Author, year)	Representative Sampling (Yes/No)	Minimal Missing data (Yes/No)	Valid measure of SB (Yes/No)	Adjusted for MVPA (Yes/No)
Preschool				
Cliff, 2009 (138)	1	0	0	0
Williams, 2008 (139)	0	0	1	0
Children				
Lopes, 2012 (137)	1	0	1	1

1= present; 0 = absent/unclear

Table S14: Characteristics of studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and cognitive outcomes** in children and adolescents

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Children (5-12y)									
Syvaoja, 2013, (141), Finland, NR	n=220 (56% girls, 79%)	12.2 ± 0.7y NR	NR	Cross-sectional	Actigraph; <100cpm; 30min; ≥3d, ≥500min/d, NR	Total SB	GPA	Self-reported/ objectively measured PA, screen-time, sleep time, family background, parental education, family income, parents' marital status, child's learning difficulties	NS for all

Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor; SB cut-point; non-wear criteria[a]; minimum wear; and average wear (days (d) and min/d)	SB volume or pattern	Variable		
Syvaoja, 2014, (142), Finland, NR	n=224 (56% girls, 81%)	12.2 ± 0.6y NR	NR	Cross-sectional	Actigraph; <100cpm; 30min; ≥3d, ≥500min/d, NR	Total SB	Reaction time, Spatial span, Rapid visual informati-on processing, Working memory	Gender, parental education, child's need for remedial education, MVPA	Rapid visual information processing: Sig (+, non-hypothesised direction). NS for all others
van der Niet, 2015, (140), The Netherlands	n=77 (55% girls, 96%)	8.9 ± 1.0y 8-12y	NR	Cross-sectional	Actigraph; <100cpm; 20min; ≥4d, ≥540min/d, NR	Total SB	Inhibition, Working memory, Cognitive flexibility, Planning,	Gender, age, SES, wear time, reading proficiency.	Inhibition: Sig (-). NS for all others

GPA, Grade Point Average; NR, not reported; NS, not significant; PA, physical activity; SB, sedentary behavior; [a] Consecutive 0 counts

Table S15: Risk of Bias scores for studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and cognitive outcomes** in children and adolescents

Cognition outcomes				
Study Name (Author, year)	Representative Sampling (Yes/No)	Minimal Missing data (Yes/No)	Valid measure of SB (Yes/No)	Adjusted for MVPA (Yes/No)
Children				
Syvaoja, 2013 (141)	0	1	1	0
Syvaoja, 2014 (142)	0	1	1	1
van der Niet 2015 (140)	0	1	1	0

1= present; 0 = absent/unclear

Table S16: Characteristics of studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and other outcomes** in children and adolescents

Study	Participants	Age		Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country	Sample size (% girls; % with complete data)	Age (Years ± SD; range)	% overweight/ obese, BMI (kg/m^2 and/or z-score	Design (duration for longitudinal studies)	Monitor, cut-point, non-wear criteria[a], minimum wear and average wear (days and min/day)	Variable	Variable		
Children (5-12y)									
Martins, 2015, (63), Portugal,	N=131 (63% girls; 82%)	Girls: 10.8 ± 3.5y Boys 10.3 ± 3.6y 7-15y	Girls: 22.8 kg/m^2 Boys: 22.1 kg/m^2	Cross-sectional	Actigraph; <100cpm; 10min; >8h/d, >4d; 20mins, NR	Total SB	Serum alanine aminotra-nsferase	Gender, maturational stage, central obesity, cardio-respiratory fitness	Sig (+)
Adolescents (13-18y)									
Ruiz, 2014, (62), Europe, HELENA	N=718 (55% girls; NR)	14.7 ± 1.2y 12-18y	15%/4.5%; 20.7 kg/m^2	Longitudinal	Actigraph; <100cpm; 20mins >8h/d, >3d; 12.9h/d	Total SB	Liver enzymes (ALT, AST, AST/ALT, GGT)	Age, sex, centre, BMI, WC, FMI, MVPA	NS

BA, bone area; BMC, bone mineral content; BMD, bone mineral density; BMI, body mass index; BUA, broadband ultrasound attenuation; CHAMPS, The Children's Activity and Movement in Preschool Study; ChiBS: Children's body composition and stress; CS, cross-sectional; FMI, fat mass index; FN, Femoral Neck; FU, follow-up; ISCED, International Standard Classification of Education; ISCOLE, The International Study of Childhood Obesity, MVPA, moderate-to-vigorous physical activity; NR, not reported; NS, not significant; SB, sedentary behavior; SI, stiffness index; Sig, significant; SOS, speed of sound; WC, waist circumference; (-), negative association; [a]consecutive 0 counts.

Table S17: Risk of Bias scores for studies examining associations between the overall volume and patterns of objectively measured **sedentary behaviour and other outcomes** in children and adolescents

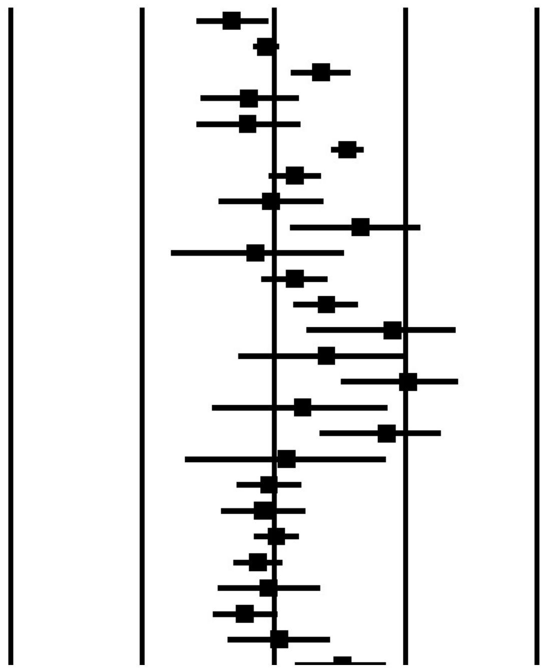
Other outcomes				
Study Name (Author, year)	Representative Sampling (Yes/No)	Minimal Missing data (Yes/No)	Valid measure of SB (Yes/No)	Adjusted for MVPA (Yes/No)
Children				
Liver Enzymes				
Martins, 2015 (63)	0	1	1	0
Liver enzymes				
Adolescents				
Ruiz, 2014 (62)	1	0	1	1

1= present; 0 = absent/unclear

Objectively measured sedentary behaviour and health outcomes in children and adolescents: Systematic review and meta-analysis. Cliff DP, et al. Early Start Research Institute, University of Wollongong, Northfields Ave, Wollongong, NSW, Australia 2522. +61 2 4221 5929. dylanc@uow.edu.au

Model	Study name	Subgroup within study	Correlation	Lower limit	Upper limit	Z-Value	p-Value
	Casazza (2009)	males/females	-0.160	-0.292	-0.022	-2.277	0.023
	Ekelund (2007)	males/females	-0.030	-0.077	0.017	-1.239	0.215
	Purslow (2008)	males/females	0.180	0.068	0.287	3.142	0.002
	Aires (2010)	males/females	-0.095	-0.276	0.093	-0.990	0.322
	Bailey (2012)	males/females	-0.100	-0.291	0.098	-0.988	0.323
	Butte (2007)	males/females	0.280	0.219	0.339	8.602	0.000
	Collings (2013)	males/females	0.080	-0.018	0.177	1.593	0.111
	Hussey (2007)	females	-0.010	-0.206	0.187	-0.098	0.922
	Hussey (2007)	males	0.330	0.063	0.553	2.400	0.016
	Kennedy (2013)	males/females	-0.070	-0.390	0.265	-0.403	0.687
	Kwon (2013)	females	0.080	-0.044	0.202	1.265	0.206
	Kwon (2013)	males	0.200	0.076	0.318	3.141	0.002
	Treuth (2005) Elementary	females	0.450	0.126	0.687	2.655	0.008
	Treuth (2005) Elementary	males	0.200	-0.133	0.492	1.182	0.237
	Treuth (2005) Middle	females	0.510	0.258	0.697	3.690	0.000
	Treuth (2005) Middle	males	0.110	-0.232	0.428	0.625	0.532
	Treuth (2005) High	females	0.430	0.175	0.631	3.186	0.001
	Treuth (2005) High	males	0.050	-0.336	0.422	0.245	0.806
	Byun (2013) CHAMPS	males/females	-0.019	-0.140	0.102	-0.306	0.759
	Byun (2013) EDPAPC	males/females	-0.041	-0.197	0.117	-0.506	0.613
	Chaput (2012)	males/females	0.010	-0.074	0.094	0.234	0.815
	Hjorth (2014)	males/females	-0.060	-0.150	0.031	-1.294	0.196
	Hsu (2012)	males/females	-0.020	-0.211	0.172	-0.202	0.840
	Machado-Rodrigues (2012) Rural	males/females	-0.110	-0.229	0.013	-1.760	0.078
	Machado-Rodrigues (2012) Urban	males/females	0.020	-0.172	0.211	0.202	0.840
	Fenton (2015)	males	0.260	0.083	0.421	2.854	0.004

Correlation and 95% CI



Model	Study name	Subgroup within study	Correlation	Lower limit	Upper limit	Z-Value	p-Value
	Casazza (2009)	males/females	0.220	0.085	0.347	3.155	0.002
	Cliff (2014)	males/females	-0.120	-0.293	0.061	-1.304	0.192
	Ekelund (2007)	males/females	0.080	0.033	0.127	3.311	0.001
	Bailey (2012)	males/females	0.000	-0.196	0.196	0.000	1.000
	Butte (2007)	males/females	0.070	0.005	0.135	2.096	0.036
	Hsu (2012)	males/females	0.040	-0.153	0.230	0.404	0.686
Fixed			0.075	0.040	0.110	4.191	0.000
Random			0.069	0.007	0.130	2.173	0.030

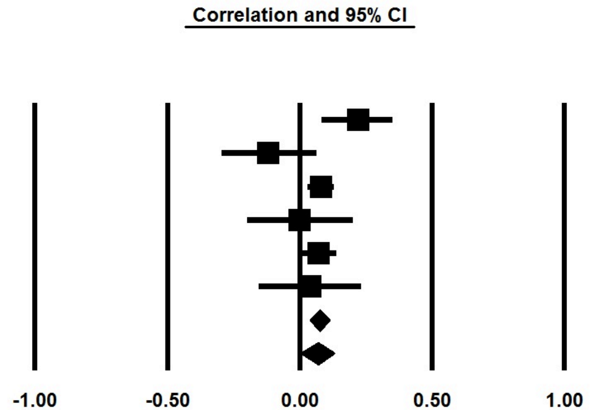


Figure S2: Forest plot for the association between objectively measured total sedentary behaviour and glucose or insulin in children and adolescents

Model	Study name	Subgroup within study	Statistics for each study				
			Correlation	Lower limit	Upper limit	Z-Value	p-Value
	Casazza (2009)	males/females	0.020	-0.118	0.158	0.282	0.778
	Cliff (2014)	males/females	-0.290	-0.446	-0.117	-3.229	0.001
	Ekelund (2007)	males/females	0.002	-0.045	0.049	0.083	0.934
	Bailey (2012)	males/females	0.060	-0.138	0.253	0.592	0.554
	Hsu (2012)	males/females	0.100	-0.093	0.286	1.013	0.311
Fixed			-0.005	-0.047	0.036	-0.244	0.808
Random			-0.021	-0.126	0.086	-0.378	0.705

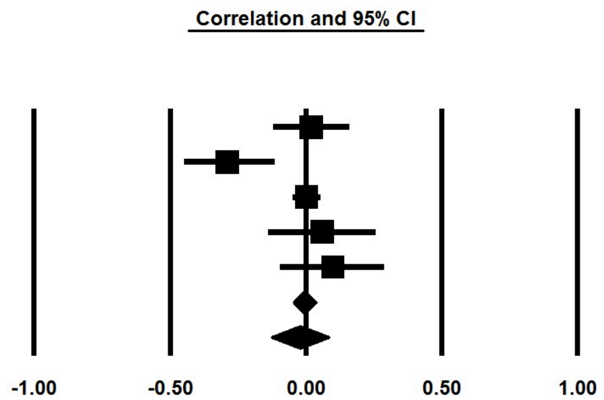


Figure S3: Forest plot for the association between objectively measured total sedentary behaviour and HDL cholesterol in children and adolescents

Model	Study name	Subgroup within study	Correlation	Lower limit	Upper limit	Z-Value	p-Value
	Casazza (2009)	males/females	-0.090	-0.225	0.049	-1.273	0.203
	Cliff (2014)	males/females	-0.040	-0.218	0.140	-0.433	0.665
	Ekelund (2007)	males/females	0.140	0.093	0.186	5.821	0.000
	Martinez-Gomez (2009)	males/females	0.064	-0.124	0.247	0.666	0.505
	Bailey (2012)	males/females	-0.030	-0.225	0.167	-0.296	0.768
	Hsu (2012)	males/females	-0.010	-0.201	0.182	-0.101	0.920
Fixed			0.095	0.054	0.135	4.575	0.000
Random			0.018	-0.084	0.119	0.343	0.732

Correlation and 95% CI

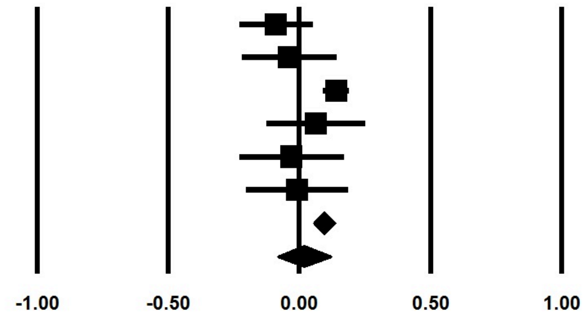


Figure S4: Forest plot for the association between objectively measured total sedentary behaviour and systolic blood pressure in children and adolescents

Model	Study name	Subgroup within study	Correlation	Lower limit	Upper limit	Z-Value	p-Value
	Cliff (2014)	males/females	-0.060	-0.237	0.121	-0.650	0.516
	Ekelund (2007)	males/females	0.140	0.093	0.186	5.821	0.000
	Martinez-Gomez (2009)	males/females	0.030	-0.157	0.215	0.312	0.755
	Bailey (2012)	males/females	-0.010	-0.206	0.187	-0.098	0.922
	Hsu (2012)	males/females	-0.100	-0.286	0.093	-1.013	0.311
Fixed			0.105	0.063	0.147	4.884	0.000
Random			0.020	-0.094	0.133	0.342	0.732

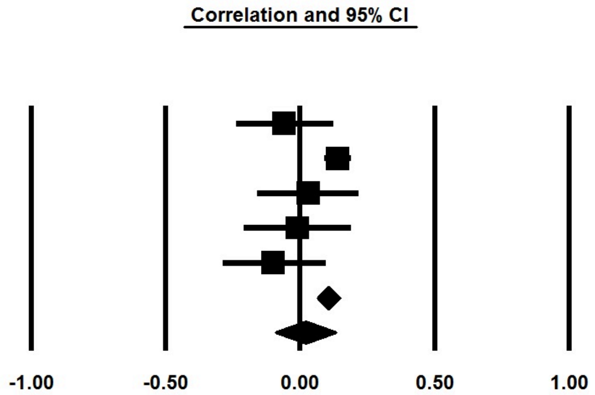


Figure S5: Forest plot for the association between objectively measured total sedentary behaviour and diastolic blood pressure in children and adolescents

Model	Study name	Subgroup within study	Statistics for each study: Correlation	Lower limit	Upper limit	Z-Value	p-Value
	Moore (2013)	males/females	0.110	-0.006	0.223	1.855	0.064
	Aires (2010)	males/females	0.105	-0.083	0.286	1.095	0.273
	Butte (2007)	males/females	-0.040	-0.105	0.026	-1.197	0.231
	Denton (2013)	females	-0.140	-0.348	0.081	-1.245	0.213
	Denton (2013)	males	0.000	-0.268	0.268	0.000	1.000
	Hjorth (2013)	males/females	-0.080	-0.152	-0.007	-2.162	0.031
	Hussey (2007)	females	-0.120	-0.309	0.078	-1.188	0.235
	Hussey (2007)	males	-0.140	-0.398	0.138	-0.986	0.324
	Ekelund (2007	males/females	-0.110	-0.157	-0.063	-4.562	0.000
	Machado-Rodrigues (2012) Rural	males/females	0.010	-0.113	0.132	0.159	0.873
	Machado-Rodrigues (2012) Urban	males/females	0.090	-0.103	0.277	0.911	0.362
	Fenton (2015)	males	-0.120	-0.294	0.062	-1.293	0.196
Fixed			-0.061	-0.090	-0.032	-4.067	0.000
Random			-0.039	-0.089	0.011	-1.515	0.130

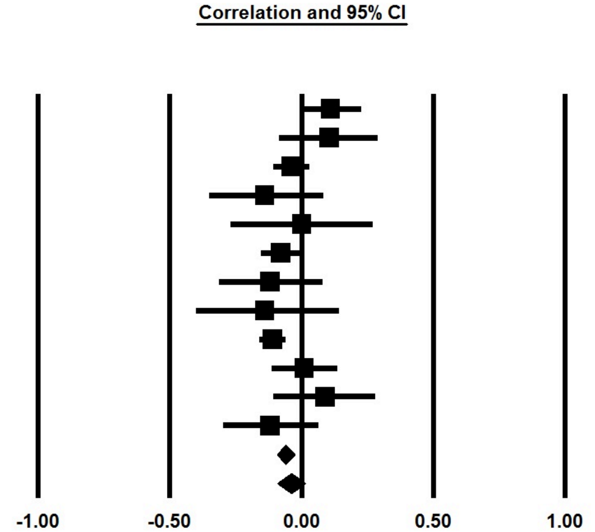


Figure S6: Forest plot for the association between objectively measured total sedentary behaviour and cardio-respiratory fitness in children and adolescents