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

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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

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

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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.

1 **Introduction**

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

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

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

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

44 **Methods**

45 *Study inclusion criteria*

46 This review aimed to identify all studies published in peer-reviewed journals that examined
47 associations between objectively measured sedentary behaviour or patterns of sedentary behaviour
48 and health outcomes in children and adolescents (2-18 years). The review was registered with
49 PROSPERO (CRD42014009084) and reported using the Preferred Reporting Items for Systematic
50 Reviews and Meta-Analyses (PRISMA) (26). The search was not delimited by date restrictions but
51 only included studies published in English. Studies were included if they met the following criteria:
52

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

4
5 *Intervention/exposure* – for observational studies, habitual daily/weekly total sedentary time or
6 patterns of sedentary behaviour were measured objectively (e.g., using wearable
7 monitors/accelerometers but not direct observation or heart rate monitoring). Studies that only used
8 subjective or objective measures of television viewing or electronic media use were not included.
9 Likewise, studies only assessing specific periods of sedentary behaviour, such as during school
10 recess, were excluded. For experimental studies, the intervention was required to incorporate a
11 component designed to decrease sedentary behaviour, and could not include strategies targeting
12 other behaviours, such as physical activity or diet, that may have influenced the health outcome of
13 interest. The control condition could not include strategies designed to reduce sedentary behaviour
14 or modify other behaviours that may have improved the targeted health outcome. Pre-test and post-
15 test values for the overall volume or pattern of sedentary behaviour must have been measured
16 objectively and reported for both groups.

17
18 *Outcomes* - for observational studies, associations between the exposure and an identified health
19 outcome (see below) were reported, and for experimental studies, the pre-test and post-test values or
20 treatment effect for an identified health outcome were reported.

21
22 *Study design* – the study was either observational or a controlled experiment (e.g., randomised or
23 non-randomised controlled trials).

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

31 *Search Strategy*

32
33 Four electronic databases were searched for relevant studies up to 12 November 2015: Ovid
34 MEDLINE (from 1950), Ovid EMBASE (from 1946), PubMed (from 1809), and Scopus (from
35 1960). An example search strategy can be found in Table S1. Articles were extracted and imported
36 into Endnote X7 (Thomson Reuters, San Francisco, CA) where duplicates were removed. Titles and
37 abstracts of potentially relevant articles were screened by two independent reviewers (a research
38 assistant and one of JV, AC, or DC), and full text articles were retrieved for all studies meeting
39 initial screening by at least one reviewer. Two independent reviewers screened all full text articles
40 for eligibility (a research assistant and one of JV, AC, or DC) and any discrepancies were discussed
41 to reach consensus. To supplement the electronic database search, international researchers were
42 contacted via the Sedentary Behaviour Research Network (<http://www.sedentarybehaviour.org/>)
43 listserv and asked to identify any additional published or accepted papers.

44 *Data extraction*

45
46 Data were extracted by a research assistant and checked by one of six reviewers (AP, NR, AO, SV,
47 RP or LH). We extracted descriptive information on the study sample (size, percentage of girls,
48 percentage with complete data, age, percentage of sample overweight or obese, BMI and/or BMI z-
49 score, and cultural background), study design (and duration of follow-up for longitudinal studies),
50 exposure measurement (activity monitor type, cut-point to define sedentary behaviour, inclusion
51 criteria for activity monitor wear time, non-wear criteria, and average wear time), variables (e.g.,
52 total sedentary time, or breaks in sedentary behaviour), outcomes examined, covariates included in
53 the analyses, and study findings. Where available, we extracted relevant model statistics for each

1 outcome variable, with preference placed on standardised regression or correlation coefficients from
2 fully adjusted models that could be synthesised via meta-analysis.

3 4 *Risk of bias assessment*

5 Information on the ROB for individual studies was extracted by one of two reviewers (TH or MT).
6 Items were as follows: i) was representative sampling/random selection used to select participants?,
7 ii) did an adequate percentage of participants have complete data? (cross-sectional: $\geq 70\%$;
8 longitudinal $\geq 60\%$), iii) was the measure of sedentary behaviour valid (i.e., Does the device and/or
9 cut-point for sedentary behaviour have established validity in children or adolescents? – Actigraph:
10 ≤ 50 to ≤ 150 cpm; Actical: ≤ 24 to ≤ 100 cpm), and iv) was MVPA included as a covariate in
11 analyses or was an analysis presented that accounted for MVPA? (e.g., by stratifying for quartiles of
12 MVPA). To determine the range of sedentary behaviour cut-points considered valid for each
13 activity monitor, we consulted relevant studies and reviews for the most common devices such as
14 the Actigraph (30-33) or Actical (11, 31, 34-36), or examined supporting evidence cited in each
15 study. Items were coded as present (“1”) or absent/unclear (“0”), and low ROB was classified as the
16 presence of $\geq 3/4$ items. Prior to extracting data, reviewers demonstrated $> 95\%$ agreement with
17 criterion assessments conducted on 12 randomly selected studies (48 items).

18 19 *Categorisation of levels of evidence and meta-analyses*

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

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

48 49 **Results**

50 Following the removal of duplicates, 7,533 studies were retrieved (Figure 1). After full-text
51 screening, 88 studies were included in the review. Of the included studies, 73 were cross-sectional,
52 8 were longitudinal, and 7 reported both cross-sectional and longitudinal results. No experimental

1 studies were deemed eligible for the review. One study used the thigh-mounted activPAL to assess
2 sedentary behaviour (41); all others used activity monitors placed on the waist, hip or wrist.

3 4 *Adiposity*

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

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

17 The meta-analysis examining the cross-sectional association between overall sedentary time
18 and adiposity outcomes included 27 studies and 7,160 participants. Using a random effects model,
19 the pooled effect size indicated a weak but statistically significant positive association ($r = 0.07$,
20 95% CI 0.00 to 0.13, $p = 0.024$) (Figure S1). However, high levels of heterogeneity were observed;
21 $Q = 142.72$ 26, $p < 0.001$ and $I^2 = 81.78$. With respect to risk of publication bias, Rosenthal’s fail-
22 safe N indicated that 124 studies with an effect size of zero would be needed for the association to
23 not be statistically significant. Both ROB ($p < 0.001$) and adjustment for MVPA ($p < 0.001$)
24 emerged as significant effect moderators. Among studies with a low ROB ($n = 6$) the association
25 was not statistically significant ($r = -0.03$, 95% CI 0.07 to 0.02, $p = 0.223$), whereas it was for the
26 remaining studies ($r = 0.11$, 95% CI 0.03 to 0.19, $p = 0.01$). Likewise, the association was not
27 statistically significant for studies ($n = 6$) that adjusted for MVPA ($r = -0.00$, 95% CI -0.07 to 0.076,
28 $p = 0.98$), but was for those that didn’t ($r = 0.10$, 95% CI 0.02 to 0.18, $p = 0.018$). Age group was
29 not a significant effect moderator ($p = 0.498$).

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

36 Of the 6 studies that reported cross-sectional associations between patterns of sedentary
37 behaviour and adiposity (46, 51-55), 3 (50%) used representative sampling, 2 (33%) had minimal
38 missing data, 6 (100%) used a valid measure of sedentary behaviour, and 4 (67%) adjusted for
39 MVPA (Table S3). Subsequently, 4 (67%) had $\geq 3/4$ ROB items. All 6 studies examined
40 associations for breaks in sedentary behaviour, and 4 also investigated bouts of sedentary behaviour
41 (51-54). Five of the 6 studies reported that the number of sedentary breaks were not statistically
42 significantly associated with adiposity outcomes. One study with low ROB found that the number
43 of breaks in sedentary time were significantly negatively associated with BMI z -score in 9 year-old
44 children ($n = 522$) who had at least one biological parent with obesity (51). Of the 4 studies that
45 examined associations for bouts of sedentary behaviour, 3 studies with low ROB reported at least
46 one significant association (51-53).

47 48 *Cardio-metabolic outcomes*

49 A description of the 29 studies (children = 22, adolescents = 7) that investigated associations
50 between total volume or pattern of sedentary behaviour and cardio-metabolic outcomes is provided
51 in Table S4. Twenty-eight studies examined associations for total sedentary behaviour volume; 27
52 were cross-sectional, one was longitudinal (56) and one study reported both cross-sectional and

1 longitudinal associations (44). Of these 28 studies, 8 (29%), 10 (36%), 22 (79%), and 16 (57%)
2 used representative sampling, had minimal missing data, used a valid measure of sedentary
3 behaviour, and adjusted for MVPA, respectively (Table S5). Subsequently, 8 (29%) had $\geq 3/4$ ROB
4 items.

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

10 The meta-analysis examining the cross-sectional associations between overall sedentary
11 time and glucose/insulin included 5 studies and 3,133 participants. Using a random effects model,
12 the pooled effect size indicated a weak but statistically significant positive association ($r = 0.07$,
13 95% CI 0.01 to 0.13, $p = 0.030$) (Figure S2). However, moderate levels of heterogeneity were
14 observed; $Q(X) = 9.61X$, $p = 0.087$ and $I^2 = 47.97$), and there was a risk of publication bias as
15 Rosenthal’s fail-safe N indicated that 10 studies with an effect size of zero would be required for the
16 association to not be statistically significant. Likewise, both ROB ($p = 0.031$) and adjustment for
17 MVPA ($p = 0.031$) emerged as significant effect moderators. In the study with low ROB that
18 adjusted for MVPA, the association was not statistically significant ($r = -0.12$, 95% CI -0.29 to
19 0.06, $p = 0.192$), whereas it was for the remaining studies ($r = 0.09$, 95% CI 0.04 to 0.13, $p <$
20 0.001). Age was not a significant effect moderator for the association between sedentary time and
21 glucose/insulin ($p = 0.775$). The pooled effect size from the 5 studies ($n = 2,236$) that examined
22 associations between sedentary behaviour and HDL cholesterol was not statistically significant ($r =$
23 -0.02 , 95% CI -0.13 to 0.09, $p = 0.705$) (Figure S3). ROB ($p = 0.001$) and MVPA adjustment ($p =$
24 0.001); however, were significant moderators of the association. In the study with low ROB that
25 adjusted for MVPA the association was statistically significant ($r = -0.29$, 95% CI -0.45 to -0.12, p
26 $= 0.001$), whereas it wasn’t for the remaining studies. Age was not a significant moderator of the
27 association between sedentary time and HDL cholesterol ($p = 0.217$). Based on the findings from 6
28 ($n = 2,347$) and 5 ($n = 2,145$) studies, respectively, associations between sedentary behaviour and
29 systolic ($r = 0.02$, 95% CI -0.08 to 0.12, $p = 0.732$) (Figure S4) and diastolic blood pressure ($r =$
30 0.02, 95% CI -0.09 to 0.13, $p = 0.732$) (Figure S5) were not statistically significant, and ROB,
31 adjustment for MVPA, and age were not significant effect moderators (all $p > 0.05$).

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

39 Of the 4 studies that investigated cross-sectional associations between patterns of sedentary
40 behaviour and cardio-metabolic health (51, 53, 54, 57), 2 (50%) used representative sampling, 2
41 (50%) had minimal missing data, 4 (100%) used a valid measure of sedentary behaviour, and 4
42 (100%) adjusted for MVPA (Table S5). Subsequently, all 4 (100%) had $\geq 3/4$ ROB items. All 4
43 studies examined associations for bouts of sedentary behaviour, and 3 also investigated breaks in
44 sedentary behaviour. Two of the 4 studies found no associations between bouts of, or breaks in,
45 sedentary time in large national samples of children and adolescents in the United States (54) and
46 Canada (53). Saunders et al. (51) found that the number of breaks in sedentary time and 1-4min
47 bouts of sedentary behaviour were significantly negatively associated with a clustered cardio-
48 metabolic risk score in 522 children (aged 9 years) who had at least one biological parent with
49 obesity. Additionally, significant positive associations were reported between 10-14min sedentary
50 bouts and fasting glucose among girls. Another study among overweight and obese children ($n =$
51 120) found that those in the highest quartile of 30min sedentary bouts exhibited significantly lower
52 HDL cholesterol compared to children in the lowest quartile (57).

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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 $\geq 3/4$ 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 $\geq 3/4$ 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 $\geq 3/4$ 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 $\geq 3/4$ 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 $\geq 3/4$ 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

1 attributed to qualitative differences between total sedentary behaviour (from objective assessment)
2 and the specific sedentary behaviours examined in other studies included in these reviews. For the
3 most part, the evidence in previous reviews comes from studies examining television viewing as the
4 sedentary behaviour exposure. Although children and young people engage in a number of different
5 types of sedentary behaviours in various contexts – such as education, transportation, and leisure
6 (10) – television viewing and electronic media use for entertainment appear to have a particularly
7 potent influence on young people’s health and development. This may be for a number of reasons,
8 including increased sitting time and decreased energy expenditure (23). However, it may also be
9 because of increased energy intake from unhealthy snacking and sugary-beverage consumption
10 during and following exposure, exposure to advertising, the displacement of opportunities for social
11 and educational development, exposure to content that promotes socially undesirable behaviour, the
12 development of biological processes of dependence, the interference of cognitive processes, and the
13 displacement of MVPA (22). As such, there may be unique mechanistic pathways through which
14 television viewing and electronic media use influence health and development in young people,
15 some of which might not be common to all sedentary behaviours, and this may in part explain the
16 contrasting findings in this review.

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

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

52 Although experimental studies are underway (80), none were retrieved that met the

1 inclusion criteria for this review, which required sedentary behaviour to be measured objectively.
2 Nonetheless, some experimental evidence indicates that the use of stand-biased desks in classrooms,
3 which are likely to decrease sedentary time, might result in increased energy expenditure among
4 school-age children compared with traditional seated-desks (81), without impeding classroom
5 engagement (82). Much sedentary time among youth occurs while at school (54). Therefore,
6 experimental research in this setting has important implications for the translation of intervention
7 strategies if it can be demonstrated that educational and development goals can be achieved, while
8 also addressing public health targets such as increased energy expenditure, and obesity and chronic
9 disease prevention. Although this review does not demonstrate that objectively measured sedentary
10 time is adversely associated with health and developmental outcomes in young people, without
11 further experimental evidence testing subtle shifts from sitting to standing or light physical activity,
12 it is premature to conclude that excessive sedentary behaviour does not adversely impact on health
13 and development in children and adolescents. Further, given the evidence of adverse effects among
14 adults, and some evidence of tracking of sedentary behaviours across the life course, continuing to
15 encourage children and young people to limit their time spent sedentary is prudent.

16 17 *Strengths and limitations*

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

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

44 A number of limitations of the review should also be taken into account when interpreting
45 the findings. Because of differences in analyses and reporting, and too few studies for some
46 outcomes, not all studies that contributed to the level of evidence grades were included in the meta-
47 analyses. Authors were not contacted to provide additional study data, and this is acknowledged as
48 a limitation. However, after accounting for study ROB and adjustment for MVPA, findings from
49 level of evidence summaries and meta-analyses were consistent. For cardio-metabolic outcomes,
50 some studies reported multiple outcomes and this might have increased the likelihood of concluding
51 that a significant association was observed in the level of evidence summary. However, because the
52 overall classification for cardio-metabolic outcomes was “no association”, this does not appear to

1 have influenced the final conclusion. Although efforts were made to consider if study findings were
2 at risk of bias by evaluating key methodological components, some criteria could be considered
3 lenient (e.g., <30% and <40% missing data for cross-sectional and longitudinal studies,
4 respectively). Likewise, other methodological aspects that were not assessed could also potentially
5 influence study results. For example, the validity of outcome measures (a post hoc examination
6 indicated that all studies used measures that appeared to be valid except one which investigated
7 associations for psycho-social outcomes and did not provide validity information but used a
8 measure with adequate face validity (84)). All others used measures that appeared to be valid),
9 sedentary behaviour data reduction protocols such as definitions of non-wear time and number of
10 days of monitoring required, and, for the level of evidence summaries, study power, could impact
11 reported associations. However, evidence to reach consensus on sedentary behaviour data reduction
12 protocols is currently lacking, and study power would not have influenced pooled meta-analysis
13 findings.

14

15 **Conclusion**

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

23

24 **Conflict of Interest Statement**

25 The authors declare that there are no conflicts of interest

26

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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 \pm 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 \pm 0.6y; 3-5y EDPAPC: 4.0 \pm 0.7y; 3-5y	CHAMPS: NR, 16.3 \pm 1.6 kg/m^2 EDPAPC: NR, 15.9 \pm 1.7 kg/m^2	Cross-sectional	Actigraph; ≤ 37.5 c/15s; ≥ 60 min; ≥ 1 dNR, ≥ 360 min/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, Southampton Women's Survey	n=398 (49% girls; 39%)	4.10 \pm 0.08y; 4y	20.1%, 16.3 kg/m^2	Cross-sectional	Actiheart; ≤ 30 c/15s; ≥ 100 min; ≥ 1 d, ≥ 600 min/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 \pm 0.4y 3-5y Girls: 4.6 \pm 0.3y; 3-5y	Boys: 27.9%, 16.3 kg/m^2 Girls: 28.7%, 16.3 kg/m^2	Cross-sectional	Actigraph; ≤ 200 c/15s; NR; ≥ 2 d, ≥ 360 min/d; NR	Total SB	BMI z-score WC	Ethnicity/race, parental education	WC: Sig (+) for girls at 90 th percentile. NS for boys and other percentiles.

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 1.33y; 10-14y	15%, z-score = -0.19	Cross-sectional	RT3; <288cpm; \geq 10 min, \geq 3d, \geq 540min/d (weekdays), \geq 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; \geq 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: -0.01 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

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 3.8y; 4-19y	NOW boys: 19.7 \pm 3.6 kg/m ² OW boys: 30.5 \pm 7.2 kg/m ² NOW girls: 19.7 \pm 3.8 kg/m ² OW girls: 29.6 \pm 6.4 kg/m ²	Cross-sectional	Actiwatch; NR; NR, \geq 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 \pm 0.7y	37%, NR	Cross-sectional	Actigraph; \leq 100cpm; \geq 60 min; \geq 4d (including 1 weekend day), \geq 600min/d; \geq 7d, 863min/d	Total SB SB breaks SB bouts (1-4 min; 5-9 min; 10-19 min; 20-29 min; \geq 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.

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.1y	Whole sample: 18.58 \pm 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 \pm 0.9y; 8-10y	41%; NR	Cross-sectional	Actigraph; $\leq 100\text{cpm}$; $\geq 60\text{min}$; $\geq 4\text{d}$, $\geq 600\text{min}/\text{d}$; 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 \pm 0.9y; 8-10y	41%; NR	Cross-sectional	Actigraph; $\leq 100\text{cpm}$ $\geq 60\text{min}$; $\geq 4\text{d}$ (including 1 weekend d), $\geq 600\text{min}/\text{d}$; 6.5d, NR	Total SB	WC	Age, sex, sleep duration, energy intake, sexual maturation (Tanner stage), parental socioeconomic status, and parental BMI, MVPA	NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.4y; 9-11y	NR 18.3 kg/m^2	Cross-sectional	Actigraph; $\leq 100\text{cpm}$; NR; $\geq 4\text{d}$ (including 1 weekend d), $\geq 600\text{min}$; 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 \pm 0.6y; 10-13y	28% 19.8 kg/m^2	Cross-sectional	Actigraph; $\leq 100\text{cpm}$; $\geq 20\text{min}$; $\geq 4\text{d}$ (including 1 weekend d), $\geq 600\text{min}/\text{d}$ on weekdays, $\geq 480\text{min}/\text{d}$ weekend; NR	Total SB	WC	Sex, country, number of sedentary bouts, MVPA	NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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%, 17.8 kg/m^2	Cross-sectional	Actical; $\leq 100\text{cpm}$; $\geq 60\text{ min}$; $\geq 4\text{d}$, $\geq 600\text{min}/\text{d}$; 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; $\leq 100\text{cpm}$; $\geq 60\text{ min}$; $\geq 4\text{d}$ (including 1 weekend d), $\geq 600\text{min}/\text{d}$; 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

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.8y 10 -12 y	BMI 18.8 kg/m^2	Cross-sectional	Actigraph; ≤ 100 cpm; ≥ 20 min; ≥ 3 d, ≥ 600 min 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 \pm 1.4y 6-10y	49%; 24.2 \pm 4.8 kg/m^2	Cross-sectional	CSA/MTI accelerometers; < 500 cpm; ≥ 60 min; ≥ 3 d, ≥ 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 \pm 0.4y; 15.5 \pm 0.5y; 9-15y	17.3 kg/m^2 20.8 kg/m^2	Cross-sectional	Actigraph; < 500 cpm; ≥ 10 min; ≥ 4 d, NR; NR	Total SB	WC BMI	Sex, age, study location, analysis birthweight, sexual maturity, smoking status, BMI, parental socioeconomic status, CRF	NS for all

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 2.8y; 4-18y	25.1%, 19.3 kg/m^2	Cross-sectional (BL) and longitudinal (2.1y)	Actigraph; $\leq 100\text{cpm}$; ≥ 60 min; $\geq 1\text{d}$, $\geq 500\text{min}/\text{d}$; 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 \pm 1.6y; 9-15y	18.6 \pm 3.2 kg/m^2	Cross-sectional	Actigraph; $\leq 100\text{cpm}$; ≥ 30 min; $\geq 4\text{d}$, $\geq 480\text{min}/\text{d}$; 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 \pm 0.37y FU: 9.7 \pm 0.37y	BA: 16.94 FU: 17.52	Longitudinal (1y)	Actigraph; $\leq 100\text{cpm}$; ≥ 10 min; $\geq 3\text{d}$, $\geq 600\text{min}$; 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 \pm 0.3y; 11y	13%, 17.9 kg/m^2	Cross-sectional	Actigraph; $\leq 100\text{cpm}$; ≥ 20 min; $\geq 3\text{d}$, ≥ 480 min/d; NR, 784 min/d	Total SB	BMI	Gender, pubertal status, parental education, breakfast consumption, TV, computer game, MVPA	NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.6y Girls: 9.9 \pm 0.7y 8-11y	13.4% , boys 0.19 z-score, girls 0.06 z-score	Cross-sectional and longitudinal	Actigraph; \leq 100cpm; \geq 15 min \geq 4d; \geq 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 \pm 0.6y; 8-11y	13.4%, BMI z-score ² 0.146	Cross-sectional and longitudinal	Actigraph; \leq 100cpm; \geq 60 min; 4d, \geq 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; \geq 4d, NR;	Total SB	BMI z-score WC	Age, gender, BMI z-score WC	WC: Sig (+) in boys. NS for all others

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.6y; 9-11y	12.4% obese; 18.4 kg/m^2	Cross-sectional	Actigraph; $\leq 100\text{cpm}$; 20min; $\geq 4\text{d}$, $\geq 600\text{min}/\text{d}$ 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 \pm 0.6y; 6-7y	NR 0.33	Cross-sectional	Actigraph; $\leq 100\text{cpm}$; NR; $\geq 3\text{d}$, $\geq 600\text{min}/\text{d}$;	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; $\leq 100\text{cpm}$; NR; $\geq 3\text{d}$, $\geq 600\text{min}/\text{d}$; 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 \pm 0.7; NR	33.8% 20.4 kg/m^2	Longitudinal (2y)	Actigraph; $\leq 100\text{cpm}$; 10min; $\geq 3\text{d}$, $\geq 480\text{min}/\text{d}$, NR	Total SB	BMI	Age, tanner stage	NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 2.3y	30.9% NR	Cross-sectional	Actigraph; NR; $\geq 3d$; $\geq 600min/d$; NR	Total SB	BMI	MVPA, health-related fitness	NS
Marques, 2015, (92), Portugal	n=510 (49% girls; 49%)	10.1 \pm 0.8y	33% NR	Cross-sectional & Longitudinal (1.7y)	Actigraph; $\leq 100cpm$; 60min; $\geq 3d$; $\geq 600min/d$; 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 \pm 0.2y 0-11y	30.3% 19.0 kg/m ²	Cross-sectional	Actigraph; $< 199cpm$; NR; $\geq 3d$, $\geq 600min/d$; 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; $\geq 3d$, $\geq 420min/d$; 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; $\leq 100cpm$; NR $\geq 3d$, $\geq 420min/d$; 84.8min/d	Total SB Breaks/h Breaks duration	WC		NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.4y;8-9y	20%, BMI SDS=0.15 (1.32)	Cross-sectional	Actigraph; $\leq 100\text{cpm}$; NR; $\geq 3\text{d}$, $\geq 600\text{min}/\text{d}$; 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; $< 100\text{cpm}$; 60 min; $\geq 4\text{d}$, $\geq 10\text{h}/\text{d}$; 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 \pm 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 \pm 0.2y 11-12y	21.4 kg/m^2	Longitudinal (4y)	Actigraph; <199cpm; 10min; $\geq 3\text{d}$, $\geq 600\text{min}/\text{d}$; 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 \pm 0.03y Girls: 10.3 \pm 0.03y; 10y	23%, Boys: 17.9 \pm 2.9 kg/m^2 Girls: 18.4 \pm 3.3 kg/m^2	Cross-sectional	Actigraph; $\leq 100\text{cpm}$; $\geq 10\text{ min}$; $\geq 3\text{d}$, $\geq 500\text{min}/\text{d}$; NR	Total SB	WC FMI BMI	Age, gender, school, SES, birth weight, maternal BMI, sleep duration, height, nutritional intake, MVPA	NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 1.0y Middle: 12.3 \pm 1.2y High: 15.9 \pm 1.4y Girls: Elementary: 9.2 \pm 0.8 Middle: 11.8 \pm 1.0y High: 15.9 \pm 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 \leq 100cpm; NR; \geq 4d (2 weekend d), \geq 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 \pm 1.4y; 5-10y	100%, 1.8 BMI z-score	Longitudinal (3y)	Actical; \leq 100cpm; \geq 20 min; \geq 5d, \geq 600 min; NR	Total SB	BMI	Initial PA, intervention status, gender, age, SEIFA, maternal BMI, maternal education	NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 1.6y; 11-18y	Girls: 27.4% Boys: 38.8%, 22.2 \pm 3.5 kg/m^2	Cross-sectional	MTI accelerometer; <500cpm; 10 min; \geq 5d (4 weekdays, 1 weekend d), \geq 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 \pm 0.4y Boys: 9.7 \pm 0.4y 15-16y Girls: 15.6 \pm 0.5y Boys: 15.6 \pm 0.4y	17.1 kg/m^2	Cross-sectional	Actigraph; <800cpm; >100min; \geq 1d, \geq 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

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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; $\leq 100\text{cpm}$; $>20\text{ min}$; $\geq 4\text{d}$ (≥ 1 weekend day), $\geq 600\text{min}/\text{d}$; 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 \pm 0.9y; 13.1-18.7y	27.7%, 21.7 kg/m^2	Cross-sectional	ActivPal; $\geq 60\text{ min}$; 240min non-wear time/d; $\geq 4\text{d}$ (≥ 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 \pm 3.0y; NR	NR, BMI% = 90.6 \pm 16.9	Cross-sectional	Actigraph; $\leq 100\text{cpm}$; $\geq 60\text{ min}$; $\geq 4\text{d}$, $\geq 600\text{min}/\text{d}$; NR	Total SB	BMI WC	Age, gender, ethnicity, pubertal Tanner stage, fat mass and lean mass, MVPA	NS for all

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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; $\leq 100\text{cpm}$; ≥ 60 min; $\geq 4\text{d}$, $\geq 600\text{min}/\text{d}$; 13.6 (children) & 14.2 (adolescents) min/d	Total SB	BMI, BMI%, WC, tricep SF, Subscapularis 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; $\leq 100\text{cpm}$; 20 min; $\geq 5\text{d}$, $\geq 600\text{min}/\text{d}$; 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

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 1.2y Girls: 14.9 \pm 1.3y 13-17y	NR Girls: 21.8 kg/m ² Boys: 22.2 kg/m ²	Cross-sectional	Actigraph; <100cpm; \geq 10 min; \geq 4d (\geq 1 weekend d), \geq 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; \geq 60 min; \geq 600 min/d, \geq 3d; \geq 2296 min/day	Total SB	BMI	MVPA, gender, race, maternal education, hours of sleep and healthy eating index	Sig (+) at 90 th , 75 th & 50 th percentiles. NS for others.
Treuth, 2009, (50), USA, TAAG	n=1968 (100% girls; 38%)	6 th Grade: 11.9 \pm 0.4y 8 th Grade: 13.9 \pm 0.4y	6 th Grades: 33%, 20.7 kg/m ² 8 th Grades: 35%, 22.6 kg/m ²	Longitudinal (3y)	Actigraph; <50c/30s; NR; \geq 1d, \geq 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

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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

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 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

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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

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 \pm 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 \pm 1.33y; 10-14y	OW: 9%, OB: 6%, z-score -0.19	Cross-sectional	RT3; <288cpm; NR; $\geq 3\text{d}$, $\geq 560\text{min}/\text{d}$ (weekdays), $\geq 480\text{min}/\text{d}$ (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 \pm 3.8y; 4-19y	NOW boys: 19.7 \pm 3.6 kg/m^2 OW boys: 30.5 \pm 7.2 kg/m^2 NOW girls: 19.7 \pm 3.8 kg/m^2 OW girls: 29.6 \pm 6.4 kg/m^2	Cross-sectional	Actiwatch; <50 cpm; ≥ 20 min; NR, $\geq 1000/1440\text{min}/\text{d}$; NR	Total SB	HDL, Insulin, Glucose, TC	Age, gender, BMI z-score, FM%	Insulin: Sig (+)

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.1y	18.58 \pm 0.2 kg/m^2	Cross-sectional	Actigraph; NR; $\geq 7\text{d}$, 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 \pm 0.9y 8-10y	41% NR	Cross-sectional	Actigraph; $< 100\text{cpm}$; $\geq 60\text{ min}$; $\geq 4\text{d}$, $\geq 600\text{min}/\text{d}$; 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 \pm 0.6y 10-13y	28%, 19.8 kg/m^2	Cross-sectional	Actigraph; $< 100\text{cpm}$; $\geq 20\text{min}$; $\geq 4\text{d}$, $\geq 600\text{min}/\text{d}$ weekdays; $\geq 480\text{min}/\text{d}$ weekend, NR	Total SB	Glucose, HDL, LDL, TG, C-peptide, Metabolic risk	Gender, Country, Number of Sedentary bouts, MVPA, WC	NS for all

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 1.1y 5.5-9y	100%, 24.7 kg/m^2 , 2.8 z-score	Cross-sectional	Actigraph; 100 cpm; ≥ 20 min; ≥ 3 d, ≥ 600 min/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 \pm 1.1y 5.5-9y	100%, 24.7 kg/m^2 , 2.8 z-score	Cross-sectional	Actigraph; 100 cpm; ≥ 20 min; ≥ 3 d, ≥ 600 min/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%, 17.8 kg/m^2	Cross-sectional	Actical; ≤ 100 cpm; ≥ 60 min; ≥ 4 d, ≥ 600 min/d; NR	Total SB	DBP, non-HDL cholesterol	Age, sex, MVPA, sleep, screen-time	NS for all

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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; $\geq 4\text{d}$, $\geq 600\text{min}/\text{d}$; 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 \pm 0.4y; 15.5 \pm 0.5y; 9-15y	17.3 kg/m^2 20.8 kg/m^2	Cross-sectional	Actigraph; <500cpm; $\geq 10\text{min}$; >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 \pm 2.8y; 4-18y	25.1%, 19.3 kg/m^2	Cross-sectional and longitudinal (2.1y)	Actigraph; <100cpm; $\geq 60\text{min}$; $\geq 1\text{d}$, $\geq 500\text{min}/\text{d}$; 5.2d, 835 min/d	Total SB	SBP, Insulin, TG, HDL	Age, sex, monitor wear time, WC, MVPA	CS: NS FU: NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.4y; 7-10y	22.2%, 17.4 kg/m^2	Cross-sectional	Actigraph; <100cpm; ≥ 20 min; ≥ 3 d, ≥ 480 min/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 \pm 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; ≥ 4 d, ≥ 600 min/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 \pm 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; ≥ 4 d, ≥ 600 min/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

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.6y; 8-11y	13.4%, BMI z-score ² 0.146	Cross-sectional and longitudinal	Actigraph; $\leq 100\text{cpm}$; $\geq 60\text{ min}$; 4d, $\geq 600\text{ min}$; 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 \pm 0.3 10-11 y	19 kg/m^2	Cross-sectional & longitudinal (6 months)	Actigraph; $< 100\text{cpm}$; $> 20\text{min}$; $\geq 3\text{d}$, $\geq 540\text{ min}/\text{d}$; NR, 714.7 min/d	Total SB Changes in SB	Endothelial 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 \pm 1.5y 3-8y	NR; 15.87 kg/m^2	Cross-sectional	Actigraph; $< 100\text{cpm}$; 3x20min; $\geq 3\text{d}$, 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 \pm 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 \pm 0.5y 11-13y	29.4%, 19.6 \pm 3.4	Cross-sectional	Actigraph; <100cpm; \geq 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 \pm 0.6y 8-11y	NR; 17.5 kg/m^2	Cross-sectional	Actigraph; <100cpm; \geq 30 min; \geq 3d, \geq 600min/d; NR	Total SB	Large or small arterial compliance	Body Surface Area, BMI, SBP, Sex	NS
Sardinha, 2008, (117), Portugal, European Heart Study	n=308 (48% girls; 58%)	9.8 \pm 0.3y	18.5% overweight 8.8% obese 18.0 kg/m^2	Cross-sectional	Actigraph; <500cpm; \geq 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; \geq 4d, \geq 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 \pm 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 \pm 0.2y 11-12y	21.4 kg/m^2	Longitudinal (4y)	Actigraph; <199cpm; 10min; $\geq 3\text{d}$, $\geq 600\text{min}/\text{d}$; 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 \pm 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 \pm 0.4y Boys: 9.7 \pm 0.4y 15-16y Girls: 15.6 \pm 0.5y Boys: 15.6 \pm 0.4y	17.1 kg/m^2	Cross-sectional	Actigraph; <800cpm; >100min; \geq 1d, \geq 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; \geq 4d, \geq 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; \geq 3d, \geq 480min/d; NR	Total SB	SBP DBP	Age, SES, parental education, smoking, BMI, WC, and clustering	NS for all

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 1.7y Boys 13.9 \pm 1.7y; 11-17yrs	Girls: 21.21 kg/ m ² Boys 21.68 kg/ m ²	Cross-sectional	Actigraph; <500cpm;NR; \geq 4 days, \geq 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 \pm 3.0y 10-16y	17%; BMI percentile 90.55(\pm 16.89)	Cross-sectional	Actigraph; <100cpm; \geq 60 min; \geq 4d, \geq 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 \pm 1.2y Girls 14.9 \pm 1.3y 13-17y	NR Girls 21.8 kg/ m ² Boys 22.2 kg/ m ²	Cross-sectional	Actigraph; GTIM <100cpm; \geq 10min; \geq 4 days incl. 1 weekend d, \geq 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 \pm 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 \pm 1.3y 13-17y	24.6%, 21.6 kg/m^2 1.2 z-score	Cross-sectional	Actigraph; GTIM <100cpm; \geq 10min; \geq 4 days, \geq 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 Health 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,

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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

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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 \pm 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 \pm 3.8yr; 4-19y	NOW boys: 19.7 \pm 3.6 kg/m^2 OW boys: 30.5 \pm 7.2 kg/m^2 NOW girls: 19.7 \pm 3.8 kg/m^2 OW girls: 29.6 \pm 6.4 kg/m^2	Cross-sectional	Actiwatch; <50 cpm; \geq 20 min; NR, \geq 1000 min/d; NR, 1410min/d	Total SB	VO ₂ peak	Age, gender, FMI	NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 1y 10-14y	NR BMI z-score = -0.3 \pm 1.4	Cross-sectional	RT3 accelerometer <288cpm; \geq 10 min; \geq 3d, \geq 540 min weekday, \geq 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 \pm 0.4y; 15.5 \pm 0.5y; 9-15y	17.3 kg/m^2 20.8 kg/m^2	Cross-sectional	Actigraph <500cpm; \geq 10 min; \geq 4d, \geq NR; NR	Total SB	CRF	Sex, age, study location	Sig (-)
Fenton, 2015, (112), England, PAPA	n=118 (100% boys; 79%)	11.7 \pm 1.6y; 9-15y	18.6 \pm 3.2 kg/m^2	Cross-sectional	Actigraph; \leq 100cpm; \geq 30 min; \geq 4d, \geq 480min/d; NA, 768 min/d	Total SB	CRF	Age, ethnicity, season, monitor wear time, MVPA	NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.6y 8-11y	13.3% overweight/obese BMI z-score 0.13 \pm 1.08	Cross-sectional	Actigraph <100cpm; \geq 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; \geq 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; \geq 30min; \geq 7d, \geq 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 \pm 1.6y; 11-18y	Girls: 27.4% Boys: 38.8%, 22.2 \pm 3.5 kg/m^2	Cross-sectional	MTI accelerometer <500cpm; \geq 10 min; \geq 5d, \geq 600 min/d; NR	Total SB	CRF	Age, gender	NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 1.1y Urban 14.1 \pm 1.0y Female Rural 14.3 \pm 1.0y Urban 13.9 \pm 1.0y 10-18y	21.9%overweight/obese Male Rural: 20.52 kg/m^2 Urban 53.5 kg/m^2 Female Rural 53.4 kg/m^2 Urban 13.9 kg/m^2	Cross-sectional	Actigraph <NR; 20min; \geq 5d, \geq 600min/d; NR	Total SB	CRF	Age, gender, wear-time	NS
Marques, 2015, (98), Portugal, NR	n=2506 (53% girls, 79%)	13.2 \pm 2.3y 10-18y	23.1% overweight/obese NR	Cross-sectional	Actigraph <100cpm; \geq 60min; \geq 3d, \geq 600 m/d; NR	Total SB	Fitness	Age, sex, wear-time, MVPA	NS
Martinez-Gomez 2011, (129), Europe, HELENA-CSS	n=1808 (53% girls, 47%)	Low CRF 14.7 \pm 1.2y High CRF 14.6 \pm 1.2y	Low CRF:22.5 kg/m^2 High CRF:20.2 kg/m^2	Cross-sectional	Actigraph <100cpm; 20min; \geq 3d, \geq 480min/d; NR	Total SB	CRF	Centre, age, BMI, wear-time, MVPA	NS

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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, wear time, (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

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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-Rodrigues, 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 \pm 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 \pm 1.5y 6-12y	NR	Cross-sectional	Actigraph <100cpm; \geq 20 min; \geq 3d, \geq 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

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.9y 9.7- 13.9y	NR	Longitudinal study (2 y)	Actigraph <100cpm; \geq 20 min; \geq 4d, \geq 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 \pm 0.9; 6-10y School-aged: 8.1 \pm 1.2; 2- <6y	NR	Cross-sectional	Actigraph/ActiTrainer <100cpm; \geq 20 min; \geq 3d, \geq 360 min/d; NR	Total SB	Bone stiffness index	Age, sex, country, fat free mass, milk & dairy consumption, daylight duration, wear time, MVPA School-aged only: Also muscle strength	Preschool: NS School-aged: Sig (-)

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.7y; 11-13y	NR, 19.8 kg/m^2	Longitudinal (12 months)	Actigraph <100cpm; 10min; \geq 3d, \geq 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 \pm 0.6y NR	NR, z = 0.33 \pm 1.18	Longitudinal study (6 yr)	Actigraph <100cpm; NR \geq 3d, \geq 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

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.3y NR	NR, 18.1 kg/m^2	Cross-sectional	CSA (Actigraph) <100cpm; NR; $\geq 3\text{d}$, $\geq 600\text{min}$; 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; $\geq 60\text{min}$; $\geq 5\text{d}$, $\geq 600\text{min}$; 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 1 st 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 \pm 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; \geq 60 min; \geq 3d, \geq 600min; Males: 844.7min/d Females: 823.37min/d	Total SB, SB breaks	Bone architecture, 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

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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 \pm 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 \pm 0.6y; NR	29%	Cross-sectional study	ActiGraph <100cpm; \geq 60min; \geq 4d, \geq 600min/d; 861.1 min/d	Total SB	Self-esteem, Self-worth	Sex, age, weight status, SES, accel wear time, school	NS for all
Herman, 2014, (84), Canada, QUALITY	n=527 (46% girls; 84%)	Boys: 9.64 \pm 1.0y Girls: 9.59 \pm 1.0y; 8-10y	40%	Cross-sectional	ActiGraph <100cpm; \geq 60min; \geq 4d, \geq 600min/d; NR, 816min/d	Total SB	Self-rated health	Age, Tanner stage, BMI, MVPA	NS

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.5y; 11-13y	NR, 19.5 kg/m^2	Cross-sectional	Actiwatch <320cpm; \geq 10min; NR, \geq 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 \pm 0.4y 10-11y	Male: BMI: 0.37 \pm 1.1 kg/m^2 Female: BMI: 0.30 \pm 1.2 kg/m^2	Cross-sectional	Actigraph <100cpm; 60 min; \geq 3d, \geq 600min/d; NR	Total SB	SDQ	MVPA, age, gender, level of deprivation, pubertal status, TV, computer use	Sig (-)

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 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; \geq 4d, days with <10,000cpm or >20million counts or \geq 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; ^aConsecutive 0 counts; (-), negative association; (+), positive association

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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

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 \pm 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 \pm 0.7y 3-5y	NR 15.9 kg/m^2	Cross-sectional	ActiGraph <1100cpm; 20min; $\geq 3\text{d}$, ≥ 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 \pm 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 \pm 0.5y 3-4y	NR 16.2	Cross-sectional	Actigraph; <37.5 c/15s; \geq 60min; \geq 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 \pm 0.43y; 9-10y	NR	Cross-sectional	Actigraph <100cpm; \geq 60min ^a ; \geq 3d, \geq 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; ^aConsecutive 0 count

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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 \pm 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 \pm 0.7y NR	NR	Cross-sectional	Actigraph; <100cpm; 30min; \geq 3d, \geq 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

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Study	Participants			Design	Exposure		Outcome	Covariates	Associations for SB
Author, year, country, Study name	Sample size (% girls; % with complete data)	Age (Years \pm 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 \pm 0.6y NR	NR	Cross-sectional	Actigraph; <100cpm; 30min; \geq 3d, \geq 500min/d, NR	Total SB	Reaction time, Spatial span, Rapid visual information 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 \pm 1.0y 8-12y	NR	Cross-sectional	Actigraph; <100cpm; 20min; \geq 4d, \geq 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; ^aConsecutive 0 counts

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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 \pm 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 \pm 3.5y Boys 10.3 \pm 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 aminotransferase	Gender, maturational stage, central obesity, cardio-respiratory fitness	Sig (+)
Adolescents (13-18y)									
Ruiz, 2014, (62), Europe, HELENA	N=718 (55% girls; NR)	14.7 \pm 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; ^aconsecutive 0 counts.

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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

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<u>Model</u>	<u>Study name</u>	<u>Subgroup within study</u>	<u>Statistics for each study</u>					<u>Correlation and 95% CI</u>
			<u>Correlation</u>	<u>Lower limit</u>	<u>Upper limit</u>	<u>Z-Value</u>	<u>p-Value</u>	
	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	
	Fontana (2015)	males	0.260	0.082	0.434	2.854	0.004	

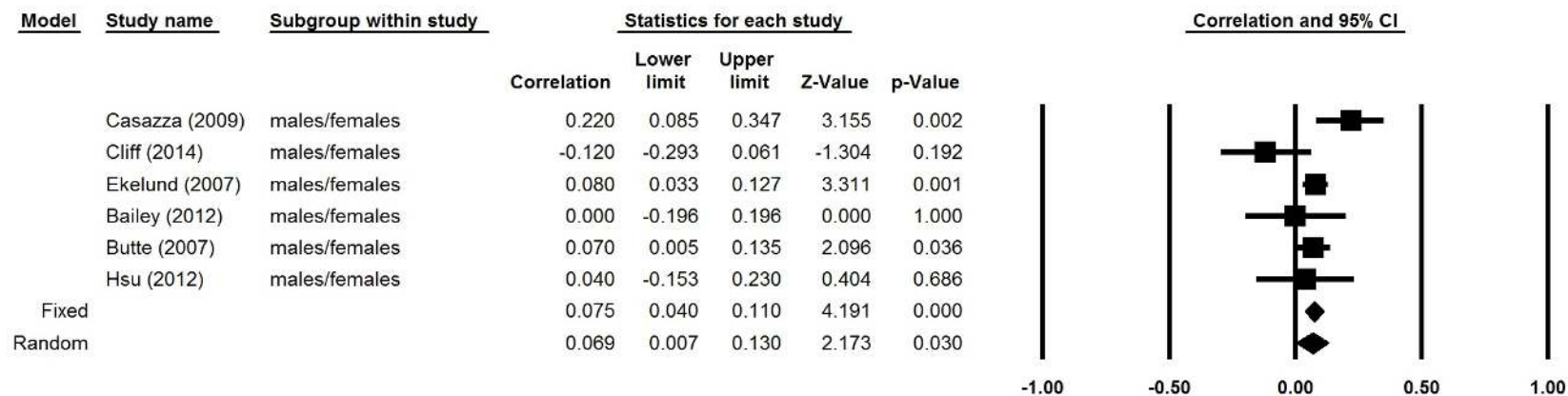


Figure S2: Forest plot for the association between objectively measured total sedentary behaviour and glucose or insulin in children and adolescents

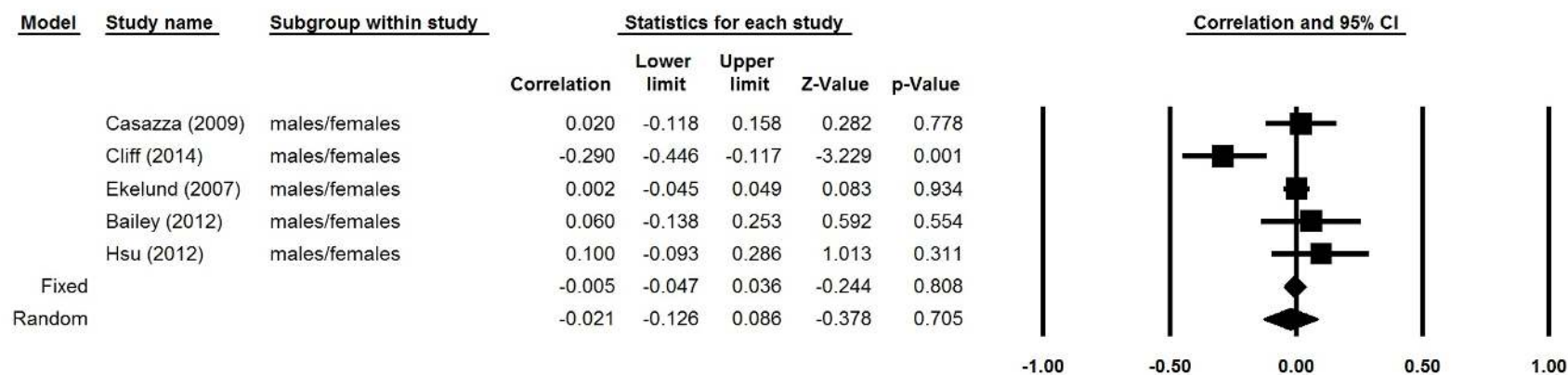


Figure S3: Forest plot for the association between objectively measured total sedentary behaviour and HDL cholesterol in children and adolescents

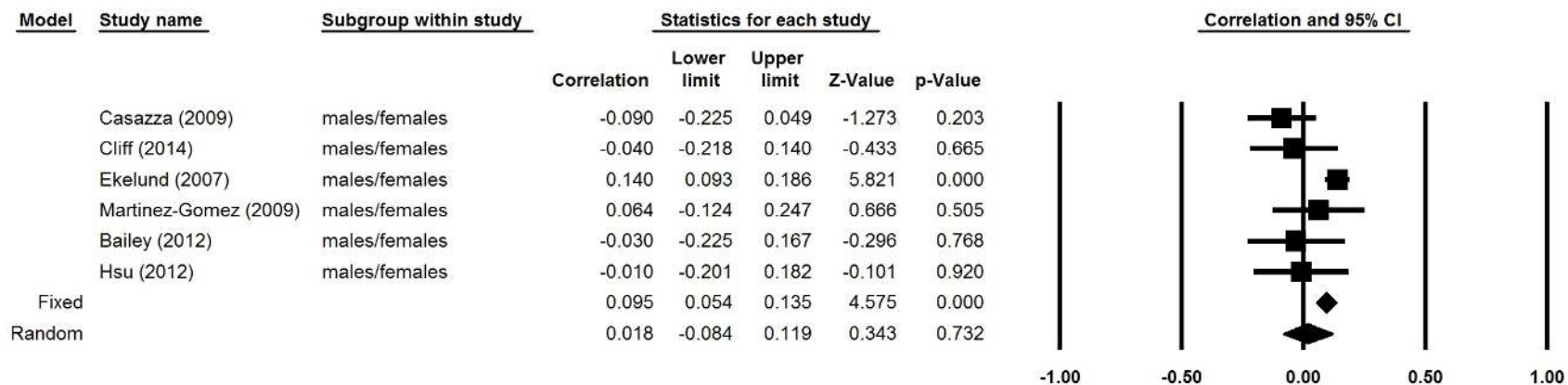


Figure S4: Forest plot for the association between objectively measured total sedentary behaviour and systolic blood pressure in children and adolescents

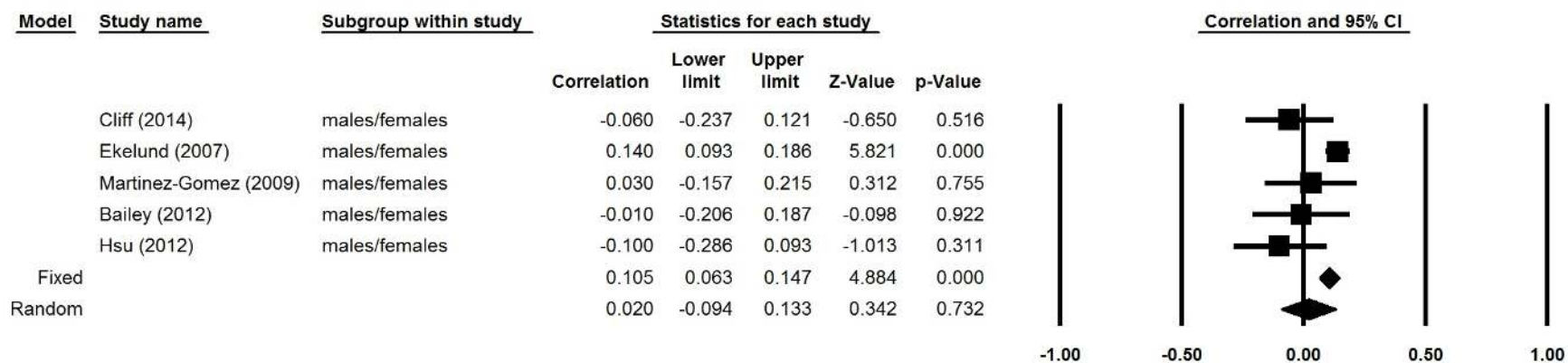


Figure S5: Forest plot for the association between objectively measured total sedentary behaviour and diastolic blood pressure in children and adolescents

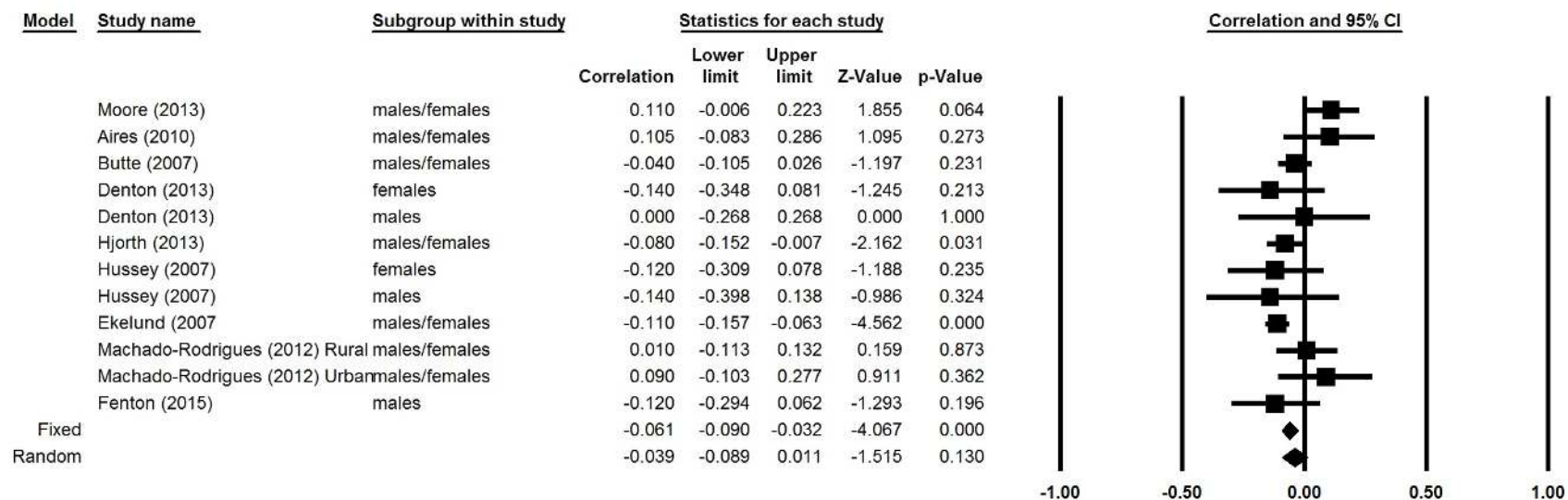


Figure S6: Forest plot for the association between objectively measured total sedentary behaviour and cardio-respiratory fitness in children and adolescents