Pediatric Obesity/Behavior

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

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Summary

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: Exercise, sedentary lifestyle, sitting, youth.

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Introduction

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

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

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

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

Methods

Study inclusion criteria

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

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

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

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

Study design – the study was either an observational or controlled experiment (e.g. randomized or non-randomized controlled trials).

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

Search strategy

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

Data extraction

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

Risk of bias assessment

Information on the ROB for individual studies was extracted by one of the two reviewers (T. H. or M. T.). Items were as follows: (i) was representative sampling/random selection used to select participants? (ii) did an adequate percentage of participants have complete data? (cross-sectional: ≥70%; longitudinal ≥60%); (iii) was the measure of sedentary behaviour valid (i.e. have the device and cut-point for sedentary behaviour established validity in children or adolescents? – ActiGraph: ≤50 to ≤150 cpm; Actical: ≤24 to ≤100 cpm); and (iv) was MVPA included as a covariate in analyses or was an analysis presented that accounted for MVPA? (e.g. by stratifying for quartiles of MVPA). To determine the range of sedentary behaviour cut-points considered valid for each activity monitor, we consulted relevant studies and reviews for the most common devices such as the ActiGraph (30–33) or Actical (11,31,34–36) or examined supporting evidence cited in each study. Items were coded as ‘present’ (1) or ‘absent/unclear’ (0), and low ROB was classified as the presence of ≥3/4 items. Prior to extracting data, reviewers demonstrated >95% agreement with criterion assessments conducted on 12 randomly selected studies (48 items).

Categorization of levels of evidence and meta-analyses

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

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

Results

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

Adiposity

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

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

The meta-analysis examining the cross-sectional association between overall sedentary time and adiposity outcomes included 27 studies and 7,160 participants. Using a random effects model, the pooled effect size indicated a weak but statistically significant positive association ($r = 0.07$, 95% CI 0.00 to 0.13, $p = 0.024$) (Figure S1). However, high levels of heterogeneity were observed; $Q = 142.72$ 26, $p < 0.001$ and $I^2 = 81.78$. With respect to risk of publication bias, Rosenthal's fail-safe *N* indicated that 124 studies with an effect size of 0 would be needed for the association to not be statistically significant. Both ROB ($p < 0.001$) and adjustment for MVPA ($p < 0.001$) emerged as significant effect moderators. Among studies with a low ROB ($n = 6$), the association was not statistically significant ($r = -0.03$, 95% CI 0.07 to 0.02, $p = 0.223$), whereas it was for the remaining studies ($r = 0.11$, 95% CI 0.03 to 0.19, $p = 0.01$). Likewise, the association was not statistically significant for studies ($n = 6$) that adjusted for MVPA ($r = -0.00$, 95% CI -0.07 to 0.076, $p = 0.98$) but was for those that did not ($r = 0.10$, 95% CI 0.02 to 0.18, $p = 0.018$). Age group was not a significant effect moderator ($p = 0.498$).

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

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

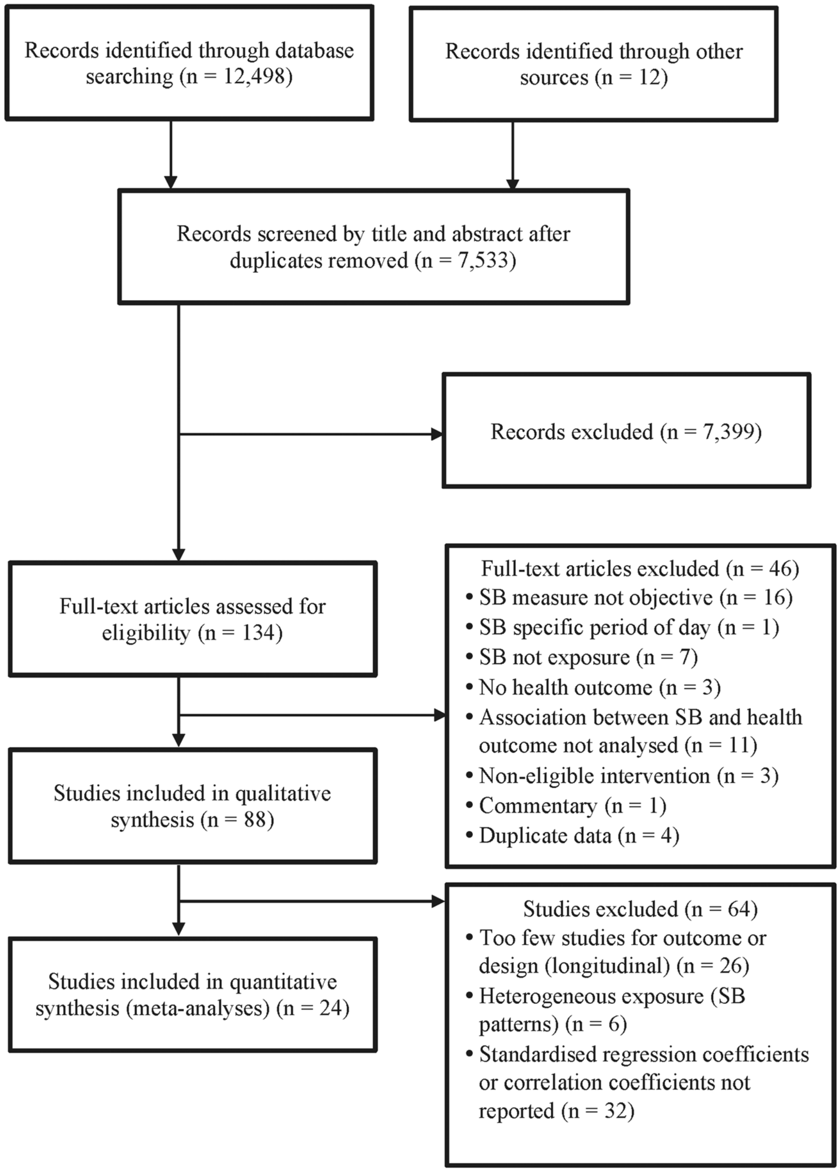

Figure 1 Review flow diagram. SB, sedentary behaviour.

least one biological parent with obesity (51). Of the four studies that examined associations for bouts of sedentary behaviour, three studies with low ROB reported at least one significant association (51–53).

Cardio-metabolic outcomes

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

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

The meta-analysis examining the cross-sectional associations between overall sedentary time and glucose/insulin

Table 1 Level of evidence from studies examining associations between objectively measured total sedentary time and health and developmental outcomes in children and adolescents

Outcome	All studies			
	Associated with SB (citations)[†]	Not associated with SB (citations)[‡]	Summary coding	
			n/*N* for outcome (%)	Association (+/−, 0, ?)
Adiposity outcomes	(49,50,66,85–92)	(11,41–48,51,52,54,56,64,93–115)	11/48 (23%)	0
Cardio-metabolic outcomes	(44,57,66,85,100,104,116,117)	(11,51,54,56,64,76,77,93,96,102,107,118–125)	8/28 (29%)	0
Fitness outcomes	(120,128,129)	(58,85,88,90,98,99,112,128,129)	3/12 (25%)	0
Bone/musculoskeletal outcomes	(59,89,130,131b)	(60,117,132c,133)	4/8 (50%)	?
Psychosocial outcomes	(134)	(61,84,135,136)	1/5 (20%)	0
Gross motor skill outcomes	(137)	(138,139)	1/3 (33%)	?
Cognitive outcomes	(140)	(141,142)	1/3 (33%)	?

included five studies and 3,133 participants. Using a random effects model, the pooled effect size indicated a weak but statistically significant positive association ($r = 0.07$, 95% CI 0.01 to 0.13, $p = 0.030$) (Figure S2). However, moderate levels of heterogeneity were observed ($Q(X) = 9.61X$, $p = 0.087$ and $I^2 = 47.97$), and there was a risk of publication bias as Rosenthal's fail-safe *N* indicated that 10 studies with an effect size of 0 would be required for the association to not be statistically significant. Likewise, both ROB ($p = 0.031$) and adjustment for MVPA ($p = 0.031$) emerged as significant effect moderators. In the study with low ROB that adjusted for MVPA, the association was not statistically significant ($r = -0.12$, 95% CI -0.29 to 0.06, $p = 0.192$), whereas it was for the remaining studies ($r = 0.09$, 95% CI 0.04 to 0.13, $p < 0.001$). Age was not a significant effect moderator for the association between sedentary time and glucose/insulin ($p = 0.775$). The pooled effect size from the five studies ($n = 2,236$) that examined associations between sedentary behaviour and HDL cholesterol was not statistically significant ($r = -0.02$, 95% CI -0.13 to 0.09, $p = 0.705$) (Figure S3). ROB ($p = 0.001$) and MVPA adjustment ($p = 0.001$), however, were significant moderators of the association. In the study with low ROB that adjusted for MVPA, the association was statistically significant ($r = -0.29$, 95% CI -0.45 to -0.12, $p = 0.001$), whereas it was not for the remaining studies. Age was not a significant moderator of the association between sedentary time and HDL cholesterol ($p = 0.217$). Based on the findings from six ($n = 2,347$) and five ($n = 2,145$) studies, respectively, associations between sedentary behaviour and systolic ($r = 0.02$, 95% CI -0.08 to 0.12, $p = 0.732$) (Figure S4) and diastolic blood pressure ($r = 0.02$, 95% CI -0.09 to 0.13, $p = 0.732$) (Figure S5) were not statistically significant, and ROB, adjustment for MVPA and age were not significant effect moderators (all $p > 0.05$).

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

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

Health-related fitness

A description of the 12 studies (children = 7 and adolescents = 5) that investigated associations between total volume of sedentary behaviour and health-related fitness is provided in Table S6. Of these, seven (58%) used

Table 1 *Continued*

Outcome	Low ROB			
	Associated with SB (citations)[†]	Not associated with SB (citations)[‡]	Summary coding	
			n/*N* for outcome (%)	Association (+/–, 0, ?)
Adiposity outcomes	(49,86,90)	(11,20,41–43,51,52,54,56,98,101,103,105–107,111–113,115)	3/22 (14%)	0
Cardio-metabolic outcomes	(57)	(11,51,54,64,77,107,120)	1/8 (13%)	0
Fitness outcomes	(126,127)	(98,112,128,129)	2/6 (33%)	0
Bone/musculoskeletal outcomes	(130)	(132c,133)	1/3 (33%)	?
Psychosocial outcomes		(84)	0/1 (0%)	?
Gross motor skill outcomes	(137)		1/1 (100%)	?
Cognitive outcomes		(142)	0/1 (0%)	?

representative sampling, nine (75%) had minimal missing data, eight (67%) used a valid measure of sedentary behaviour and six (50%) adjusted for MVPA, respectively (Table S7). Subsequently, six (50%) had ≥3/4 ROB items.

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

The meta-analysis examining the cross-sectional association between overall sedentary time and cardiorespiratory fitness included nine 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 cardiorespiratory fitness in studies ($n = 8$) among school-aged 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 cardiorespiratory fitness (58).

Bone and musculoskeletal outcomes

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

A summary of the associations between the total volume of sedentary behaviour and bone outcomes can be found in Table 1. The association was classified as 'inconsistent/uncertain' for all studies (4/8), low ROB studies (1/3) and those that adjusted for MVPA (1/4). One longitudinal study that was not classified as low ROB reported that total sedentary time was negatively associated with bone mineral content and density of the femoral neck over 12 months in 11- to 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 five studies (children = 4 and adolescents = 1) that investigated associations between total volume or patterns of sedentary behaviour and psychosocial outcomes is provided in Table S10. Of these, zero (0%) used representative sampling, one (20%) had minimal missing data, four (80%) used a valid measure of sedentary behaviour and three (60%) adjusted for MVPA (Table S11). Subsequently, one (20%) had ≥3/4 ROB items.

A summary of the associations between the total volume of sedentary behaviour and psychosocial outcomes can be found in Table 1. The evidence was classified as 'no association' for all studies (1/5), and 'inconsistent/uncertain' for the one 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 three studies (preschoolers = 2 and children = 1) that investigated associations between the total

Table 1 *Continued*

Outcome	Adjusted for MVPA			
	Associated with SB (citations)†	Not associated with SB (citations)‡	Summary coding	
			n/*N* for outcome (%)	Association (+/−, 0, ?)
Adiposity outcomes	(49,92)	(11,41–46,51,52,54,56,64,93,95–98,101–103,105–108,111–113,115)	2/29 (7%)	0
Cardio-metabolic outcomes	(44,57)	(11,51,54,56,64,76,77,93,96,107,115,120,122,124,125)	2/16 (13%)	0
Fitness outcomes	(126,127)	(98,112,128,129)	2/6 (33%)	0
Bone/musculoskeletal outcomes	(131)	(60,132c,133)	1/4 (25%)	?
Psychosocial outcomes	(135)	(61,84)	1/3 (33%)	?
Gross motor skill outcomes	(137)		1/1 (100%)	?
Cognitive outcomes		(142)	0/1 (0%)	?

†Citations for studies reporting a significant association between total sedentary behaviour and the health/developmental outcome.
‡Citations for studies reporting a non-significant association between total sedentary behaviour and the health/developmental outcome. 'c' significant association only for school-aged children, not preschool children. 'd' significant association (non-hypothesized direction); 0 = no association; ? = association is inconsistent/uncertain.
MVPA, moderate-intensity to vigorous-intensity physical activity; ROB, risk of bias; SB, sedentary behaviour.

volume of sedentary behaviour and gross motor skills is provided in Table S12. Of the three studies, two (67%) used representative sampling, zero (0%) had minimal missing data, two (67%) used a valid measure of sedentary behaviour and one adjusted for MVPA (33%) (Table S13). Subsequently, one (33%) had ≥3/4 ROB items.

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

Cognitive outcomes

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

A summary of the associations between the total volume of sedentary behaviour and cognitive outcomes can be found in Table 1. Because of small numbers, the evidence was classified as 'inconsistent/uncertain' for all studies (1/3), and the one 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). The study of Ruiz *et al.* (62) was classified as low ROB and found no significant associations between overall sedentary behaviour and liver enzymes among 12- to 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- to 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, owing 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- to 19-year-olds (25). Froberg and Raustorp (25) summarized 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-aged children and adolescents (18,19,64). While the contrasting findings in this review may be accounted for by methodological differences between studies relying on self-report versus objective assessment, they may equally be attributed to qualitative differences between total sedentary behaviour (from objective assessment) and the specific sedentary behaviours examined in other studies included in these reviews. For the most part, the evidence in previous reviews comes from studies examining television viewing as the sedentary behaviour exposure. Although children and young people engage in a number of different types of sedentary behaviours in various contexts – such as education, transportation and leisure (10) – television viewing and electronic media use for entertainment appear to have a particularly potent influence on young people's health and development. This may be for a number of reasons, including increased sitting time and decreased energy expenditure (23). However, it may also be because of increased energy intake from unhealthy snacking and sugary-beverage consumption during and following exposure, exposure to advertising, the displacement of opportunities for social and educational development, exposure to content that promotes socially undesirable behaviour, the development of biological processes of dependence, the interference of cognitive processes and the displacement of MVPA (22). As such, there may be unique mechanistic pathways through which television viewing and electronic media use influence health and development in young people, some of which might not be common to all sedentary behaviours, and this may in part explain the contrasting findings in this review.

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

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

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

Strengths and limitations

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

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

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

Conclusion

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

Study registration

PROSPERO: International Prospective Register of Systematic Reviews. 2014: CRD42014009084.

Conflict of interest statement

No conflict of interest was declared.

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Supporting information

Additional Supporting Information may be found in the online version of this article, http://dx.doi.org/10.1111/obr.12371.

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