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REVIEW

Objectively measured sedentary behaviour and cardio-metabolic risk in youth: a review of evidence

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Abstract The aim of this paper was to review studies that examine the association between volume and pattern of objectively measured sedentary behaviour and markers of cardio-metabolic risk in youth. A search for relevant articles was conducted in PubMed and SportDiscus, and the following inclusion criteria were applied: (i) youth participants (age range 6–19); (ii) accelerometer-measured volume and/or pattern of sedentary behaviour and its association with ≥1 cardio-metabolic outcome; and (iii) published, in press or accepted in an English language peer-reviewed journal between January 2000 and October 2013. A total of 45 articles met the a priori criteria and, thus, were considered eligible for inclusion. Although youth accumulate approximately 6 to 8 h of daily sedentary behaviour, little evidence supports an association with individual and clustered cardio-metabolic risk when adjusted for moderate-to-vigorous physical activity (MVPA). *Conclusion*: We suggest that youth should be encouraged to engage in recommended levels of MVPA and reduce excessive time spent in screen-based sedentary behaviour. Future studies should examine the association between volume and pattern of objectively measured sedentary behaviour and cardio-metabolic risk independent of time spent in MVPA.

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Abbreviations

BMI	Body mass index
BP	Blood pressure
DBP	Diastolic blood pressure
HDL-C	High-density lipoprotein cholesterol
LDL-C	Low-density lipoprotein cholesterol
MVPA	Moderate-to-vigorous physical activity
PA	Physical activity
SBP	Systolic blood pressure
TV	Television
WC	Waist circumference

Introduction

An increasing bulk of evidence suggests that physical activity (PA) is associated with numerous health benefits, and youth are encouraged to engage in a minimum of 60 min per day of moderate-to-vigorous PA (MVPA) (≥4 metabolic equivalent of tasks (METs)) [42, 71]. However, in the past decade, there has been a rapidly growing interest in sedentary behaviour (Latin *sedere*, 'to sit') defined as any waking behaviour characterized by low energy expenditure (≤1, 5 METs) while in a sitting or reclining posture [4]. Emerging data [35, 36, 38, 68] reveal an association between the amount of sedentary behaviour, the pattern in which it is accumulated, and increased cardio-metabolic risk in the adult population. Possible underlying mechanisms for adverse health effects are complex, but they are at least partially connected to changes in lipoprotein lipase activity [31, 34, 61] caused by reduced muscle contractions. Data suggest that youth accumulate up to 9 h of objectively measured daily sedentary behaviour [20, 65, 78], and the average daily minutes in sedentary behaviour tend to increase by age [20, 78]. A few years ago, Tremblay and associates [73] reported an association between sedentary behaviour and unfavourable body composition, increased risk for metabolic syndrome and cardio-vascular disease in youth. In response to this finding, Canadian recommendations [72] suggest that youth should limit their time spent sedentary during waking hours. These conclusions appear to be primarily based on self- or parent-reported screen-based sedentary behaviour, and evidence suggests that such proxy measure fail to represent total accumulated sedentary behaviour [77]. In connection with this finding, correlation coefficients of 0.08 (television (TV) time) [10] and 0.06 (screen time) [70] have been reported between youths' self- or parent-reported screen-related time and their volumes of objectively measured sedentary behaviour. Moreover, a very weak-to-negligible correlation (i.e. r=0.05) was found between sedentary bouts and TV time, suggesting that prolonged sedentary behaviour is not necessarily accumulated in front of the TV set [10]. This indicates that youth accumulate high volumes of sedentary behaviour outside the context of TV, and therefore, sitting during the school day, at home while doing homework and other similar activities should also be recognized as sedentary. Objective measurement devices such as accelerometers have the advantages that they provide an accurate estimation of the total accumulated volume of sedentary behaviour throughout the day and, thus, are not limited to a certain context [9, 48]. Accelerometers are valid motion sensors and are considered a reference method to accurately classify sedentary behaviour, as described in details elsewhere [48]. Although self- or parent-reported screen time suggests an association between sedentary behaviour and increased cardio-metabolic risk, when looking at objective measures, the association is less certain. Therefore, the objective of this paper was to review studies that examine the association between volume and pattern of accelerometer-measured sedentary behaviour and cardio-metabolic risk in youth.

Method

Inclusion criteria

The following inclusion criteria were applied: (i) youth participants (age range 6–19); (ii) accelerometer-measured volume and/or pattern of sedentary behaviour and its association with ≥1 cardio-metabolic outcome; and (iii) published, in press or accepted in an English language, peer-reviewed journal between January 2000 and October 2013. Articles were not excluded on the basis of study design (e.g. cross-sectional and longitudinal studies), selection of accelerometer brand and/or model (e.g. ActiGraph or Actical) or process for collecting and/or analysing accelerometer raw data (e.g. choice of epoch or cut-point for sedentary behaviour). However, articles examining clusters of activity behaviour and their associations with cardio-metabolic risk were excluded due to difficulties in determining the isolated effect of sedentary behaviour.

For the purpose of this review, the term 'volume' refers to total accumulated time spent in sedentary behaviour. Furthermore, the term 'pattern' refers to both 'bouts' and 'breaks' in sedentary behaviour. Although the duration varies across studies, the term 'bout' is defined as prolonged sedentary behaviour (i.e. consecutive minutes of sedentary behaviour), while the term 'break' is defined as any interruption of sedentary behaviour. These definitions have been employed in previous literature [21, 34, 35].

Literature search

In October 2013, searches for potential articles were undertaken in the electronic bibliographic databases PubMed and SportDiscus. The key words 'sedentar*' (e.g. 'sedentary behaviour', 'sedentary time', 'sedentary lifestyle', 'sedentariness' and 'sedentarism') and 'objective*' (e.g. 'objective measurements','objectively measured', 'objectively assessed' and 'objectively determined') were selected in addition to 'accelerometer', as well as 'children', 'adolescents' and 'youth', to restrict the search outcome to a priori inclusion criteria. These key words were used in conjunction with the following individual markers of cardio-metabolic outcomes: 'body mass index', 'weight', 'overweight', 'obesity', 'blood pressure', 'cholesterol', 'triglycerides', 'glucose', 'insulin' and 'inflammatory markers', employed in different combinations. All key words were limited to words appearing in the title and/or abstract. Furthermore, in October 2013, electronic platforms (e.g. Sedentary Behaviour Research Network (SBRN)) were searched for articles recently accepted for publication.

Screening procedure

Articles were imported into an electronic-based reference management library created especially for this review. Duplicates were initially removed using the reference management system, and remaining duplicates were removed manually by the authors. Subsequently, titles and abstracts were independently screened in an unblinded manner by the authors, and any differences during this process were reconciled by discussion and mutual agreement, and thus, consensus was obtained for all included articles. Furthermore, full text copies were obtained for all articles meeting the initial screening and the two reviewers examined the articles, and similarly to the initial screening, any uncertainty of inclusion during this process was resolved by consensus between the authors. Furthermore, the first author searched reference lists of selected reviews and included primary source articles, as well as articles published on electronic platforms, to find additional articles of interest.

Extraction process

Data were extracted by the first author using a standardized data extraction sheet and tabulated. Subsequently, the data were checked for accuracy by the second author. Furthermore, tables were created, and information regarding study characteristics and results was extracted. Results of the reviewed studies were interpreted as statistically significant at an alpha level ≤0.05. The table (Table 2) summarizing the study results was divided in two sections: section one for studies adjusting for covariates including time spent in MVPA and section two for studies controlling for covariates but not including MVPA. MVPA was separated as a factor in this study because evidence suggests that MVPA is an important contributor to metabolic health [26]. The reviewers were blinded to neither the authors nor the journals of these articles when extracting and checking data.

Methodological quality index assessment

The two reviewers assessed the methodological quality (i.e. risk of bias) using a previously proposed checklist [24], and differences during the scoring process were discussed until consensus was reached. The original checklist consists of 27 items (maximal quality index 32, with a higher index reflecting greater methodological quality) across five domains, including reporting, external validity, internal validity (i.e. bias and confounding) and power. The reviewers modified the checklist to fit methodological quality assessment of the reviewed observational studies (i.e. cross-sectional and longitudinal studies) with a maximal score of 22. A quality index was calculated for each study and expressed as a number of compliant items by the percentage of the total applicable items. Item 27 was simplified, awarding the score 1 for studies with a power/sample size calculation and 0 when no calculation was detected (or it was unable to be determined). Furthermore, studies adjusting for covariates including MVPA were considered as the highest level of evidence (section one in Table 2). Articles were not excluded due to methodological quality.

Results

When duplicates were removed, a total of 1,152 potential articles were retrieved from the initial electronic bibliographic database search. Subsequently, titles and abstracts were screened and full-text copies were obtained for 40 articles. Of these, ten did not specifically examine the association between volume and/or pattern of accelerometer-measured sedentary behaviour and markers of cardio-metabolic risk, leaving 30 articles meeting a priori inclusion criteria. Furthermore, 12 and 3 articles, respectively, were found after screening reference lists of selected published reviews and included primary source articles, as well as searching electronic platforms. Thus, a total of 45 articles were considered eligible for inclusion.

Table 1 provides a summary of methods used in each individual study, and Table 2 displays characteristics of individual studies and study results.

Assessment of risk for bias

An assessment of methodological quality was completed for all included articles. The average quality index percentage was 77.2 (range 64–91 %). Approximately 51 % of the reviewed studies adjusted for covariates including MVPA.

Volume and pattern of sedentary behaviour

Markers of obesity

Numerous observational studies [1, 5, 7, 11, 21, 22, 29, 33, 41, 49, 69, 70, 74 76] have reported a null association between volume of objectively measured sedentary behaviour and body mass index (BMI), with two studies [21, 22] employing representative data from the Canadian Health Measures Survey (CHMS). Two cross-sectional studies [1, 49] detected no association between volume of sedentary behaviour and being overweight or obese (defined according to the sex- and age-specific BMI cut-off [19]) in youth. Fewer evidence [11, 17, 21, 56, 69, 75] indicates an association between volume and pattern of sedentary behaviour and BMI. One study [17] reported greater BMI in youth who accumulated the highest volumes of sedentary behaviour when compared with their least sedentary peers. Another study [75] observed a correlation between volume of sedentary behaviour and BMI in girls, but not boys. Three studies [11, 21, 69] reported that the pattern in which sedentary behaviour is accumulated may be important for BMI, although this finding was limited to certain durations and periods of discretionary free time. In addition, one study [56] found that volume of sedentary behaviour was associated with increased BMI at the 50th, 75th and 90th BMI percentile between ages 9 and 15, although this association attenuated towards the 50th percentile.

Both large- [10, 15, 21, 22, 25, 69, 70] and small-scale [3, 12, 17, 29, 33, 40, 41, 58, 62] observational studies have reported a null association between volume of sedentary behaviour and waist circumference (WC). One of these studies [10] observed no association between patterns of sedentary behaviour and WC. Furthermore, one study [50] suggest no differences between highly and less sedentary youth in terms of WC.

Table 1 Methods used when examine the association between volume and pattern of objectively measured sedentary behaviour and cardio-metabolic risk in youth

Reference	Outcome	Accelerometer	Cut-point/definition of bouts and breaks	Epoch	Valid days	Valid h/min	Non-wear time[a]
Aires et al. [1]	Volume	ActiGraph	<500 CPM	60-s	≥4	>10 h	≥10 min
Atkin et al. [2]	Volume	ActiGraph	Various	60-s	≥1	≥500 min	Various
Bailey et al. [3]	Volume	RT3	<288 CPM	60-s	≥3	≥9 h	≥10 min
Basterfield et al. [5]	Volume	ActiGraph	<1,100 CPM	15-s	≥3	≥6 h	ME[b]
Butte et al. [8]	Volume	Actiwatch	<50 CPM	60-s	≥3	≥1,000 min	≥20 min
Butte et al. [7]	Volume	Actiwatch	<50 CPM	60-s	NC	NC	NC
Carson and Janssen [10]	Volume	ActiGraph	<100 CPM	60-s	≥4	≥10 h	≥20 min
	Bouts	ActiGraph	≥30 min with ≥80 % of <100 CPM	60-s	≥4	≥10 h	≥20 min
	Breaks	ActiGraph	≥100 CPM	60-s	≥4	≥10 h	≥20 min
Carson et al. [11]	Volume	ActiGraph	≤100 CPM	5-s	≥4	≥10 h	≥60 min
	Bout	ActiGraph	1–4, 5–9, 10–19, 20–29 and ≥30 min of ≤100 CPM	5-s	≥4	≥10 h	≥60 min
	Breaks	ActiGraph	>100 CPM	5-s	≥4	≥10 h	≥60 min
Casazza et al. [12]	Volume	ActiGraph	NS	60-s	NC	NC	NC
Chaput et al. [14]	Volume	ActiGraph	≤100 CPM	60-s	≥4	≥10 h	≥60 min
Chaput et al. [15]	Volume	ActiGraph	<100 CPM	60-s	≥4	≥10 h	≥60 min
Chinapaw et al. [17]	Volume	ActiGraph	<100 CPM	15-s	≥4	≥10 h	≥20 min
	Bouts	ActiGraph	≥10 min <100 CPM	15-s	≥4	≥10 h	≥20 min
Cliff et al. [18]	Volume	ActiGraph	<100 CPM	60-s	≥3	≥10 h	≥20 min
Colley et al. [22]	Volume	Actical	<100 CPM	60-s	≥4	≥10 h	≥60 min
Colley et al. [21]	Volume	Actical	<100 CPM	60-s	≥4	≥10 h	≥60 min
	Bouts	Actical	20, 40, 60, 80, 100 and 120 min with ≥80 % of <100 CPM	60-s	≥4	≥10 h	≥60 min
	Breaks	Actical	≥100 CPM	60-s	≥4	≥10 h	≥60 min
Ekelund et al. [27]	Volume	ActiGraph	<500 CPM	60-s	≥3	≥10 h	NC
Ekelund et al. [25]	Volume	ActiGraph	<500 CPM	60-s	≥3	≥10 h	≥10 min
Fischer et al. [29]	Volume	ActiGraph	<100 CPM	60-s	≥3	≥10 h	≥10 min
Gaya et al. [30]	Volume	ActiGraph	<500 CPM	60-s	>4	>8 h	NC
Hay et al. [33]	Volume	Actical	<100 CPM	15-s	≥3	≥8 h	≥60 min
Henderson et al. [37]	Volume	ActiGraph	<100 CPM	60-s	≥4	≥10 h	≥60 min
Hopkins et al. [39]	Volume	ActiGraph	<100 CPM	5-s	≥3	≥9 h	≥20 min
Hsu et al. [40]	Volume	ActiGraph	<100 CPM	60-s	≥4	≥10 h	≥60 min
Hussey et al. [41]	Volume	RT3	<100 CPM	60-s	≥3	NC	NC
Kwon et al. [46]	Volume	ActiGraph	<100 CPM	60-s	≥3	≥10 h	≥60 min
	Breaks	ActiGraph	≥100 CPM	60-s	≥3	≥10 h	≥60 min
Machando-Rodrigues et al. [49]	Volume	ActiGraph	<800 CPM	60-s	≥5	≥10 h	≥20 min
Martinez-Gomez et al. [53]	Volume	ActiGraph	<100 CPM	15-s	≥4	≥10	≥10 min
Martinez-Gomez et al. [52]	Volume	ActiGraph	<100 CPM	30-s	≥3	NC[c]	NC[c]
Martinez-Gomez et al. [50]	Volume	ActiGraph	<100 CPM	15-s	≥4	≥10 h	≥10 min
Martinez-Gomez et al. [51]	Volume	ActiGraph	<100 CPM	15-s	≥4	≥10 h	≥10 min
McClain et al. [54]	Volume	ActiGraph	<100 CPM	15-s	≥4	≥10 h	NC
Mitchell et al. [55]	Volume	ActiGraph	≤199 CPM	60-s	≥3	≥10 h	NC
Mitchell et al. [56]	Volume	ActiGraph	<100 CPM	60-s	≥3	≥10 h	≥60 min
de Moraes et al. [23]	Volume	ActiGraph	<100 CPM	15-s	≥3	≥8 h	NC
Oliver et al. [57]	Volume	Actical	<300 CPM	60-s	≥3	≥7 h	NC
Oliver et al. [58]	Volume	Actical	<100 CPM	60-s	≥3	≥7 h	NC
	Breaks	Actical	≥100 CPM	60-s	≥3	≥7 h	NC
Purslow et al. [62]	Volume	ActiGraph	<100 CPM	60-s	≥3	≥10 h	≥10 min

Table 1 (continued)

Reference	Outcome	Accelerometer	Cut-point/definition of bouts and breaks	Epoch	Valid days	Valid h/min	Non-wear time[a]
Rizzo et al. [64]	Volume	ActiGraph	<100 CPM	60-s	≥3	≥10 h	NC
Sardinha et al. [66]	Volume	ActiGraph	<500 CPM	60-s	≥3	≥10 h	≥10 min
Saunders et al. [69]	Volume	ActiGraph	<100 CPM	60-s	≥4	≥10 h	≥60 min
	Bout	ActiGraph	1–4, 5–9, 10–14, 15–29 and ≥30 min of <100 CPM	60-s	≥4	≥10 h	≥60 min
	Break	ActiGraph	≥100 CPM	60-s	≥4	≥10 h	≥60 min
Saunders et al. [67]	Volume	Actical	<100 CPM	60-s	≥4	≥10 h	≥60 min
	Bouts and beaks	Actical	8 h of uninterrupted sitting, 8 h sitting interrupted with a 2-min LIPA every 20 min, and 8 h sitting interrupted with a 2-min LIPA every 20 min and 2×20 min of MVPA				
Steele et al. [70]	Volume	ActiGraph	<100 CPM	5-s	≥3	≥500 min	≥10 min
Treuth et al. [75]	Volume	Actiwatch	<100 CPM	60-s	≥4	≥1,000 min	NC
Treuth et al. [74]	Volume	ActiGraph	<100 CPM	30-s	≥1	≥6 h	NC
Trinh et al. [76]	Volume	Actical	<100 CPM	60-s	≥5	≥10 h	≥20 min

CPM count per minutes, *H* hours, *LIPA* light intense physical activity, *ME* manually excluded, *Min* minutes, *MVPA* moderate-to-vigorous physical activity, *NC* no criteria, *NS* not stated, *S* seconds

[a] Consecutive minutes of 0 counts

[b] Data were reduced manually in order to delete explained or unexplained consecutive minutes of 0 counts

[c] A day of monitoring was considered non-adherent if it contained 3 or more of 20 min of consecutive 0 counts

Accumulating evidence also suggests no association between volume of sedentary behaviour and other markers of body fat [2, 5, 14, 27, 29, 46, 50, 53–55, 57, 70, 74]. However, one study [17] reported greater WC in highly sedentary youth in comparison with their less sedentary peers. Two studies [8, 41] found a weak-to-moderate positive correlation between sedentary behaviour and WC. One study [21] reported that prolonged sedentary bouts after 3 pm were associated with increased WC, whereas interruption of sedentary behaviour was negatively associated with WC in boys ages 11–14. Similarly, one study [69] found that shorter bouts of sedentary were negatively associated with WC in girls with a family history of obesity. Some studies have also reported a weak-to-moderate positive association [8, 25, 46, 62, 74, 75] between volume of sedentary behaviour and markers of body fat, with one study [46] detecting a weak negative correlation between number of sedentary breaks and body fat.

Blood pressure

A vast majority of cross-sectional studies support a null association between objectively measured sedentary behaviour and systolic and diastolic blood pressure (SBP and DBP) and median BP [3, 10, 12, 15, 21, 23, 33, 40, 50, 52], with one study [10] reporting no association between sedentary breaks and bouts and BP. Conversely, two studies [25, 30] reported a positive association between volume of sedentary behaviour, SBP and DBP. In addition, one study [50] reported differences between quartiles of sedentary behaviour and SBP, with less sedentary youth reporting healthier SBP.

Insulin

A null association has been found between volume [17, 37, 64, 69] and pattern [67, 69] of sedentary behaviour and markers of insulin, including samples with at least one obese parent [69]. When stratified by sedentary quartiles, two studies [17, 66] reported unfavourable levels of insulin in the fourth, in comparison to the first, quartile. In addition, four studies [8, 25, 37, 66] have reported weak associations between volume of sedentary behaviour and insulin, though only one [37] adjusted for time spent in MVPA.

Glucose

Most cross-sectional studies [3, 15, 17, 40, 64, 69] have reported a null association between volume of sedentary behaviour and glucose. One study [67] detected no difference between a prolonged bout of sitting, interrupted sitting and glucose levels. Conversely, a few studies [12, 25] have found a weak positive association between volume of sedentary behaviour and glucose. One study [69] reported an association between sedentary bouts lasting 10–14 min and increased levels of glucose in girls with at least one obese parent.

Table 2 Association between volume and pattern of objectively measured sedentary behaviour and cardio-metabolic risk in youth

Reference	Score (%)	Study design	Country, population, age	Outcome	N/% (boys/girls)	Adjusted covariates	Results[a]
Section one: studies with adjustment for covariates including MVPA (i.e. highest level of evidence)							
Aires et al. [1]	64	CS	Portugal, GP, 11–18 Y	Volume	111 (49/62)	Sex, age, LIPA, MPA, VPA, VVPA, MVPA, accelerometer-counts per minute and CRF	No association between sedentary behaviour and BMI, overweight and obesity
Basterfield et al. [5] (GMS)	86	LS	UK, GP, 7–9 Y	Volume	403 (198/205)	Sex, SES, FMI and MVPA	No association between sedentary behaviour and BMI and FMI
Carson and Janssen [10] (NHANES)	82	CS	USA, GP, 10–16 Y	Volume, bouts and breaks	2,527 (50.8/49.2 %)	Sex, age, ethnicity, SES, smoking, total fat, saturated fat, dietary cholesterol, sodium and MVPA. The model for breaks in sedentary behaviour was additionally adjusted for volume of sedentary behaviour	No association between volume and pattern of sedentary behaviour and WC, SBP, non-HDL-C, CRP and CMR
Carson et al. [11] (BEAT)	68	CS	Canada, GP, 11 Y	Volume, bouts and breaks	787 (45.7/54.3 %)	Sex, age, SES and MVPA. The model for breaks in sedentary behaviour was additionally adjusted for volume of sedentary behaviour	No association between volume of sedentary behaviour and BMI. Minutes spent in sedentary bouts lasting 5–9 min during weekdays was positively associated with BMI, while minute spent in sedentary bouts lasting 1–4 and 5–9 min during weekend was positively associated with BMI. Number of sedentary breaks was not associated with BMI
Chaput et al. [14] (QUALITY)	82	CS	Canada, FHO, 8–10 Y	Volume	550 (299/251)	Sex, age, sexual maturation, parental SES and BMI, sleep duration, energy intake and MVPA	No association between sedentary behaviour and percent BF and waist-height ratio
Chaput et al. [15] (QUALITY)	77	CS	Canada, FHO, 8–10 Y	Volume	536 (292/244)	Sex, age, sexual maturation, parental SES and BMI, sleep duration, WC, energy intake and MVPA	No association between sedentary behaviour and SBP, DBP, WC, fasting TG, fasting glucose and HDL-C
Chinapaw et al. [17] (ENERGY)	73	CS	Dutch and Hungaria, GP, 10–12 Y	Volume and bouts	142 (69/73)	Sex, country, WC, number of sedentary bouts and MVPA (covariates only adjusted in linear regression analysis)	Difference between the 1st and 4th quartile of volume of sedentary behaviour in BMI, WC and C-peptide, but not glucose, LDL-C, HDL-C, TG and CMR. No association between volume of sedentary behaviour and WC, glucose, LDL-C, HDL-C, TG, C-peptide and CMR. No association between sedentary bouts and metabolic indicators
Cliff et al. [18] (HIKCUPS)	73	CS	Australia, OW or OB, 5–10 Y	Volume	126 (40/60 %)	Sex, age, WC, energy intake and MVPA	No association between sedentary behaviour and HDL-C, LDL-C, TC and TG

Table 2 (continued)

Reference	Score (%)	Study design	Country, population, age	Outcome	N/% (boys/girls)	Adjusted covariates	Results[a]
Colley et al. [21] (CHMS)	82	CS	Canada, GP, 6–19 Y	Volume, bouts and breaks	1,608 (809/799)	Age, accelerometer wear time and average daily minutes of MVPA on valid days	No association between volume of sedentary behaviour and BMI, WC, non-HDL-C, SBP and DBP. Number of sedentary bouts after 3 pm on weekdays lasting ≥40 min were positively associated with WC, and sedentary bouts lasting ≥80 min were positively associated with BMI and WC in boys ages 11–14. Number of sedentary breaks after 3 pm on weekdays was negatively associated with WC in boys ages 11–14
Fisher et al. [29] (PEACHES)	86	LS	UK, GP, 8–10 Y	Volume	280 (49/51 %)	Sex, ethnicity, SES, outcome measure (baseline), total PA and MVPA	No association between sedentary behaviour and BMI, WC and FMI
Henderson et al. [37] (QUALITY)	73	CS	Canada, FHO, 8–10 Y	Volume	424 (222/202)	Sex, age, pubertal stage, FM percent, season, Vo_{2peak} and MVPA	Positive association between sedentary behaviour and HOMA-IR but not Matsuda insulin sensitivity index and fasting insulin
Hay et al. [33] (Healthy Hearts Prospective Cohort Study of Physical Activity and Cardiometabolic Health in Youth)	73	CS	Canada, OB, 9–17 Y	Volume	156 (ND/ND)	Sex, age, diet, LIPA, MPA and VPA	No association between sedentary behaviour and WC, BMI and SBP
Hopkins et al. [39] (SportsLINX)	73	CS	UK, GP, 11 Y	Volume	116 (46/70)	Sex, maturation, BMI, total PA and MVPA	No correlation between sedentary behaviour and vascular function
Hsu et al. [40] (SANO, STAND and TRANSITION, research projects)	68	CS	USA, MY, 8–19 Y	Volume	105 (26/79)	Sex, age, ethnicity, Tanner stage, FM, lean tissue mass. The model for metabolic syndrome was additionally adjusted for MVPA	No association between sedentary behaviour and WC, SBP, DBP, TG, fasting glucose, HDL-C and metabolic syndrome
Kwon et al. [46] (IBDS)	77	LS	USA, GP, 8–15 Y	Volume and breaks	554 (277/277)	Height (correlation analysis). Age, body size, physical maturity and MVPA (multivariable growth model)	Weak positive correlation between volume of sedentary behaviour and BF in boys aged 8, but not 11–15, nor girls ages 8–15. Number of sedentary breaks was weakly negatively correlated with BF in boys aged 8 and 11, respectively, but not in boys ages 13–15 and girls ages 8–15. No association between sedentary behaviour and BF
Machado-Rodrigues et al. [49] (MALS)	64	CS	Portugal, GP, 13–16 Y	Volume	362 (165/197)	Sex, chronological age, (correlation analysis). Sex, chronological age, measured time in sedentary behaviour and PA, CRF, accelerometer-counts per minute and MVPA (logistic regression)	No correlation between sedentary behaviour and BMI. No association between sedentary behaviour and overweight and obesity

Table 2 (continued)

Reference	Score (%)	Study design	Country, population, age	Outcome	N/% (boys/girls)	Adjusted covariates	Results[a]
Martinez-Gomez et al. [51] (AFINOS)	73	CS	Spain, GP, 13–17 Y	Volume	183 (95/88)	Sex, age, pubertal status, BMI and MVPA	No association sedentary behaviour and white blood cells, CRP, interleukin-6, complement factor 3, complement factor 4, adiponectin, leptin, ICAM-1, VCAM-1, L-selection, E-selectin and plasminogen activator inhibitor-1
McClain et al. [54] (TRANSITION)	73	CS	US, MY, 8–11 Y	Volume	53 (0/53)	Age, ethnicity, Tanner stage, lean mass, total energy intake and MVPA	No association between sedentary behaviour and FM
Mitchell et al. [55] (ALSPAC)	86	CS	UK, GP, 12 Y	Volume	5,434 (2,590/ 2,844)	Sex, birth weight, pubertal status, gestational age, social factors, social class, TV time per week at 38 months, sleep time at 30 months, maternal education, smoking status during pregnancy, mother obesity and MVPA	No association between sedentary behaviour and FM
Mitchell et al. [56] (NICHD)	82	LS	USA, GP, 9–15 Y	Volume	798 (391/407)	Sex, ethnicity, maternal education, hours of sleep, healthy eating index and MVPA	Positive association between sedentary behaviour and BMI at 50th, 75th and 90th, but not at the 10th and 25th percentile between ages 9 to 15
Saunders et al. [69] (QUALITY)	77	CS	Canada, FHO, 8–11 Y	Volume, bouts and breaks	522 (286/236)	Age, Tanner stage, BMI, wear-time, parental income and education, LIPA and MVPA	No association between volume of sedentary behaviour and WC, BMI, insulin, glucose, HDL-C, TG, CRP and CMR. Number of shorter (i.e. 1–4 and 5–9 min) and longer (i.e. 10–14 and 15–29 min) sedentary bouts was positive respectively negatively associated with few marker of CMR. Number of sedentary breaks was negatively associated with CMR and BMI, but not WC, insulin, glucose, HDL-C, TG and CRP
Steele et al. [70] (SPEEDY)	82	CS	UK, GP, 9–10 Y	Volume	1,862 (820/1,042)	Sex, age, birth weight, height, parental SES, maternal BMI, sleep duration and MVPA	No association between sedentary behaviour and WC, BMI and FM
Trinh et al. [76] (LEAP)	90	LS	Australia, OB, 5–10 Y	Volume	115 (ND/ND)	Sex, age, PA, intervention status, SES, maternal BMI, maternal education, LIPA and MVPA	No association between sedentary behaviour and BMI
Section two: studies with adjustment for covariates but not including MVPA							
Atkin et al. [2] (EYHS)	82	CS	Europe, GP, 9–10, 15–16 Y	Volume	2,327 (1,059/ 1,268)	Sex, age group, age, study location, sexual maturity, adiposity, season, day of the week, registered wear time and total	Positive association between sedentary behaviour and CMR, but not sum of skinfolds

Table 2 (continued)

Reference	Score (%)	Study design	Country, population, age	Outcome	N/% (boys/girls)	Adjusted covariates	Results[a]
						accelerometer counts per registered minute	
Bailey et al. [3] (HAPPY)	68	CS	UK, GP, 10–14 Y	Volume	100 (41/59)	Sex, age, ethnicity and SES	No difference between groups (low, medium and high sedentary) and CMR. No correlation between sedentary behaviour and WC, SBP, DBP, TG/HDL-ratio, TG, glucose and CMR
Butte et al. [8] (Viva la Familia Study)	77	CS	USA, FHO, 4–19 Y	Volume	897 (441/456)	Sex, age, BMI and percent FM (correlation analysis). Sex, age, BMI/percent FM (GEE model)	Weak positive correlation between sedentary behaviour and percent FM, fasting insulin and WC. Positive association between sedentary behaviour and fasting insulin. Positive association (when adjusting for age, sex and percent FM) and negative association (when adjusting for age, sex and BMI) between sedentary behaviour and WC
Butte et al. [7] (Viva la Familia Study)	73	LS	USA, FHO, 4–19 Y	Volume	798 (410/388)	Sex, age, age squared, Tanner stage and BMI	No association between sedentary behaviour and weight gain
Casazza et al. [12]	73	CS	US, MY, 7–12 Y	Volume	202 (53/47 %)	Sex, age, ethnicity, SES and BF (additionally adjusted for height and TG when evaluating BP and HDL-C, respectively)	Positive association between sedentary behaviour and glucose, but not WC, SBP, TG and HDL-C
Colley et al. [22] (CHMS)	82	CS	Canada, GP, 6–11 Y	Volume	878 (51.2/48.8 %)	Sex and age	No association between sedentary behaviour and BMI and WC
Ekelund et al. [25] (EYHS)	86	CS	Europe, GP, 9–10, 15–16 Y	Volume	1,709 (1,008/738)	Age group, sex and study location (correlation analysis). Sex, age group, study location, birth weight, sexual maturity, WC, smoking status, maternal BMI, parental SES and CRF (regression analysis)	Weak positive correlation between sedentary behaviour and SBP, DBP, glucose, insulin, triacylglycerol and sum of skinfold thicknesses, but not WC and HDL-C. Positive association between sedentary behaviour and SBP, DBP, glucose, insulin, triacylglycerol and metabolic syndrome, but not WC and HDL-C
Ekelund et al. [27] (EYHS)	86	CS	Europe, GP, 9–10 Y	Volume	1,292 (638/654)	Sex, sexual maturity and study location	No association between sedentary behaviour and BF
Gaya et al. [30]	68	CS	Portugal, GP, 8–17 Y	Volume	163 (66/97)	Sex, age, height and BMI	Positive association between sedentary behaviour and SBP

Table 2 (continued)

Reference	Score (%)	Study design	Country, population, age	Outcome	N/% (boys/girls)	Adjusted covariates	Results[a]
Hussey et al. [41]	68	CS	Ireland, GP, 7–10 Y	Volume	152 (52/100)	Sex, age, BMI and WC (regression analysis)	Moderate positive correlation between sedentary behaviour and WC in boys, but not girls. No correlation between sedentary behaviour and BMI. No association between sedentary behaviour and BMI and WC
Martinez-Gomez et al. [50] (AFINOS)	82	CS	Spain, GP, 13–17 Y	Volume	201 (102/99)	Valid daily wear time	Difference between groups (low, medium and high sedentary) in SBP, TG, glucose and CVR, but not sum of skinfolds, WC, TAD, median BP, LDL-C, HDL-C, TC, apolipoprotein A-1 and apolipoprotein B-100
Martinez-Gomez et al. [52]	73	CS	USA, GP, 3–8 Y	Volume	111 (57/54)	Sex, age, height and BF	No difference between groups (low, medium and high sedentary) and SBP and DBP. No association between sedentary behaviour and SBP and DBP
Martinez-Gomez et al. [53] (AFINOS)	77	CS	Spain, GP, 13–16 Y	Volume	214 (107/107)	Registered valid time	No difference between groups (low, medium and high sedentary) and total BF
de Moraes et al. [23] (BRACAH and HELENA)	86	CS	Europe, GP, 12–17 Y	Volume	3,308 (1,580/ 1,728)	Age, SES, parental education, BMI, WC and regular tobacco smoking	No association between sedentary behaviour and SBP and DBP
Oliver et al. [57] (PIF; PAC)	73	CS	New Zealand, GP, 6 Y	Volume	102 (45/57)	No adjustments were made	No association between sedentary behaviour and BF
Oliver et al. [58] (PIF; PAC)	73	CS	New Zealand, GP, 6 Y	Volume and breaks	126 (52/74)	No adjustments were made	No association between volume of sedentary behaviour and WC. Number of sedentary breaks was not associated with WC
Purslow et al. [62] (PEACHES)	82	CS	UK, GP, 8–9 Y	Volume	301 (155/146)	Sex, age, ethnicity and SES	Positive association between sedentary behaviour and FM, but not WC
Rizzo et al. [64] (EYHS)	77	CS	Europe, GP, 15 Y	Volume	613 (261/352)	Sex, country, pubertal status and markers of BF	No association between sedentary behaviour and HOMA, insulin and glucose
Sardinha et al. [66] (EYHS)	86	CS	Portugal, GP, 9–10 Y	Volume	308 (161/147)	Sex, birth weight and sexual maturity (correlation analysis). Sex, birth weight, sexual maturity, overall FM, central FM and wear time (regression analysis)	Weak positive correlation between sedentary behaviour and fasting insulin and HOMA-IR. Positive association between sedentary behaviour and HOMA-IR
Saunders et al. [67]	91	LB	Canada, GP, 10–14 Y	Bouts and breaks	19 (11/8)	Sex, age, Tanner stage, BMI, WC and baseline PA and sedentary behaviour	No differences between uninterrupted and interrupted sedentary behaviour and insulin, glucose, LDL-C, HDL-C and TG

Table 2 (continued)

Reference	Score (%)	Study design	Country, population, age	Outcome	N/% (boys/girls)	Adjusted covariates	Results[a]
Treuth et al. [75]	64	CS	USA, GP, 7–19 Y	Volume	229 (99/130)	No adjustments were made	No correlation between sedentary behaviour and BMI, FM and FP for boys. Moderate to strong correlation between sedentary behaviour and BMI, FM and FP in girls
Treuth et al. [74] (TAAG)	82	LS	USA, GP, 12–14 Y	Volume	984 (0/984)	No adjustments were made	CS association between sedentary behaviour and BF, but not BMI. No association between volume of sedentary behaviour and BMI and BF in prospective analysis

Abbreviations: *AFINOS* Physical Activity as a Preventive Measure Against Overweight, Obesity, Infections, Allergies, and Cardiovascular Disease Risk Factors in Adolescents, *ALSPAC* The Avon Longitudinal Study of Parents and Children, *BF* body fat, *BMI* body mass index, *BRACAH* Brazilian Cardiovascular Adolescent Health, *CHMS* Canadian Health Measures Survey, *CMR* cardio-metabolic risk (clustered score), *CPM* counts per minutes, *CRF* cardiorespiratory fitness, *CRP* C-reactive protein, *CS* cross-sectional, *CVR* cardio-vascular risk, *DBP*, diastolic blood pressure, *ENERGY* European Energy balance Research to prevent excessive weight Gain among Youth, *EYHS* European Youth Heart Study, *FHO* family history of obesity, *FM* fat mass index, *FMI* fat mass index, *FP* fat percent, *GEE* generalized estimating equations, *GMS* The Gateshead Millennium Study, *GP* general population, *HAPPY* Health and Physical Activity Promotion in Youth, *HDL-C* high-density lipoprotein cholesterol, *HELENA* Healthy Lifestyle in Europe by Nutrition in Adolescence, *HFO* Hispanic families, and they were required to have ≥1 overweight child, *HIKCUPS* Hunter Illawarra Kids Challenge Using Parent Support, *IBDS* The Iowa Bone Development Study, *LB* laboratory based, *LDL-C* low-density lipoprotein cholesterol, *LEAP* Live Eat and Play 2, *LIPA* light physical activity, *LS* longitudinal studies, *MALS* Midlands Adolescents Lifestyle Study, *MPA* moderate physical activity, *MY* minority youth, *ND* no data, *NHANES* National Health and Nutrition Examination Surveys, *NICHD* The National Institute of Child Health and Human Development, *Non-HDL-C* non-high-density lipoprotein cholesterol, *OB* obese, *OW* overweight, *PA* physical activity, *PEACHES* Physical Exercise and Appetite in Children Study, *PIF;PAC* The Pacific Islands Families: Child and Parental Physical Activity and Body Size, *QUALITY* Québec Adipose and Lifestyle Investigation in Youth, *SANO* Strength and Nutrition Outcomes for Latina Girls, *SBP* systolic blood pressure, *SES* socioeconomic status, *SPEEDY* Sport, Physical Activity and Eating behavior, Environmental Determinants in Young people, *STAND* Strength Training and Nutrition Development in African American Youth, *TAAG* Trial of Activity for Adolescent Girls, *TC* total cholesterol, *TG* triglycerides, *TRANSITION* Insulin Resistance and Declining Physical Activity Levels in African American and Latina Girls, *VPA* vigorous physical activity, *VVPA* very vigorous physical activity, *WC* waist circumference, *Y* years

[a] The final model of adjustments for covariates was included in the table

Another study [50] compared tertiles of sedentary behaviour and concluded that youth who accumulated higher proportions of sedentary behaviour had less favourable levels of glucose compared to their less sedentary peers.

Blood lipids

Studies [3, 10, 12, 15, 17, 18, 21, 25, 40, 69] enrolling youth from Australia, Europe and North America support a null association between volume of sedentary behaviour and blood lipids. Two studies found no association between the pattern in which volume of sedentary behaviour was accumulated and non-high-density lipoprotein cholesterol (HDL-C) [10] and HDL-C [69], while another study [67] detected no difference between prolonged sitting, interrupted sitting and low-density lipoprotein cholesterol (LDL-C), HDL-C and triglycerides. One study [69] found a negative association between bouts lasting 15–29 min and triglycerides in boys with at least one obese parent. One small study reported no difference between tertiles of sedentary behaviour and LDL-C, HDL-C and total cholesterol [50]. However, one study [25] reported a weak positive association when analysing volume of sedentary behaviour together with triacylglycerol. Another study [50] detected less favourable levels of triglycerides in youth who accumulated high volumes of sedentary behaviour compared to their less sedentary peers.

Clustered cardio-metabolic risk and inflammatory markers

Some studies have reported a null association between volume of sedentary behaviour and individual and clustered cardio-metabolic risk [3, 17, 39, 40, 69], and studies have also found a null association between volume of sedentary behaviour and individual inflammatory markers [10, 51, 69]. Some studies suggest a null association between numbers of sedentary bouts [10, 17] and breaks [10] and clustered cardio-metabolic risk. Three studies [3, 10, 17] detected no difference between highly versus less sedentary youth when related to clustered cardio-metabolic risk. Conversely, two large studies [2, 25] support an association between volume of sedentary behaviour and cardio-metabolic risk. One study [69] found a positive association between number of sedentary breaks, shorter sedentary bouts and reduced cardio-metabolic risk in a sample of 522 youth with a family history of obesity. This study also suggests a negative association between prolonged bouts of sedentary behaviour and inflammatory marker [69]. One study [50] reported that, in comparison to highly sedentary, less sedentary youth experienced reduced cardiovascular risk.

Discussion

Research on sedentary behaviour is in its infancy, yet it is expanding rapidly, and the current review provides important insights regarding the association between objectively measured sedentary behaviour and cardio-metabolic risk in youth. Most reviewed studies appear to have examined volume of sedentary behaviour and its association with markers of obesity, yet limited evidence supports such association when adjusting for MVPA. The importance of sedentary bouts and breaks appears to be inconsistent; some evidences, however, indicate that prolonged sedentary bouts are positively associated with obesity, whereas sedentary breaks may be beneficial and, thus, negatively associated with obesity. The longitudinal association between volume of sedentary behaviour and obesity is rather unexplored though previous work suggests a weak association when taking study quality into account.

A vast majority of evidence does not support an association between volume of sedentary behaviour and BP, even though it should be acknowledged that three studies reported such association. Two of these, however, utilized a relatively high cut-point (i.e. <500 CPM) to estimate sedentary behaviour, suggesting greater volume of sedentary behaviour can increase the likelihood of detecting an unfavourable association. None of the reviewed studies reported an association between volume of sedentary behaviour and BP when adjusting for covariates including MVPA.

We found limited evidence to support an association between objectively measured sedentary behaviour and glucose. No study reported such association when adjusting for time spent in MVPA. Likewise, reviewed studies indicate a weak association between objectively measured sedentary behaviour and markers of insulin. Because this review's authors found few studies that explore this connection, future work ought to continue examine the effect of objectively measured sedentary behaviour and its association with glucose and insulin.

Taken together, reviewed evidence suggests a lack of association between objectively measured sedentary behaviour and blood lipids, though it should be recognized that the opposite has been reported. However, the only two studies reporting an association between objectively measured sedentary behaviour and blood lipids did not adjust for time spent in MVPA.

Most of the reviewed studies indicate a null association between volume of sedentary behaviour and clustered cardio-metabolic risk. This conclusion is unchanged when taking study quality into consideration. However, it is noteworthy that one study suggests that the manner in which sedentary behaviour is accumulated has an association with clustered cardio-metabolic risk; frequent breaks in sedentary behaviour are beneficial for youth with a family history of obesity.

We found only three studies that examine the association between sedentary behaviour and inflammatory markers; thus, additional research is urgent. However, based on these studies, volume of sedentary behaviour is not associated with inflammatory markers.

Although youth accumulate roughly 6 to 8 h of sedentary behaviour throughout the day, limited evidence indicates an association between objectively measured sedentary behaviour and individual and clustered cardio-metabolic risk. To support this further, Ekelund and colleagues [26] used data from the International Children's Accelerometry Database, comprising 20,871 youth, and employed a meta-analytic approach to examine the association between volume of objectively measured sedentary behaviour, MVPA and indicators of increased cardio-metabolic risk. Evidence was only found to suggest an association between volume of sedentary behaviour and insulin, yet this association attenuated towards the null when additionally adjusting for time spent in MVPA. A similar pattern was observed in some of the reviewed studies [5, 18, 70, 55] indicating that MVPA may be more important than volume of sedentary behaviour in relation to cardio-metabolic risk in the youth population. Collectively, we found few studies reporting an association between volume of sedentary behaviour and cardio-metabolic risk when controlling for MVPA. As partially suggested above, time spent in MVPA [11, 14, 15, 22, 29, 40, 46, 54, 76], or simply VPA [14, 33], was associated with reduced cardio-metabolic risk independent of volume of objectively measured sedentary behaviour even though most youth would be classified as physically inactive (i.e. not meeting current PA recommendations [4]). Therefore, it appears critical to stress additional health benefits associated with MVPA, not necessarily simply to advocate for reducing sedentary behaviour. For example, in addition to improvements in components of cardio-metabolic health, body composition and cardio-respiratory fitness [42], MVPA appears to be important for stimulating and improving bone mineral content [43] which is unlikely to occur when engaging in light intense PA.

Previous reviews [63, 73] have predominantly incorporated subcomponents of sedentary behaviour, and therefore, it is not surprising that this review provides results that are somewhat contrary to prior observations. Since other studies have focused on certain subcomponents of sedentary behaviour, such as time spent in front of the TV, which are clearly associated with unhealthy eating and increased beverage consumption [47, 59, 60], this association may not be detected when considering total accumulated time spent in sedentary behaviour. With this in mind, limiting screen-based sedentary behaviour is an important challenge for public health authorities and organizations even though this may be difficult due to strong habitual component and environmental cues [6].

Some limitations should be taken into consideration when interpreting the present results. Most reviewed studies are cross-sectional in nature, and as a consequence, the long-term effects of objectively measured sedentary behaviour appear to be rather unexplored. In addition, few studies have examined the effect of prolonged sedentary behaviour and its association with cardio-metabolic health in youth. Moreover, there is a gap in the literature regarding ideal accelerometer-data proceeding methods [45], and consensus is urgently required since different methodological approaches complicate the comparability between studies. For example, the reviewed studies have collected sedentary behaviour in 5- to 60-s epochs and employed cut-points between <50 and <1,100 CPM though <100 CPM is the most common (65 % of cases) and is an appropriate cut-point [28]. This is a limitation since evidence suggests that the choice of cut-point will influence the association between sedentary behaviour and cardio-metabolic risk, with higher cut-points producing stronger associations [2]. Even though accelerometers provide accurate estimate of sedentary behaviour, the devices may categorize standing as sedentary behaviour as well [13, 16] even though it does not meet the definition of this behaviour: both <1.6 MET and a sitting or reclining posture [4]. To overcome this bias, future studies could use inclinometer output to distinguish between postures [44], yet some evidence suggests that these outputs are not an appropriate indicator for youth's posture since misclassifications are common [32]. Furthermore, accelerometers do not provide distinctions between sedentary behaviour so it is not possible to determine the contexts volumes and patterns that sedentary behaviour are accumulated. This is important in studies investigating the association between subcomponents of sedentary behaviour in relation to cardio-metabolic health.

Conclusion

Available evidence suggests a weak association between volume and pattern of objectively measured sedentary behaviour and individual and clustered cardio-metabolic risk in youth when adjusting for time spent in MVPA. Therefore, future studies should examine the association between objectively measured sedentary behaviour and cardio-metabolic risk independent of MVPA. Finally, we suggest that youth should be encouraged to engage in recommended levels of MVPA and reduce excessive time spent in screen-based sedentary behaviour.

Competing interests The authors have declared no competing interests.

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