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Review

Sedentary Behaviour as an Emerging Risk Factor for Cardiometabolic Diseases in Children and Youth

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ABSTRACT

Sedentary behaviour (e.g. TV viewing, seated video game playing, prolonged sitting) has recently emerged as a distinct risk factor for cardiometabolic diseases in children and youth. This narrative review provides an overview of recent evidence in this area and highlights research gaps. Current evidence suggests that North American children and youth spend between 40% and 60% of their waking hours engaging in sedentary pursuits. Although data are lacking concerning temporal trends of objectively measured sedentary time, self-reported sedentary behaviours have increased over the past half century, with a rapid increase since the late 1990s. Excessive sedentary behaviour has been found to have independent and deleterious associations with markers of adiposity and cardiometabolic disease risk. These associations are especially consistent for screen-based sedentary behaviours (TV viewing, computer games, etc), with more conflicting findings observed for overall sedentary time. The above associations are possibly mediated by the influence of screen-based sedentary behaviours on energy intake. Although excessive sitting has been reported to have adverse acute and chronic metabolic impacts in adults, research on children is lacking. Research is particularly needed to investigate the impact of characteristics of sedentary behaviour (i.e. type/context, sedentary bout length, breaks in sedentary time, etc), as well as interventions that examine the health and behavioural impacts of sitting per se.

RÉSUMÉ

Le comportement sédentaire (p. ex. l'écoute de la télévision, la pratique des jeux vidéo en position assise, la position assise prolongée) s'est récemment imposé comme un facteur de risque distinct des maladies cardiométaboliques chez les enfants et les jeunes. Cette revue narrative offre un aperçu des données scientifiques récentes dans ce domaine et souligne les lacunes en matière de recherche. Les données scientifiques actuelles montrent que les enfants et les jeunes de l'Amérique du Nord passent entre 40 % et 60 % de leur journée à faire des activités sédentaires. Bien qu'il manque de données sur les tendances temporelles du temps consacré à des activités sédentaires mesurées de manière objective, les comportements sédentaires qui sont rapportés ont augmenté au cours de la seconde moitié du siècle dernier, et ce, plus rapidement depuis la fin des années 1990. Le comportement sédentaire excessif a montré des liens indépendants et délétères avec les marqueurs de l'adiposité et du risque de maladie cardiométabolique. Ces liens sont particulièrement cohérents pour ce qui est des comportements sédentaires liés au temps passé devant un écran (écoute de la télévision, jeux sur ordinateur, etc.), et des résultats plus contradictoires ont été observés pour l'ensemble du temps consacré à des activités sédentaires. Les liens susmentionnés sont possiblement influencés par les comportements sédentaires liés au temps passé devant un écran. Bien que la position assise excessive soit rapportée comme ayant des conséquences métaboliques indésirables à court et à long terme chez les adultes, il manque de recherches en ce qui a trait aux enfants. La recherche est nécessaire en particulier pour étudier les conséquences des caractéristiques du comportement sédentaire (c.-à-d. type/contexte, durée des périodes de sédentarité, pauses durant le temps consacré à des activités sédentaires, etc.) ainsi que les interventions qui examinent les conséquences sur la santé et le comportement de la position assise en soi.

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Introduction

It is well established that high levels of physical activity are associated with reduced health risk in children and youth (1–3). Physical activity exhibits a dose-response relationship with health indicators in the pediatric population, and even modest amounts of physical activity can result in improved health for those at greatest risk (1). However, in addition to the consistent association between physical activity and health in the pediatric population, accumulating evidence suggests that the amount of time children and youth spend engaging in sedentary behaviours (i.e. activities that involve sitting or reclining while expending ≤1.5 metabolic equivalents [4]) may be associated with increased cardiometabolic disease risk independent of other factors, such as physical activity and abdominal obesity (5–12). In response to this new research, Canada has recently created pediatric sedentary behaviour guidelines, which are separate from (but complementary to) physical activity guidelines for this age group (11). These guidelines recommend that school-aged children and youth accumulate no more than 2 hours of recreational screen time each day and that they also limit periods of prolonged sitting and motorized transport (11). Although a number of recent narrative reviews have examined the health impacts of sedentary behaviour in adults (13–17), there is a lack of such a review in the pediatric population. Thus, this article aims to provide a comprehensive overview of the available evidence concerning sedentary behaviour and markers of cardiometabolic disease risk in school-aged children and youth.

What is sedentary behaviour?

The meaning of the word *sedentary* has evolved rapidly in recent years (18). Although the Latin root of the word *sedentary* literally means *to sit* (15), the term has historically been used by health researchers to refer to an individual who is not sufficiently physically active (4). Similarly, the phrase *sedentary lifestyle* has typically been used to refer to a lifestyle that includes little or no physical activity (19). It has, therefore, been relatively common for researchers to refer to individuals as sedentary because of their lack of physical activity, rather than the amount of time they spend sitting. However, recent evidence suggests that sitting too much and exercising too little are separate and distinct risk factors for chronic diseases, including cancer, cardiovascular disease and diabetes (15,16,20,21). Further, individuals can easily meet physical activity guidelines while spending the vast majority of their days engaging in seated activities or vice versa (Figure 1). As a result, it has been proposed that the term *sedentary* should be used to refer only to activities that are defined by both seated and reclining postures and energy expenditures at or near resting levels (4). Therefore, in this review the term *sedentary* is used to refer specifically to waking behaviours characterized by energy expenditure ≤1.5 metabolic equivalents while in a sitting or reclining posture (4). In contrast, the term *inactive* is used to refer to an individual who is not sufficiently physically active (e.g. not meeting physical activity guidelines).

How is pediatric sedentary behaviour measured?

As with physical activity, sedentary behaviour can be assessed using a variety of self- and proxy-report questionnaires or by direct measurement tools (15,22,23). Self- and proxy-report tools typically take 1 of 2 approaches: 1) asking children or their parents to estimate the amount of time they spend engaging in common sedentary behaviours (e.g. watching television, using a computer, playing passive video games, driving in a car, etc), which may be reflective of total sedentary time or 2) asking them to estimate the amount of total time, on a daily basis, they spend sitting. These tools are attractive because they are inexpensive and result in data that are relatively simple to analyze while providing information related to specific modalities or contexts of sedentary behaviours (e.g. television viewing vs. reading). A recent systematic review suggests that self- and proxy-report tools generally display acceptable reliability and validity in assessing sedentary behaviour (22). However, these measures have a number of limitations. First and foremost, they are known to be limited by high levels of error and recall bias (23–26). Further, no single sedentary activity is representative of an individual's total sedentary behaviour profile (23,27,28), which can pose an issue when data collection focuses on a limited number of sedentary behaviour modalities.

In contrast to self-report tools, accelerometers and inclinometers allow for the direct measurement of sedentary behaviour in childhood (15,22,23). Accelerometers assess the number of movement "counts" in a given time period, and their use has increased rapidly in recent years (29). A variety of thresholds have been proposed to distinguish between sedentary behaviour and light-intensity physical activity, with a threshold of 100 counts per minute (CPM) being shown to have high sensitivity and specificity for the measurement of sedentary behaviour in pediatric populations using both ActiGraph (ActiGraph, Pensacola, FL, US) and Actical (Philips Respironics, Andover, MA, US) accelerometers (22,30–36). Accelerometers can also be used to assess the frequency of breaks in sedentary time and the duration of sedentary bouts, neither of which can be determined easily via self-report tools (37–39). However, a key limitation of accelerometers is their inability to distinguish between sitting and stationary standing (40) and the lack of information regarding the modality of sedentary behaviour (e.g. TV viewing vs. reading). Inclinometers such as the activPAL (PAL Technologies, Glasgow, UK) have been reported to be more accurate than accelerometers in differentiating between sitting and standing (40,41), with Aminian and Hinckson reporting that the activPAL was able to distinguish perfectly between the 2 postures in healthy elementary school children (41). As with accelerometers, however, inclinometers are unable to provide information on the modality of sedentary behaviour and have been used far less frequently. As a result of the limitations of both self-report and direct-measurement tools, researchers have, therefore, advocated for the concurrent use of both strategies whenever possible (22,23).

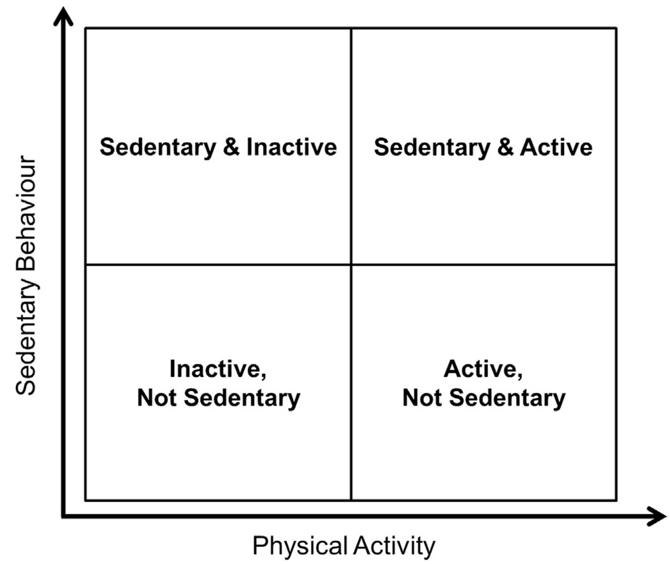

Figure 1. Sedentary behaviour and physical activity as distinct constructs.

Prevalence of sedentary behaviour in the pediatric population

Available evidence suggests that children and youth in developed nations currently spend 40% to 60% of their waking hours engaging in sedentary pursuits. Colley et al used accelerometers to assess total sedentary time in a representative sample of 1608 Canadians between the ages of 6 and 19 years (37,42). They estimated that girls and boys, respectively, accumulate 7.4 and 8.5 hours of daily sedentary time, roughly half of which is accumulated during school hours (37,42). Sedentary time also tends to increase with age; children under 11 years averaged approximately 1.3 hours less daily sedentary time than those aged 11 to 14 years of age and roughly 2 hours less than those 15 to 19 years of age (42). Similar levels and trends for accelerometer-derived sedentary behaviour have been reported in cross-sectional examinations of American (43) and European (44) children and youth.

The above-mentioned findings are also supported by longitudinal studies, which suggest that both screen time and total sedentary time increase with age (45,46). For example, a longitudinal study of 759 Vietnamese students observed that boys and girls increased their daily sedentary time by more than 1 hour between the ages of 13 and 16 years (45). Similarly, Brodersen et al found that self-reported screen time increased by more than 2.5 hours per week during a 5-year period in a study of 5863 British adolescents (46). It is worth noting that the frequency of breaks in sedentary time also appears to decrease with age; a longitudinal study of roughly 500 children found a decrease of approximately 2 breaks per hour per year from age 5 to age 15 (47). These findings suggest that children become more sedentary with age and also accumulate their sedentary time in increasingly prolonged bouts.

Temporal trends in sedentary behaviour among children and youth

Given the relatively recent introduction of accelerometry in population-based research, it is difficult to assess temporal trends in objectively measured sedentary time. However, self-reported media use (including TV, radio, audio, reading, etc) appears to have increased since the 1960s, with rapid increases observed in the past decade. Schramm et al (48) reported that American children in grades 6 and 12 averaged roughly 37 hours per week of total media exposure in 1961. In contrast, recent evidence from the Kaiser Family Foundation reported that American children between the ages of 8 and 18 years averaged 53 hours per week of total media exposure in 1999, and 75 hours in 2009 (49) (Figure 2). After adjusting for multitasking (e.g. engaging with 2 forms of media simultaneously), the average American youth currently spends 54 hours engaging with media each week (49). The same report estimated that total media use increased by 1.5 hours per day among Caucasian American children between 1999 and 2009 and by more than 3 hours per day among African American and Hispanic children over the same period (49). A nationally representative study of 52 000 children and youth produced a similar estimate of total daily screen time among contemporary Canadian students (50), and temporal increases in self-reported screen time have also been reported in Czech girls (but not boys) (51) and in Chinese children and youth (52,53) during the late 1990s and early 2000s, although reductions in total screen time have been reported in Norwegian children (54) and Czech boys (51). Consequently, it is not surprising that the majority of children in developed nations currently exceed the recommendations for pediatric screen time (11,55).

Along with the reported increases in total screen time, there has also been a shift away from TV viewing and toward increased computer and video game use in recent decades (49,51,56,57). In a study of Czech children, between 1998 and 2008, the percent of sedentary time accounted for by TV viewing decreased from 17% to 12% among girls and from 24% to 15% among boys (51). During the same period, the proportion of sedentary time accounted for by computer use more than doubled in both sexes (51). Finally, evidence suggests that sedentary modes of transportation (e.g. driving) have also increased dramatically since the 1960s throughout the Western world (58–60). Taken together, the above evidence suggests that the volume of total daily sedentary time has likely increased in the past 50 years, with computer and video-game use playing a larger role in recent years.

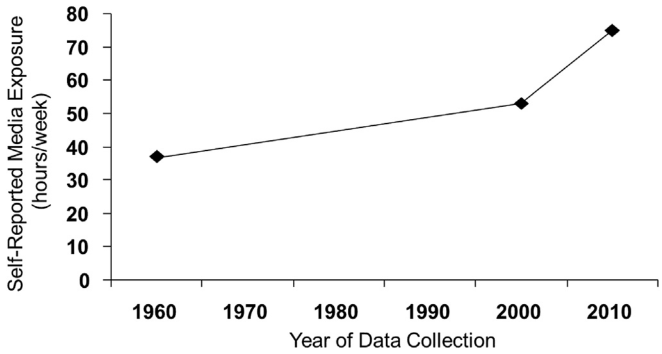

Figure 2. Self-reported media exposure of American youth over time. Data from Schramm et al (48) and Rideout et al (49). Data have not been adjusted for multitasking (e.g. engaging with multiple media simultaneously).

Sedentary time and markers of adiposity in children and youth

A recent systematic review by Tremblay et al (61) examined the relationship between sedentary behaviour (typically assessed via self- or proxy-reported screen time) and adiposity in 170 separate studies of school-aged children. Among 119 cross-sectional studies, 94 observed positive associations between sedentary behaviour and markers of adiposity. Further, the risk of being identified as obese increased in a dose-response manner with sedentary time. For example, in a sample of 461 Mexican children and youth, Hernández and colleagues observed that the odds of being classified as obese increased by 12% for every hour of self-reported television viewing (62). These cross-sectional findings are also supported by longitudinal evidence (61,63,64). Mitchell et al (64) showed that objectively measured sedentary time was independently associated with increased weight gain between 9 and 15 years of age among children in the 50th, 75th and 90th body weight percentiles, independent of other covariates, including physical activity, sleep and diet.

Finally, evidence from randomized controlled trials demonstrates that reductions in sedentary time may result in reductions in adiposity (61,65,66). For example, Robinson reported that elementary school children who were randomized to receive an intervention aimed at reducing screen time experienced a 0.45 kg/m^2 reduction in body mass index (BMI) and a 2.30 cm reduction in waist circumference when compared to control students over a 6-month period (65). These findings are supported by a recent systematic review and meta-analysis, which concluded that interventions that reduce sedentary behaviour in children result in a mean decrease in BMI of 0.89 kg/m^2 (61). These results suggest that sedentary behaviour (especially screen time) has an independent and causal influence on the risk for excess weight gain and obesity in the pediatric age group (61,67).

Sedentary time and markers of cardiometabolic disease risk in children and youth

Although it has been the focus of less research than adiposity, emerging evidence suggests that sedentary behaviour is also independently associated with other markers of cardiometabolic disease risk in children and youth (5,8–10,12,61,68–71). Goldfield et al have recently reported that television viewing and video game playing are associated with risk factors for diabetes and cardiovascular disease, respectively, independent of physical activity in overweight and obese adolescents (9,10). Similarly, Kriska et al (71) observed that in comparison to obese youth without diabetes, those recently diagnosed with diabetes accumulated roughly 1 additional hour of objectively measured sedentary time each day. These results are also supported by a recent report by Wennberg et al (72), who found that self-reported TV viewing at age 16 is prospectively associated with the risk for metabolic syndrome at 43 years of age. Participants who reported watching "several TV shows a day" at baseline had twice the odds of having metabolic syndrome at follow up, independent of physical activity, socioeconomic status and family history of diabetes. Associations were also seen for individual metabolic syndrome components, including central obesity, lipids and blood pressure (72). As with adiposity, these findings suggest that sedentary behaviour (typically measured as self-reported screen time) is independently associated with increased cardiometabolic disease risk in the pediatric population.

The role of sedentary behaviour modality: screen based vs. non-screen-based sedentary time

In the 5-year span between 2005 and 2010, the number of investigations assessing sedentary behaviour using objective measures doubled (29). As the volume of studies using both objective measures of sedentary behaviour (which assess total sedentary time) and self-reported sedentary behaviour (which typically focuses on specific sedentary behaviours such as screen time) has increased, a surprising trend has become apparent in the literature. While self-reported screen time is consistently associated with increased adiposity and risk for cardiometabolic disease in children and youth, independent of physical activity levels (7–10,61,68,70,73–75), the relationship between objectively measured sedentary time and health indicators is far less clear. Of the numerous studies examining the relationship between objectively measured sedentary time and markers of adiposity and cardiometabolic disease risk in the pediatric population (5,12,37,64,68,69,71,74–82), only a small number (64,69,79) have detected associations that remained significant after adjustment for physical activity (Table). These findings raise questions about the health impact of sitting per se, in comparison to the impact of specific screen-based sedentary behaviours.

The differences between self-reported screen time and directly measured total sedentary time are most apparent when examined using a single cohort. For example, Carson and Janssen observed that self-reported TV viewing was independently associated with clustered cardiometabolic disease risk in a nationally representative sample of American children and youth (70). In contrast, the authors observed no independent associations between accelerometer-derived sedentary time and markers of cardiometabolic risk in the same sample. Similar findings have also been reported in other cohorts (68,73–75,77). Chaput and colleagues found that self-reported screen time (but not objectively measured total sedentary time) was independently associated with increased waist circumference and reduced HDL cholesterol concentrations in a cohort of 536 children at risk for obesity (68). Similarly, Martinez-Gomez et al (75) reported that several biomarkers were independently and deleteriously associated with self-reported TV viewing, but not with objectively measured sedentary time, in a group of Spanish adolescents.

Given the bias and error that are known to be associated with self-report measures (24,26), it is somewhat surprising that self-reported screen time appears to be more closely associated with health indicators than objective measures of total sedentary time such as accelerometry. It is not uncommon for studies to report levels of self-reported screen time that seem highly implausible (26,83), a characteristic that has been observed in other forms of self-report data collection as well (84). For example, a recent study found that groups of highly active and highly sedentary 10- to 11-year-old students self-reported an average of 13.9 hours per day of screen time, and another 5.9 hours of physical activity (26,83). If this were true, it would leave only 4.2 hours each day for eating, sleeping and attending school, which seems unlikely. It has also been noted that the association between self-reported and directly measured sedentary behaviour can be extremely small (23,70). Carson and Janssen observed a correlation of just 0.08 between self-reported TV viewing and accelerometer-derived sedentary time in a nationally representative sample of American children and youth (70), suggesting little overlap between the 2 measures.

There are a number of factors that could explain the differences observed between self- and proxy-reported screen time and objectively measured sedentary time in children and youth. Self-reports and proxy reports of sedentary behaviour typically provide information only about a single behaviour (a subset of total sedentary time), whereas objective measures of sedentary time provide global measures of time spent being sedentary. The 2 types of measures are, therefore, assessing different things (23). For this reason, self-reported and proxy-reported sedentary behaviour typically account for far less total time than do objective measures; Colley et al found that parent-reported screen time was equivalent to only a third of total sedentary time assessed via accelerometry in a representative sample of Canadian children (23). Given the highly sedentary nature of contemporary life (42,43,47,85,86), it has also been suggested that the weak associations seen between objective measures of sedentary behaviour and various health indicators in children and youth may be due to a lack of inter-individual variability (23). Further, it has been noted that a variety of methods have been used to process accelerometer data in the pediatric population, and this may have a significant impact on the results of individual studies, making it difficult to compare directly results of separate investigations (29,79). For example, studies have excluded data as "non-wear" time when there are as few as 10 (5,75) or as many as 100 (79) consecutive minutes with accelerometer values of 0 CPM. Further, although an accelerometer threshold of 100 CPM is used most commonly to identify sedentary behaviour, thresholds as high as 1100 CPM have been used in studies examining the relationship between sedentary time and markers of adiposity and cardiometabolic risk in the pediatric age group (79). Although the impact of such methodologic issues is not certain, a recent report by Atkin et al (79) suggested that discrepancies in sedentary thresholds (e.g. 100 CPM vs. 1100 CPM) are likely to have a much larger impact than differences in non-wear time. Counterintuitively, the same authors reported that higher thresholds, which therefore classify higher intensities of movement as sedentary time, resulted in stronger associations between sedentary time and markers of cardiometabolic disease risk in the pediatric population. Further research into the impact of such methodologic issues and techniques for comparing across studies employing different methodologies is clearly warranted.

Finally, as discussed below, it is also possible that certain forms of sedentary behaviour (e.g. TV viewing and other forms of screen time) may disproportionately promote other unhealthy behaviours, such as excess food intake, which may explain why they are more consistently associated with health risk in the pediatric population (67,87). Taken together, these findings suggest that screen time (and especially TV viewing time [88]) may be more closely associated with markers of cardiometabolic disease risk than total objectively measured sedentary time in the pediatric population, and this reinforces the notion that researchers should collect data using both measures whenever possible (22,23).

Table
Comparison of reports examining the association between objectively measured sedentary time and markers of adiposity and cardiometabolic disease risk among children and youth

Reference	Setting (population)	Age	N (M/F)	Accelerometer	Sedentary cut-point	Key findings
No significant associations reported						
Colley et al (37)	Canada (general population)	6–19 years	1608 (809/799)	Actical	<100 CPM	Sedentary time was not associated with BMI, waist circumference, HDL-cholesterol or systolic or diastolic blood pressure independent of age, wear time and MVPA.
Carson and Janssen (70)	USA (general population)	6–19 years	2527 (1284/1243)	ActiGraph AM-7124	<100 CPM	Sedentary time was not associated with clustered cardiometabolic risk after adjustment for age, sex, race, SES, smoking, total fat, saturated fat, cholesterol and sodium, or after additional adjustment for MVPA.
Martinez-Gomez et al (75)	Spain (general population)	13–17 years	183 (95/88)	ActiGraph GT1M	<100 CPM	Sedentary time was not associated with CRP, adiponectin or other adipokines after adjustment for sex, age, and pubertal status, or after further adjustment for BMI and MVPA.
Kwon et al (78)	USA (general population)	8–15 years	554 (277/277)	ActiGraph 7164	<100 CPM	Sedentary time was not associated with fat mass after adjustment for height and MVPA.
Chaput et al (74)	Canada (children with a family history of obesity)	8–11 years	550 (299/251)	ActiGraph LS 7164	<100 CPM	Sedentary time was not associated with body fat percentage or waist-to-height ratio with or without adjustment for age, sex, sleep duration, energy intake, sexual maturation, parental SES and BMI or MVPA.
Martinez-Gomez et al (77)	US (general population)	3–8 years	111 (57/54)	ActiGraph 7164	<100 CPM	Sedentary time was not associated with systolic or diastolic blood pressure after adjustment for age, sex, height or body fat percentage.
Significant associations reported for at least one outcome, not independent of physical activity						
Sardinha et al (5)	Portugal (general population)	9–10 years	308 (161/147)	MTI ActiGraph	<500 CPM	Sedentary time positively associated with insulin resistance after adjustment for sex, sexual maturity, birth weight, measurement time and both total and central adiposity.
Cliff et al (12)	Australia (overweight and obese)	5–10 years	126	ActiGraph 7164	<100 CPM	Sedentary time was negatively associated with HDL cholesterol, but not triglycerides, total or LDL cholesterol after adjustment for age, sex, adiposity and diet. Sedentary time was not associated with any outcome after additional adjustment for MVPA.
Kriska et al (71)	USA (youth with obesity and type 2 diabetes)	10–18 years	551	ActiGraph AM7164	<1 MET	Obese youths with T2D were sedentary for 56 more minutes/day than obese youth without T2D.
Ekelund et al (82)	UK, Switzerland, Belgium, US, Australia, Denmark, Estonia, Norway, Brazil, Portugal (general population)	4–18 years	20,870 (10,097/10,773)	Various types of ActiGraph	<100 CPM	Sedentary time was associated fasting insulin, but not waist circumference, systolic blood pressure, triglycerides or HDL cholesterol after adjustment for age, sex, wear time, waist circumference and height. Sedentary time was not associated with any outcome after further adjustment for MVPA.
Chaput et al (68)	Canada (children with a family history of obesity)	8–11 years	536 (292/244)	ActiGraph LS 7164	<100 CPM	Sedentary time was positively associated with diastolic blood pressure, but not waist circumference, triglycerides, systolic blood pressure, fasting glucose, or HDL cholesterol, after adjustment for age, sex, waist circumference, sleep duration, energy intake, sexual maturation, parental SES and BMI. Sedentary time was not associated with any outcome after further adjustment for MVPA.
Basterfield et al (76)	UK (general population)	7–9 years	377 (186/191)	ActiGraph GT1M	<1100 CPM	Changes in sedentary time were associated with increased fat gain in the entire sample independent of SES, baseline sedentary time, and baseline fat mass index. This association was no longer significant after additional adjustment for MVPA.
Mitchell et al (80)	UK (general population)	12 years	5,434 (2,950/2,844)	ActiGraph AM7164	≤199 CPM	Sedentary time was significantly associated with increased risk of obesity independent gender, SES, pubertal status and early life sleep and TV habits. These associations were no longer significant after adjustment for MVPA.
Steele et al (81)	UK (general population)	9–10 years	1862 (820/1042)	ActiGraph GT1M	<100 CPM	Sedentary time was positively associated with waist circumference and fat mass index (but not BMI) in unadjusted analyses. Sedentary time remained associated with fat mass index after adjustment for age, sex, SES, birth weight, sleep duration or maternal BMI. Sedentary time was not associated with any outcome after further adjustment for MVPA.

(*continued on next page*)

Table (*continued*)

Reference	Setting (population)	Age	N (M/F)	Accelerometer	Sedentary cut-point	Key findings
Hsu et al (73)	US	8–19 years	105 (26/79)	ActiGraph GT1M	<100 CPM	Sedentary time was positively associated with waist circumference and systolic blood pressure, but not triglycerides, fasting glucose, HDL cholesterol or diastolic blood pressure in unadjusted analyses. After adjustment for MVPA, sedentary time was not associated with any outcome.
Significant associations reported for at least one outcome, independent of physical activity						
Henderson et al (69)	Canada (children with a family history of obesity)	8–11 years	424 (222/202)	ActiGraph LS 7164	<100 CPM	Sedentary time was positively associated with insulin resistance after adjustment for sex, age, pubertal stage, fitness and MVPA, but not after additional adjustment for adiposity.
Mitchell et al (64)	US (general population)	9–15 years	798 (391/407)	ActiGraph 7164 and GTM1	<100 CPM	Sedentary time was associated with weight gain the 50th, 75th and 90th BMI percentiles independent of sex, race, maternal education, hours of sleep, healthy eating scores, and MVPA. No significant associations were observed at lower BMI percentiles.
Atkin et al (79)	Denmark, Estonia and Portugal (general population)	9, 15 years	2327 (1,059/1,268)	MTI ActiGraph	<100, <500, <800, and <1100 CPM	In metaregression using data from all cutpoints, sedentary time was associated with increased clustered cardiometabolic disease risk (but not adiposity) independent of age group, age, sex, study location, sexual maturity, day of the week, season, wear time, adiposity and total physical activity. The relationship between sedentary time and clustered risk was stronger at higher accelerometry thresholds.

BMI, body mass index; *CPM*, counts per minute; *CRP*, C-reactive protein; *HDL*, high-density lipoprotein; *MET*, *MVPA*, moderate and vigorous physical activity; *SES*, socioeconomic status; *T1D*, type 1 diabetes; *T2D*, type 2 diabetes.

Characteristics of sedentary behaviour: impact on health indicators

In addition to the health impact of total sedentary time and specific sedentary behaviours (e.g. screen time), recent evidence in adults suggests that certain patterns of sedentary behaviour may also have an important health impact (38,39,89,90). A recent systematic review (89) concluded that prolonged bouts of uninterrupted sedentary behaviour have a rapid and deleterious impact on insulin sensitivity, glucose tolerance and triglyceride levels in adults. Further, interruptions in sedentary time have been shown to be beneficially associated with body weight, abdominal fat, triglycerides and glucose metabolism in adults (38,39,90). These findings have yet to be replicated in the pediatric population.

Carson and Janssen failed to detect any associations between breaks in sedentary time or sedentary bout length and cardiometabolic disease risk in a nationally representative sample of 2527 American children and youth after adjustment for potential confounders (70). Kwon et al (47) also reported no association between breaks in sedentary time and fat mass in a sample of 544 boys and girls in the Iowa Bone Development Study, with similar findings being reported in children from the Pacific Islands (91). To our knowledge, only 1 study to date has reported an association between characteristics of sedentary time and health indicators in children and youth; Colley and colleagues found that prolonged bouts of sedentary behaviour (those lasting 80+ minutes) are positively associated with waist circumference in boys aged 11 to 14 years in the Canadian Health Measures Survey, whereas the opposite is true for breaks in sedentary time (37). However, these associations were not observed in older or younger boys or in girls of any age.

The limited evidence available to date suggests that characteristics of sedentary behaviour may be less closely associated with cardiometabolic disease risk in children than has been reported previously in adults. However, it should be noted that the studies that have been published to date have focused primarily on nationally representative samples of children and youth (37,70). It is possible that associations between characteristics of sedentary behaviour and cardiometabolic disease risk may be stronger in populations with family histories of obesity; this has previously been associated with increased childhood cardiometabolic risk (92–94).

Mechanisms by which sedentary behaviour can lead to poor health outcomes in children and youth

A number of mechanisms have been suggested that could explain the reported associations between sedentary behaviour and cardiometabolic disease risk in the pediatric population. Sedentary behaviours are defined by their low energy expenditure, and it has historically been assumed that they displace physical activity (4). This view is supported by a recent randomized crossover study that observed that exposing children to several hours of prolonged sitting did not result in any changes in physical activity levels in the subsequent 24-hour period (95). This suggests that when children engage in a bout of prolonged sedentary behaviour, they do not compensate by increasing physical activity levels later on, thereby promoting positive energy balance (95). However, other evidence suggests that the displacement of physical activity plays a relatively small role in mediating the relationship between sedentary time and cardiometabolic disease risk in children and youth (56,67,88,96,97). In a systematic review and meta-analysis examining the relationship between sedentary behaviours and physical activity, Marshall et al (96) reported that although the 2 are negatively associated, the magnitude of the relationship is too small to be of clinical significance. As noted above, numerous studies have also observed significant associations between sedentary behaviour (whether self-reported or directly measured) and markers of cardiometabolic disease risk independent of physical activity levels in the pediatric population (9,10,61,70). These findings suggest that a lack of physical activity is not the primary factor linking sedentary behaviour with health indicators in this age group.

In contrast to a lack of physical activity, a number of studies suggest that screen-based sedentary behaviours may lead to increased caloric consumption through a variety of mechanisms (98,99). A recent intervention by Harris et al (100) observed that exposing children to televised food advertisements increases subsequent ad libitum food intake by 45%. Similar results have also been reported by Halford and colleagues (101,102), who reported that the impact of advertisements on increased food intake is seen across all body weight categories, although it is most pronounced in children with obesity (101). They also noted that the ability to recognize food advertisements was positively associated with food intake, and that children with overweight and obesity were more likely to remember food advertisements after being exposed to them, when compared to their lean peers (101). It is possible that television viewing may also result in increased food intake by inducing "mindless eating" (103). An intervention study by Temple et al (104) found that children spend more time eating and consume roughly twice as many calories while watching a continuous television program in comparison to a control condition without entertainment. Passive videogame playing has also been shown to increase food intake and result in a positive energy balance in the pediatric population. A randomized crossover study by Chaput et al (105) observed that compared to sitting quietly, 1 hour of passive video game play resulted in an 80 kcal increase in ad libitum food intake in adolescent boys. The collective findings suggest that sedentary screen-based behaviours (in particular television viewing) are likely to result in increased energy intake and positive energy balance in the pediatric population.

Finally, studies of adults suggest that prolonged sitting may have rapid and direct impacts on metabolic health, independent of changes in body weight or other health behaviours (15,89). For example, intervention studies report that even relatively short bouts of uninterrupted sedentary behaviour result in reduced insulin sensitivity, glucose tolerance and increased triglyceride levels in adults (20,89,90,106,107). In comparison to a day of sitting that included periodic light-intensity walk breaks, Dunstan et al reported that a day of uninterrupted sitting resulted in a 30% increase in insulin resistance in a group of overweight and obese adults (90). Similar results have also been reported in normal-weight adults (106,107) and may be due to reductions in lipoprotein lipase and glucose transport protein activity at the level of the skeletal muscles (13,15).

To date only 1 intervention study has examined the acute effect of prolonged sitting in a pediatric population. Saunders et al (108) exposed healthy 10- to 14-year-olds to a day of uninterrupted sitting, as well as days with periodic interruptions of light and moderate-intensity physical activity. In contrast to previous reports in adults (90), they reported that uninterrupted sitting did not have any impact on the insulin, glucose or lipid response to a standardized meal in this population. Although further intervention studies in children and youth are needed, the available evidence suggests that sitting per se may not have a direct deleterious impact on cardiometabolic health in healthy children and youth. Although it could be that the inherent metabolic health of children is such that current analytic methods have limited sensitivity to the detection of subtle, but adverse, physiologic changes.

Opportunities for future research

Although the relationship between certain sedentary behaviours (e.g. screen time) and cardiometabolic disease risk in children and youth are well established, the impact of sitting per se is far less clear. As discussed above, independent associations between objectively measured sedentary time and cardiometabolic risk have been reported by some but not all studies. More research is, therefore, needed to clarify the relationship between objectively measured sedentary behaviour and health indicators in the pediatric age group. Systematic reviews and meta-analyses focusing specifically on objectively measured sedentary behaviour (as opposed to previous reviews that have focused on all sedentary behaviours) may be especially useful in this regard. Standardization of accelerometry methodology would also allow for much easier comparisons across studies. Future research should also examine whether any personal factors, such as sex or body weight, influence the reporting of screen time and why some screen-based sedentary behaviours are associated with health outcomes in certain populations but not others (9,10).

More research is also needed into the role played by specific characteristics of sedentary behaviour in the pediatric population. Only a small number of studies have investigated the impact of sedentary bout length or breaks in sedentary time in the pediatric population or the importance of sedentary behaviours during differing periods of the day (37,70). A better understanding of the characteristics of sedentary behaviour that are most closely associated with cardiometabolic disease risk is needed in order to develop interventions that are maximally efficacious in reducing cardiometabolic risk in children and youth. It is also possible that previously unexamined aspects of accelerometry data, such as total movement variability, may provide additional valuable information on movement patterns in the pediatric age group.

Finally, intervention studies are needed to examine the health and behavioural impacts of prolonged sitting by the pediatric population. A recent systematic review concluded that uninterrupted sedentary behaviour results in rapid and deleterious changes in insulin sensitivity, glucose tolerance and lipid levels in adults (89). However, as noted above, these findings have yet to be replicated in children or youth (108). By extension, it is also unclear whether substituting sedentary behaviour for standing or light-intensity physical activity can lead to improvements in cardiometabolic disease risk in the pediatric population. Further research on the relationship between sedentary behaviours and sleep quality and quantity is also required, given the importance of a good night's sleep for overall health (109). Additionally, given the decline of outdoor active play observed over recent decades in children and youth (110), more research is urgently needed to better understand the implications on children's health of excessive indoor time and its associated sedentary, technology-centered activities.

Conclusions

Available evidence suggests that North American children and youth spend between 40% and 60% of their waking hours engaging in sedentary behaviours (42–44). Markers of adiposity and cardiometabolic risk are positively associated with sedentary behaviours in general and with screen-based sedentary behaviours in particular. These relationships appear to be due to the influence of screen-based sedentary behaviours on food intake and may also be due to a direct metabolic impact of prolonged sitting, although this has received little research attention in the pediatric population. More research is needed to investigate the impacts of characteristics of sedentary behaviour (sedentary bout length, breaks in sedentary time, etc) and interventions that examine the health and behavioural impacts of sitting per se. Despite limited evidence in children and youth, reducing sedentary time in addition to increasing physical activity may have significant roles in the prevention of chronic diseases, including diabetes.

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Author Contributions

The article was conceived and designed by TJS, JPC and MST. TJS wrote the initial draft of the manuscript, while MST and JPC provided critical edits and additions. All authors approved the final manuscript.

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