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Systematic review of the relationships between sedentary behavior and health indicators in the early years (aged 0-4 years)

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ABSTRACT

Background: The purpose of this systematic review was to examine the relationships between sedentary behavior (SB) and health indicators in children aged 0 to 4 years, and to determine what doses of SB [i.e., duration, patterns (frequency, interruptions), and type] were associated with health indicators.

Methods: Online databases were searched for peer-reviewed studies that met the a priori inclusion criteria: population (apparently healthy, 1 month to 4.99 years), intervention/exposure and comparator (durations, patterns, and types of SB), and outcome/health indicator (critical: adiposity, motor development, cognitive development; important: bone and skeletal health, cardiometabolic health, fitness, risks/harm). The quality of the evidence was assessed by study design and outcome using the Grading of Recommendations Assessment, Development and Evaluation (GRADE) framework.

Results: Due to heterogeneity meta-analyses were not possible; narrative syntheses were conducted, structured around the health indicator and type of SB. A total of 96 studies were included (195,430 total participants from 33 countries). Study designs were: randomized controlled trial (n=1), case-control (n=3), longitudinal (n=25), longitudinal with additional cross-sectional analyses (n=5), and cross-sectional (n=62). Evidence quality ranged from “very low” to “moderate”. Associations between objectively-measured total sedentary time and indicators of adiposity and motor development were predominantly null. Associations between screen time and indicators of adiposity, motor or cognitive development, and psychosocial health were primarily unfavorable or null. Associations between reading/storytelling and indicators of cognitive development were favorable or null. Associations between time spent seated (e.g., in car seats or strollers) or in the supine position and indicators of adiposity and motor development were primarily unfavorable or null. Data were scarce for other outcomes.

Conclusions: These findings continue to support the importance of minimizing screen time for disease prevention and health promotion in the early years, but also highlight the potential cognitive benefits of interactive non-screen based sedentary behaviors such as reading and storytelling. Additional high-quality research using valid and reliable measures is needed to more definitively establish the relationships between durations, patterns, and types of SB and health indicators, and to provide insight into the appropriate dose of SB for optimal health in the early years.

Key words: sedentary behavior, infants, toddlers, preschoolers, early years, screen time, sitting, reading, adiposity, motor development, cognitive development, bone and skeletal health, cardiometabolic health, fitness, risks
BACKGROUND

Sedentary behavior is defined as any waking behavior with an energy expenditure of ≤1.5 METs while in a sitting or reclining posture [1]. It is increasingly recognized that too much sedentary behavior can have negative health effects across the lifespan [2-4], which are distinct from those that result from low physical activity [5]. This may be of particular importance in the early years of life, given that these years are critical for growth and development and that lifestyle behaviors established early in life tend to track over time [6-8].

In this regard, the Canadian Sedentary Behaviour Guidelines for the Early Years (ages 0-4 years) [9], and guidelines in other countries around the world (e.g., Australia [10] and USA [11]), recommend that children less than 2 years of age have no exposure to screens, and that those aged 2 to 4 years have <1 hour/day of screen time. In addition, guidelines (e.g., in Canada [9], Australia [10], and the United Kingdom [12]) recommend that parents and caregivers minimize the time that children spend sitting or being restrained (e.g., in a stroller or high chair) while awake.

In contrast to these recommendations, ≥80% of young children are exposed to screens before the age of 2 years [13, 14], only 22% of Canadian children aged 3 to 4 years are meeting the screen time guidelines of <1 hour/day, and on average parent-reported screen time for this age group is 2.0 hours/day [15]. Moreover, young children are spending a substantial proportion of their time sedentary, and no guidance regarding an “appropriate” amount of total sedentary time exists. This is a notable gap, given that a recent review including data from 10 countries reported that children aged 2 to 5 years were sedentary for 34% to 94% of the day [16]. For instance, objectively-measured data from a large, nationally-representative sample of Canadian
children showed that on average 3- to 4-year-olds were sedentary for 436 minutes/day (7 hours, 16 minutes), which was roughly equivalent to 60% of their waking time [15].

The Canadian Sedentary Behaviour Guidelines were informed by a systematic review of the evidence that found that high levels of television (TV) time were associated with increased adiposity and reduced psychosocial health and cognitive development [2]. However, there was no evidence of benefits or harms for any other type of sedentary behavior, for total sedentary time, or for patterns (e.g., frequency, interruptions) of sedentary time. This may be in part because only intervention and longitudinal studies were included in this earlier review [2]. This is a critical limitation because in recent years there has been a dramatic shift in the media landscape (e.g., evolving technologies including smartphones and tablets) [17], and because different types of sedentary behavior (e.g., reading, sitting, playing video games) [18, 19] and different patterns of sedentary behavior [20] may have different health effects. Evidence from large cross-sectional studies (with samples representative of the general population), together with new studies published since the original review, may provide additional insight. In the intervening years, new systematic reviews have been conducted to investigate the relationships between sedentary behavior and particular health indicators. For instance, Hinkley et al. 2014 found that too little evidence existed to draw conclusions regarding associations between sedentary behaviors and psychosocial well-being [21], and Carson et al. 2015 identified that different types of sedentary behavior may have different effects on cognitive development in the early years of life (e.g., screen time may be detrimental, and reading beneficial) [18]. These recent reviews present focused summaries, however no previous review has provided a balanced consideration of different types of sedentary behavior and a range of holistic health indicators across study designs. Accordingly, a comprehensive review of the literature is needed in order
to: 1) understand the health effects of sedentary behavior in the early years, 2) inform and update population-level recommendations, and 3) identify research gaps and guide the design of future research and/or assist in the translation of current research to practice.

Therefore, the purpose of this study was to perform a systematic review that examined the relationships between sedentary behavior and health indicators in children of the early years (aged 0 to 4 years). An additional aim was to determine what doses of sedentary behavior [i.e., duration, patterns (frequency, interruptions), and type] were associated with health indicators.

METHODS

Protocol and registration

This systematic review was registered with the International Prospective Register of Systematic Reviews (PROSPERO; Registration no. CRD42016035270; Available from http://www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42016035270], and was conducted and reported following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [22].

Eligibility criteria

The participants, interventions, comparisons, outcomes and study design (PICOS) framework [23] was used to identify key study concepts in the research question, and to facilitate the searching process.
Population: Apparently healthy children (i.e., general populations, including those with overweight and obesity; samples of clinical populations were ineligible) with a mean age of 1 month to 4.99 years (or, if no mean age was reported, samples described as: infants, toddlers, preschoolers, pre-elementary or pre-primary school age) for at least one sedentary behavior measurement point. Subgroups were defined as follows: infants, 1 month to 1 year; toddlers, 1.1 to 3.0 years; and preschoolers, 3.1 to 4.99 years.

Intervention (exposure): Specific measure of sedentary behavior (e.g., TV viewing, video gaming, iPad/tablet/touch-screen, smart phone, reading, puzzles, bouts, breaks, sedentary time, and “screen time” – defined as composite measures of screen use) obtained via objective (e.g., accelerometry) or subjective (e.g., proxy-report) methods. For infants, sedentary behavior was operationally defined as any waking behavior characterized by low energy expenditure (i.e., non-purposefully active) while restrained (e.g., stroller/pram, high chair, car seat/capsule), or when sedate (e.g., lying/sitting in a chair with little movement but not restrained). Time spent in the prone position (“tummy time”) was not considered sedentary behavior because this is “physical activity” in this age group. For toddlers and preschoolers, sedentary behavior was defined as any waking behavior characterized by an energy expenditure of $\leq 1.5$ METs while in a sitting or reclining posture [1]. Studies defining sedentary behavior as “physical inactivity” or “failing to meet physical activity guidelines” were excluded, because these definitions do not differentiate between sedentary behavior and light-intensity physical activity. Active video gaming exposures (e.g., Nintendo Wii™, Microsoft Kinect™, Sony's Playstation Move™) were excluded because they may elicit energy expenditure $>1.5$ METs [24], as were studies reporting background TV or screen access (e.g., TV is turned on, but not necessarily being watched by the child) because the child could be engaged in a non-sedentary behavior. For experimental studies,
interventions had to target sedentary behavior exclusively and not multiple health behaviors (e.g., both sedentary behavior and diet).

Comparison: Various durations, patterns (frequencies, interruptions), and types of sedentary behavior. A comparison or control group was not required.

Outcomes (Health Indicators): Eight health indicators were chosen by expert consensus among a 22-member group with expertise in movement behaviors in children. The health indicators were selected given consideration of the literature (previous reviews; e.g., [2]) and of the importance of including a range of holistic health indicators (i.e., physical, psychological/social, and cognitive health). Four health indicators were identified as critical (primary) health indicators by expert consensus: (1) adiposity (e.g., % body fat, weight status, waist circumference); (2) motor development (e.g., developmental milestones, gross/fine motor skills, locomotor-object control); (3) psychosocial health (e.g., depressive/anxiety symptoms, pro-social behavior, aggression, self-regulation); and (4) cognitive development (e.g., language development, attention, executive function). Four health indicators were identified as important (secondary): (1) bone and skeletal health (e.g., bone mineral density, bone mineral content, skeletal area); (2) cardiometabolic health (e.g., blood pressure, insulin resistance, blood lipids); (3) fitness (cardiovascular and musculoskeletal); and (4) risks (injury)/harm (e.g., plagiocephaly, torticollis).

Study design: All study designs were considered. For longitudinal studies, any follow-up length was allowed as long as there was at least one measure of sedentary behavior between the ages of 1 month to 4.99 years. For logistic reasons, and to maximize generalizability, minimum sample size requirements were imposed [25]; randomized controlled trials (RCTs) and non-randomized intervention studies were required to have at least 15 participants in at least one
intervention group, and observational studies were required to have a minimum sample size of 100 participants. Published peer-reviewed original manuscripts and in-press manuscripts, in English or French, were eligible for inclusion. Grey literature (except for registered clinical trials) and conference abstracts were excluded.

**Information sources and search strategy**

The following databases were searched using the Ovid interface: MEDLINE (1946 to April 13, 2016), EMBASE (1980 to 2016 week 15), PsycINFO (1806 to April Week 1 2016), and CENTRAL (February 2016). PubMed was searched for any additional studies not yet indexed in MEDLINE (April 11, 2016). SPORTdiscus (1949 to April 14, 2016) and Communication Source (April 12, 2016) were searched using the EBSCOhost interface, and the Communications and Mass Media Collection was searched using Gale. The MEDLINE search strategy was created by a research librarian with expertise in systematic review searching and peer-reviewed by a second research librarian. The search was then adapted for other databases. No study design limits were applied, and searches were limited to English and French publications.

Updates to all search strategies, limited to randomized controlled trials for logistic reasons, were performed on November 1, 2016, to capture any additional studies that were published in the interim between the initial searches and the data synthesis. The search strategies are presented in Additional File 1. Trial Registries were also searched (https://clinicaltrials.gov/ and http://www.who.int/ictrp/en/; October 11, 2016) for ongoing clinical trials, using search terms for the sedentary behavior concept and age group of interest. The International Journal of Child-Computer Interaction was hand-searched, because this journal was not yet indexed in any of these databases.
Bibliographic records were extracted as text files from the Ovid, EBSCOHost, and Gale interfaces and imported into Reference Manager Software (Version 11; Thompson Reuters, San Francisco, CA, USA), where duplicate records were removed. Titles and abstracts of the remaining records were uploaded to DistillerSR (Evidence Partners; Ottawa, Canada), a secure internet-based software, where they were screened against inclusion criteria independently by two reviewers. Exclusion by both reviewers was required for a study to be excluded at the title and abstract stage; all other studies passed to full-text article screening. Two independent reviewers examined all full-text articles, and consensus was required for article inclusion in the review. Discrepancies between reviewers were resolved by discussion between the reviewers, or with the larger review team if needed. Relevant review articles identified during screening were also procured, and their reference lists manually checked for studies potentially missed by the search.

Data extraction

Data extraction forms were created by the study coordinators, and reviewed and piloted by the review team. Extraction was completed in Microsoft Excel by one reviewer and checked for accuracy by a second reviewer. Reviewers were not blinded to the authors or journals when extracting data. Information was extracted regarding important study characteristics (e.g., citation, study design, country, sample size, age and sex of participants); exposure [i.e., sedentary behavior characteristics (e.g., type, volume, duration, frequency, pattern, and measurement and/or description of sedentary behavior intervention)]; outcome/health indicators (e.g., measurement type); results (e.g., odds ratio, difference in means); and covariates included in the analyses (if applicable; e.g., diet, physical activity). If data were unavailable for extraction (e.g.,
reported only in a graph, or described as “data not shown”), the authors were contacted. If data
were presented subdivided by sex, data for each sex independently were only extracted if data
pooled across sex were unavailable. If analyses were reported for any other subsets of data, results were extracted for only the analyses using the full sample. The results from finally adjusted models were extracted when studies presented multiple models. Study findings were considered statistically significant at p<0.05.

Risk of bias and study quality assessment

The risk of bias in primary research studies contributing to each health indicator was systematically evaluated using the methods described in the Cochrane Handbook [26]. All individual studies were assessed for the following potential sources of bias: selection bias, performance bias, detection bias, attrition bias, reporting bias, and other sources of bias (see Poitras et al. 2016 [25] for details).

The quality of evidence for each health indicator by each type of study design was assessed using the Grading of Recommendations, Assessment, Development and Evaluation (GRADE) framework [27]. The “quality of evidence” is the level of confidence in the estimate of effect. As such, the higher the quality of the evidence the greater the confidence in the findings, and the lower the quality the more likely it is that future research will change the level of confidence in the estimates and the estimates themselves. According to GRADE, there are four levels of quality (“high”, “moderate”, “low” or “very low”); evidence quality ratings start at “high” for randomized studies and “low” for all other studies. The quality of evidence is downgraded if there are limitations across studies due to serious risk of bias, inconsistency (e.g., unexplained heterogeneity in the direction of the effect), indirectness (e.g., differences between
the population, intervention and/or outcomes in included studies and those of interest, such as a surrogate measure instead of a direct measure of an outcome), or imprecision (e.g., wide confidence intervals that lead to uncertainty about the true magnitude of the effect) [28]. If there is no reason to downgrade, the quality of evidence can be upgraded if there is a large effect size, there is a dose-response gradient, or if an effect is detected in the presence of plausible confounders or other biases that would decrease an apparent treatment effect [29]. The overall quality of evidence for each study design within each health indicator was evaluated by two independent reviewers and verified by the larger review team. The review team decided a priori not to downgrade for risk of bias if the only potential sources of bias identified were use of a convenience sample or lack of exposure/outcome blinding, as in previous movement behavior systematic reviews [25, 30].

**Synthesis of results**

Meta-analyses were planned if data were sufficiently homogeneous in terms of statistical, clinical, and methodological characteristics. If meta-analyses were not possible, qualitative syntheses structured around the health indicator and type of sedentary behavior were conducted, with all studies weighted equally, and the results presented narratively. Results were presented in “evidence profile” tables by outcome (health indicator) as per the GRADE framework (see Guyatt et al. 2011 [27] for details). For the purposes of this review, sedentary behaviors were grouped into three categories: 1) objectively-measured sedentary time, 2) screen-based sedentary behaviors, and 3) other sedentary behaviors (e.g., reading, storytelling).

**RESULTS**
A total of 10,830 records were identified in the initial searches, and 11 were identified by checking the reference lists of review articles. After de-duplication, 8,915 records remained. In the search update, an additional 106 records were identified (10,936 total), and 101 remained after deduplication. No relevant records were identified in the Trial Registry searches. After screening 9,016 titles and abstracts (from the initial and updated searches), 334 full-text articles were obtained for further review. Reasons for exclusion were: not in English or French language (n=1), review paper (n=2), sedentary behaviour was included only as a covariate or outcome and not as the exposure (n=2), sedentary behaviour defined as “failing to meet physical activity guidelines” (n=2), sedentary behaviour exposure included background screens (n=3), intervention did not target sedentary behaviour specifically/exclusively (n=9), not original research (n=9), no sedentary behaviour exposure (n=9), sample size (n=15), did not assess the relationship between sedentary behaviour and a relevant health indicator (n=77), participants not within appropriate age range (n=92), other (n=17; e.g., comparator was the same “dose” of sedentary behaviour with different content, predatory publisher and problems with data such as incongruent values in text and tables). Some studies were excluded for multiple reasons. A total of 96 studies (from 73 unique samples) met the inclusion criteria.

Detailed findings for the individual 96 studies are presented in Supplementary Tables S1-S7 (Additional File 2) and summarized in Tables 1-8. Data across studies involved 195,430 participants (147,752 from 73 unique samples), ranging from 103 [31] to 50,589 [32] participants. Participants from one study were not included in this sample size calculation because the sample size for the age group of interest was not reported [33]. Studies were conducted in 33 different countries, but were most commonly conducted in the United States (n
Belgium (n = 7), Canada (n = 7), Australia (n = 6), Germany (n = 5), and the Netherlands (n = 5), with four or fewer studies from all other countries (Tables S1-S7). The approximate baseline age ranged from 0.3 to 4.95 years. One study used an experimental design (randomized controlled trial); the remaining 95 studies used observational designs, including case-control (n=3), longitudinal (n=25), longitudinal with additional cross-sectional analyses (n=5), and cross-sectional (n=62).

**Quality of evidence**

Overall, the quality of evidence ranged from “very low” to “moderate” across study designs and health indicators. The most common reason for downgrading the quality of evidence was because of a serious risk of bias that reduced the level of confidence in the observed effects. Common sources of bias included: not accounting for potentially important confounders or mediating factors (e.g., diet); the use of potentially inappropriate measurement tools (e.g., exposure or outcome measures with unknown reliability and/or validity); and an unknown amount of, or reasons for, missing data. The quality of evidence was not upgraded in any instance. For specific details regarding the quality of evidence by study design and health indicator, see Tables 1-7.

**Data synthesis**

Meta-analyses could not be performed because of heterogeneity in the sedentary behavior exposure and health indicators (statistical, clinical, and methodological). Narrative syntheses are presented. Unless otherwise stated, results did not differ by sex, age, or specific sub-indicator within the 8 health indicator categories. Within each health indicator, results are presented first by study design, then by type of sedentary behavior exposure (objectively-measured sedentary
time, screen-based sedentary behaviors, and other sedentary behaviors), and finally by sub-
indicator (i.e., specific measures of the eight health indicators). The reader is referred to the
supplementary results Tables (Supplementary Tables S1–S7) for statistic values and additional
details.

**Critical (primary) health indicators**

**Adiposity**

The relationships between sedentary behavior and adiposity were examined in 60 studies (see
Table 1 and Supplementary Table S1) [31-90]. Study designs were: randomized controlled trial
(n=1) [34], longitudinal (n=13) [33, 45, 54, 81-90], case-control (n=2) [35, 36], and cross-
sectional design or also reported cross-sectional findings (n=47) [31-33, 37-80]. Indicators of
adiposity [e.g., body mass index (BMI), percent body fat] were measured objectively (e.g.,
measured by dual-energy x-ray absorptiometry) or assessed subjectively (e.g., parent-reported
height and weight; see Table 1 for summary of measures). The quality of evidence ranged from
“very low” to “moderate” across study designs (Table 1).

In the randomized controlled trial of an intervention to reduce screen time, screen time
was significantly lower for preschoolers in the intervention versus control group at 2, 6 and 9
months post-intervention [34]. BMI z-scores were not different between the intervention and
control groups at baseline or 9-month follow-up, but BMI z-scores increased in both groups [34]
(Supplementary Table S1).
Among the 12 longitudinal studies, sedentary behavior was assessed from age ~9 months to 4.95 years as screen-based (i.e., computer time, frequency of playing computer games, time watching DVDs, TV time, and total screen time) or other sedentary behaviors (i.e., time in the car or in baby seats). Adiposity indicators were assessed between ~1.25 and 12 years follow-up.

For screen-based sedentary behaviors, computer time [85] and frequency of playing computer games [82] at age 4.8 years were not associated with total fat mass or lean mass, or weight status, at ~6 and 12 years of follow-up respectively. Time watching DVDs at ages ~3-4 years was unfavorably associated with weight status at kindergarten entry [83]. Total screen time in toddlers was unfavorably associated with weight status at preschool or school age in 2/3 studies [33, 84].

Ten longitudinal studies examined the relationships between TV time (at ages ranging from ~6 months to 4.8 years) and adiposity indicators at ~1.5 to 12 years of follow-up. Of these, unfavorable associations were reported in 6/10 studies [33, 54, 81, 83, 88, 90], null associations in 1/10 studies [86], and mixed unfavorable and null associations in 3/10 studies [82, 85, 89]. Specifically, TV time was prospectively unfavorably associated with these adiposity indicators: BMI z-score in 1/1 studies [88], BMI in 2/3 studies [54, 90], percent change in BMI and percent change in waist-to-height ratio in 1/1 studies [33], fat mass in 1/1 studies [82], and weight status in 2/2 studies [81, 83] (Supplementary Table S1). TV time at age ~3 years was not associated with the rate of weight gain from ages 3 to 5 years [86]. TV time at age 2.4 years was not associated with waist circumference at age 10.15 years, but the change in TV time from ages 2.4 to 4.4 years was unfavorably associated with waist circumference at age 10.15 years [89]. TV time at age 3.2 years was unfavorably associated with fat mass at age 15 years.
Regarding other sedentary behaviors, types of sitting were examined in three longitudinal studies. Among preschoolers, time in the car was not prospectively associated with adiposity indicators in 2/2 studies [82, 85]; however, among infants there were mixed unfavorable, null and favorable associations between time in baby seats and adiposity indicators [45]. Specifically, time in baby seats at age ~9 months was unfavorably associated with change in weight-for-height and change in weight-for-age from ~9 months to 2 years, was not associated with weight-for-height or weight-for-age at age ~2 years, and was favorably associated with waist circumference-for-age at age ~2 years and change in waist circumference-for-age from ~9 months to 2 years [45] (Supplementary Table S1).

In the two case-control studies, TV time [35, 36] and total sedentary time (assessed by one-day parent-recall) [36] were not significantly different between preschoolers with overweight/obese (case group) or normal weight (control group) status, but watching TV for ≥1 hour/day was unfavorably associated with having overweight status [35] (Supplementary Table S1).

Among the 47 cross-sectional studies, sedentary behavior was assessed as accelerometer-derived sedentary time, screen-based (i.e., computer time, time playing inactive video games, using the internet, watching DVDs/videos, TV time, and total screen time), or other sedentary behaviors (i.e., sedentary quiet play, and time in the car or in baby seats).

The relationships between accelerometer-derived sedentary time and adiposity indicators in toddlers and preschoolers were examined in 11 cross-sectional studies; null associations were reported in 10/11 studies [37-40, 47, 53, 60, 75, 78, 80] and mixed unfavorable and null associations in 1/11 studies [77] (Supplementary Table S1). Specifically, total sedentary time
was not associated with: percent body fat, fat mass index, trunk fat mass index or lean mass
index in 1/1 studies [78]; BMI in 1/1 studies [75]; BMI z-score in 4/4 studies [37-39, 47]; and
weight status in 4/4 studies [40, 53, 60, 80] (Supplementary Table S1). Total sedentary time was
not associated with BMI z-score percentile or waist circumference, but was associated with waist
circumference percentile in girls (not boys) in 1/1 studies [77]. Accelerometer-derived sedentary
time in 30 minute bouts was not associated with weight status [40].

For screen-based sedentary behaviors, time playing inactive video games was
unfavorably associated with preschoolers’ BMI percentile, but using the internet and watching
DVDs/videos were not cross-sectionally associated with BMI percentile [69] (Supplementary
Table S1). Computer time was not associated with preschoolers’ weight status in 4/4 studies [63,
67, 71, 79], but was unfavorably associated with sum of skinfold thicknesses in 1/1 studies [71].

The relationships between total screen time and adiposity indicators were examined in 18
cross-sectional studies; unfavorable associations were reported in 6/18 studies [32, 33, 46, 50,
59, 73], null associations in 10/18 studies [44, 52, 57, 58, 62, 64, 65, 71, 72, 79], and mixed
unfavorable and null associations in 2/18 studies [41, 61] (Supplementary Table S1). Of these,
screen time was unfavorably associated with: sum of skinfold thicknesses in 0/1 studies, waist-
to-height ratio in 1/1 studies [33], BMI in 2/2 studies [46, 50], and at least one measure of weight
status in 6/16 studies [32, 33, 41, 59, 61, 73]. Only one of these studies was in infants (no
association between screen time and weight status [58]); the rest were in toddlers and
preschoolers.

The relationships between TV time and adiposity indicators in toddlers and preschoolers
were examined in 22 cross-sectional studies; unfavorable associations were reported in 5/22
studies [33, 55, 66, 67, 71], null associations in 11/22 studies [31, 42, 43, 49, 50, 56, 60, 63, 69, 75, 76], mixed unfavorable and null associations in 5/22 studies [48, 51, 54, 68, 79], mixed null and favorable associations in 1/22 studies [74], and mixed unfavorable, null, and favorable associations in 1/22 studies [70] (Supplementary Table S1). Of these, TV time was unfavorably associated with waist-to-hip ratio in 0/1 studies, waist-to-height ratio in 1/1 studies [33], triceps skinfold thickness in 0/1 studies, waist circumference in 0/2 studies, sum of skinfolds in 1/3 studies [71], BMI percentile in 0/1 studies, BMI in 2/11 studies [51, 54], and at least one measure of weight status in 9/13 studies [33, 48, 55, 66-68, 70, 71, 79]. Weekday (but not weekend) TV time was favorably associated with the ratio of triceps to subscapular skinfold thickness (representing limb to trunk adiposity ratio) in girls but not boys in 1/1 studies [74]. TV time was favorably associated with BMI z-score in boys but not girls in 1/1 studies [70] (Supplementary Table S1).

Regarding other sedentary behaviors, infants’ time in baby seats was not cross-sectionally associated with weight-for-height/age or waist circumference-for-age [45]. Among preschoolers, time using books [69] was not associated with BMI percentile [69]. Sedentary quiet play (defined as “e.g., looking into books, playing with blocks, playing with dolls, drawing, construction”) on weekdays or weekend days was not associated with weight status in boys [79]. In girls, sedentary quiet play on weekend days (but not weekdays) was unfavorably associated with weight status [79].

**Motor development**

The relationships between sedentary behavior and motor development were examined in seven studies (see Table 2 and Supplementary Table S2) [37, 40, 88, 91-94]. Study designs were:
longitudinal (n=3) [88, 91, 92], and cross-sectional (n=4) [37, 40, 93, 94]. Indicators of motor development were measured objectively (e.g., visual-motor abilities measured using the Wide-Range Assessment of Visual Motor Ability) or assessed subjectively by parent-report (e.g., age at first sitting; see Table 2 for summary of measures). The quality of evidence was “very low” across study designs (Table 2).

Among the three longitudinal studies, sedentary behavior was assessed from age 3.9 months to 2.4 years as screen-based (i.e., TV time) or other sedentary behaviors (i.e., time in a baby carrier/sling, car seat, high chair/other chair, playpen, or stroller). Motor development indicators were assessed between 1.3 to 3 years of follow-up. For screen-based sedentary behaviors, TV time was not prospectively associated with age at first sitting, crawling, or walking [91], visual-motor abilities [88], or object control [92], but was unfavorably associated with locomotion skills [92].

Regarding other sedentary behaviors, infants’ time in a baby carrier/sling, stroller, high chair or other chair, or playpen were not associated with age at first sitting, crawling, or walking [91] (Supplementary Table S2). Greater time in a car seat at age ~9 months was associated with earlier (i.e., favorable) age at first sitting and age at first crawling, but was not associated with age at first walking; time spent in a car seat at ages ~4 months and 1.7 years was not associated with age at first sitting, crawling, or walking [91].

In the 4 cross-sectional studies [37, 40, 93, 94], sedentary behavior was assessed as accelerometer-derived sedentary time, screen-based (i.e., TV time), or other sedentary behaviors (i.e., time in the supine position). The relationships between accelerometer-derived sedentary time and motor development were examined in two cross-sectional studies. Total sedentary time
was not associated with motor skills at age ~2 years [40] or ~3 to 4 years [37], or with object control skills at age ~3 to 4 years [37], but percent sedentary time was unfavorably associated with locomotor skills at age ~3 to 4 years [37]. The number of 30 minute bouts of sedentary behavior was not associated with motor skills [40].

For screen-based sedentary behaviors, TV time was unfavorably associated with motor skill development; children with delayed motor skill development spent more time watching TV compared to children with typical motor skill development, and children who were frequently exposed to TV (>0 hours/day for children <2 years and >2 hours/day for children ≥2 years) were more likely to have delayed motor skill development than those who were infrequently exposed [94].

For other sedentary behaviors, time in the supine position before 6 months of age was not associated with gross motor performance, but time in the supine position after age 6 months was unfavorably associated with gross motor performance [93].

**Psychosocial health**

The relationships between sedentary behavior and psychosocial health in toddlers and preschoolers were examined in 15 studies (no studies in infants; see Table 3 and Supplementary Table S3) [34, 90, 92, 95-106]. Study designs were: randomized controlled trial (n=1) [34], longitudinal (n=9) [90, 92, 95-97, 99, 100, 102, 103], and cross-sectional design or additionally reported cross-sectional findings (n=7) [98, 100, 101, 103-106]. Indicators of psychosocial health (e.g., aggression, symptoms of anxiety and depression) were assessed subjectively by parent-, teacher-, or self-report using questionnaires (see Table 3 for summary of measures). The quality of evidence ranged from “very low” to “moderate” across study designs (Table 3).
In the randomized controlled trial of an intervention to reduce screen time, preschoolers’ screen time was significantly lower in the intervention versus control group at 2, 6 and 9 months post-intervention [34]. Aggressive and delinquent behaviors were not significantly different between the intervention and control groups at baseline, but were significantly lower in the intervention versus control group at 9-months post-intervention [34] (Supplementary Table S3).

Among the nine longitudinal studies, screen-based sedentary behavior (i.e., time e-gaming or on a computer, or TV time) was assessed from age ~1.5 to 5 years. Psychosocial health indicators were assessed between ~1 to 9.5 years of follow-up.

Time spent e-gaming or on a computer (on weekdays or weekend days) at age 4.3 years was not associated with being at risk for the following at age 6.3 years: peer problems, self-esteem problems, social well-being problems, social functioning problems, or family functioning problems [107]. Time spent e-gaming or on a computer on weekdays (but not weekend days) at age 4.3 years was unfavorably associated with being at risk for emotional problems at age 6.3 years in girls but not boys [107] (Supplementary Table S3).

The relationships between TV time among toddlers and preschoolers and psychosocial health indicators at follow-up were examined in nine longitudinal studies; unfavorable associations were reported in 2/9 studies [95, 103], null associations in 1/9 studies [100], mixed unfavorable and null associations in 5/9 studies [90, 92, 96, 97, 99], and mixed null and favorable associations in 1/9 studies [102] (Supplementary Table S3). Specifically, TV time was prospectively unfavorably associated with the following psychosocial health indicators: victimization [90, 95], victimization by classmates [92], being a victim of bullying [97], being a bully [103], externalizing problems [99], and being at risk for family functioning problems [96]
Null associations were reported between TV time and: emotional symptoms [100]; conduct problems [100]; peer-problems [100]; prosocial behavior [92, 100]; externalizing problems [99, 102]; anxiety or depressive symptoms [101, 102]; physical aggression [100] or aggressive behavior [102]; being a bully, being a victim of bullying, or being a bully-victim [97]; being at risk for emotional problems, peer problems, self-esteem problems, emotional well-being problems, or social functioning problems [96]; and cooperation, self-control, assertion, responsibility, or total social skills [102]. TV time at age ~2.5 years was favorably associated with emotional reactivity scores at ~3 years of follow-up [102].

In the 7 cross-sectional studies, sedentary behavior was assessed as accelerometer-derived total sedentary time or screen-based (i.e., TV time) sedentary behavior. Total sedentary time (accelerometer-derived) was not cross-sectionally associated with preschoolers’ psychosocial health indicators (soothability, sociability, or emotionality) [104].

The relationships between TV time and psychosocial health indicators in toddlers and preschoolers were examined in six cross-sectional studies; unfavorable associations were reported in 2/6 studies [101, 103], null associations in 2/6 studies [100, 106], mixed unfavorable and null associations in 1/6 studies [105], and mixed unfavorable and favorable associations in 1/6 studies [98]. Specifically, TV time was unfavorably associated with aggression [101], bullying [103], total externalizing behavior problems [105], and total behavior problems [105]. Null associations were reported between TV time and emotional symptoms, conduct problems, peer problems, and prosocial behavior [100], aggression toward a sibling [106], and internalizing behavior problems [105]. TV time was favorably associated with social-emotional competence in one study [98].
The relationships between sedentary behavior and cognitive development were examined in 25 studies (see Table 4 and Supplementary Table S4) [88, 90, 92, 94, 100, 102, 104, 107-124]. Study designs were: longitudinal (n=11) [88, 90, 92, 100, 102, 112, 113, 119-122], case-control (n=1) [116], cross-sectional design or additionally reported cross-sectional findings (n=16) [90, 94, 100, 104, 107-111, 114, 115, 117, 118, 121, 123, 124]. Indicators of cognitive development were measured objectively (e.g., working memory capacity measured using the Memory for Digit Span test) or assessed subjectively by parent-report interview or questionnaire (e.g., receptive vocabulary; see Table 4 for summary of measures). The quality of evidence was “very low” across study designs (Table 4).

Among the 11 longitudinal studies, sedentary behavior was assessed from age ~6 months to 5 years as screen-based (i.e., electronic media exposure and TV time) or other sedentary behaviors (i.e., frequency of parents reading). Cognitive development indicators were assessed between ~8 months to 8 years of follow-up.

For screen-based sedentary behaviors, electronic media exposure at age ~6 months was unfavorably associated with the following at age 14 months: cognitive development, language development, and auditory comprehension [112]. The relationships between TV time and cognitive development indicators in toddlers and preschoolers were examined in 10 longitudinal studies; unfavorable associations were reported in 5/10 studies [90, 92, 100, 120, 121], null associations in 4/10 studies [88, 102, 113, 122], and mixed unfavorable, null, and favorable associations in 1/10 studies [119]. Specifically, TV time was prospectively unfavorably associated with the following cognitive development indicators: rate of change in language
development [121]; receptive vocabulary, number knowledge [92]; classroom engagement [90, 92]; mathematical achievement [90]; attentional problems [120]; and hyperactivity-inattention [100] (Supplementary Table S4).

Regarding other sedentary behaviors, the frequency of parents reading to their child from ages ~8 months to 4 years was favorably associated with language development at age 4 years and the rate of change in language development between ages 5 to 7 years [121] (Supplementary Table S4).

In the case-control study, toddlers with language delay (cases) had significantly greater TV time than those with normal language development [116]. Compared with ≤2 hours/day TV time, children with >2 hours/day TV time had increased odds of language delay [116].

In the 16 cross-sectional studies, sedentary behavior was assessed as accelerometer-derived sedentary time, screen-based (i.e., computer use, mobile phone use, time playing inactive video games, TV time, total media exposure, and total screen time), or other sedentary behaviors (i.e., reading or storytelling with parents). Only one cross-sectional study examined the association between accelerometer-derived total sedentary time and cognitive development indicators; total sedentary time was not associated with attention span in preschoolers [104].

For screen-based sedentary behaviors, computer use was not associated with the prevalence of speech disorders, but mobile phone use (any versus none) was unfavorably associated with speech disorders in toddlers and preschoolers [109]. Time playing inactive video games was not associated with hyperactivity or attention problems in preschoolers [107]. Total screen time was unfavorably associated with communication development in toddlers [111], and total media exposure was unfavorably associated with receptive language development and
expressive language development in infants and toddlers aged ~6 months to 1.3 years, but not with total language development in toddlers aged ~1.4 to 2.3 years [124].

The relationships between TV time and cognitive development in toddlers and preschoolers were examined in eight cross-sectional studies; unfavorable associations were reported in 3/8 studies [94, 108, 123], null associations in 4/8 studies [100, 114, 115, 121], and mixed unfavorable and null associations in 1/8 studies [118] (see Table S4 for statistics).

Specifically, TV time was unfavorably associated with language development or capacity in 2/5 studies [94, 108] (Supplementary Table S4). TV time was unfavorably associated with delayed cognitive development [94], and executive function [123] (Supplementary Table S4). TV time was not associated with hyperactivity-inattention in toddlers [100], and was unfavorably associated with teacher-reported but not parent-reported attention-deficit/hyperactivity disorder (ADHD) symptoms in preschoolers [118] (Supplementary Table S4).

Regarding other sedentary behaviors, the relationships between reading with parents and cognitive development indicators in infants, toddlers, and preschoolers were examined in three cross-sectional studies [110, 117, 124], two of which analyzed the same dataset in different ways [117, 124]; reading with parents was favorably associated with language development percentile in both infants and toddlers [117], but was not associated with absolute language development in toddlers (not analyzed in infants) [124]. Reading with parents was favorably associated with absolute receptive language development, but not expressive language development, in infants [124]. In the third study, reading with parents was not associated with executive function in preschoolers [110]. Storytelling with parents was favorably associated with language development percentile in infants [117]. In toddlers, storytelling was favorably associated with absolute language development [124], but not language development percentile [117].
Storytelling with parents was favorably associated with absolute receptive language development but not expressive language development in infants [124] (Supplementary Table S4).

Important (secondary) health indicators

Bone and skeletal health

The relationship between sedentary behavior and bone and skeletal health in preschoolers was examined in one cross-sectional study (see Table 5 and Supplementary Table S5) [125]. The quality of evidence was rated as “very low”. As summarized in Table 5, parent-reported screen time and accelerometer-derived total sedentary time were not associated with bone stiffness index in preschool children [125]. No other indices of bone and skeletal health were examined.

Cardiometabolic health

The relationship between sedentary behavior and cardiometabolic health in preschoolers was examined in one cross-sectional study (see Table 6 and Supplementary Table S6) [126]. The quality of evidence was rated as “very low”. Watching TV for ≥2 hours/day was not associated with high blood pressure in preschool children [126]. No other cardiometabolic biomarkers were examined.

Fitness

The relationship between sedentary behavior and fitness in toddlers and preschoolers was examined in two longitudinal studies (no studies in infants; see Table 7 and Supplementary Table S7) [89, 90]. The quality of evidence was rated as “very low”.
As summarized in Table 7, higher TV time at age ~ 2.4 years was unfavorably associated with standing long jump performance at age ~ 8.2 years [89] and physical fitness level (assessed as “relative to other children” via parent-report) in Grade 4 (age ~ 10 years) [90]. A greater increase in TV time between age ~ 2.4 and ~ 4.4 years was unfavorably associated with standing long jump performance at age 8.2 years [89] and physical fitness level in Grade 4 [90].

Risks/Harm

No studies examined harms associated with sedentary behavior.

DISCUSSION

The objective of this study was to perform a systematic review that examined the relationships between sedentary behaviors and health indicators in children aged 0 to 4 years, and to determine what doses of sedentary behaviors [i.e., duration, patterns (frequency, interruptions), and type] were associated with health indicators. The main findings are the following: 1) associations between objectively-measured total sedentary time and health indicators (adiposity and motor development) were predominantly null; 2) associations between screen-based sedentary behaviors and health indicators (adiposity, motor or cognitive development, and psychosocial health) were largely unfavorable or null; 3) associations between reading or storytelling and cognitive development were favorable or null; and 4) associations between time spent seated (e.g., in baby seats, car seats, high chairs or strollers) or in the supine position and health indicators (adiposity, motor development) were primarily unfavorable or null. Few studies examined indicators of bone and skeletal health, cardiometabolic health, or fitness, and no studies reported on risks or harms (e.g., torticollis, injuries) associated with
sedentary behaviors. These findings suggest that, in the early years, total sedentary time may have a negligible impact on health, but the way that time is spent is important, with screen-based and seated/supine sedentary behaviors likely to have unfavorable or null health effects (unlikely to have favorable effects), and interactive non-screen based activities such as reading and storytelling having favorable health effects. A summary of the findings is presented in Table 8. The finding of no associations between objectively-measured total sedentary time and health indicators in the early years is in contrast to the relationships in older age groups, in particular adults [4, 127]. While this suggests that in the early years a certain amount of sedentary behavior may be innocuous and perhaps even necessary for healthy growth and development, these findings should be interpreted with caution. First, objectively-measured total sedentary time was only examined in cross-sectional studies, and it is plausible that, rather than there being no effects of total sedentary time on health indicators, there simply was not yet time for effects to manifest. This hypothesis is supported by comparison of findings from longitudinal and cross-sectional studies for subsets of total sedentary behavior; for instance, 9/10 (90%) longitudinal studies reported at least one unfavorable association between TV time and adiposity indicators, compared to only 11/22 (50%) cross-sectional studies. Total sedentary time was only examined in relation to adiposity and motor development (and in one study each for indicators of psychosocial health, cognitive development, and bone and skeletal health) however; it remains possible that total sedentary time is associated with other health indicators, particularly those likely to be acutely affected in the early years such as cognitive development. More well-designed studies with objective measures of sedentary behavior are needed. Second, in the present review studies that utilized accelerometry measures applied a range of sampling intervals (epochs) and cut-points. Given that these measurement parameters influence the amount of
sedentary behavior captured [128, 129], individual studies may have under- or overestimated the total amount of sedentary time and may therefore have resulted in an underestimation or overestimation of true effects. However, Byun et al. 2013 applied three different accelerometry cut-points in two cross-sectional datasets to test whether this would influence the findings, and found no association between total sedentary time and BMI z-score, regardless of the cut-points used [38]. Nonetheless, the most appropriate way to objectively measure sedentary behavior in the early years is still unknown and remains an important area for future work. Lastly, total sedentary time was not objectively assessed in any studies in the infant age group; however, such measures may not be meaningful in non-ambulatory infants. Although the associations between total sedentary time and health indicators were primarily null, the present data do not allow for recommendations regarding “appropriate” amounts or patterning (e.g., breaks) of total sedentary time.

Regarding screen-based sedentary behaviors, the present findings support and extend those of the earlier systematic review [2]; overall, screen time (namely TV time) was unfavorably associated with a range of health indicators. Notably, TV time was the predominant measure of screen-based behavior, followed by total screen time, with only 8 studies reporting relationships between computer use and any health indicator, 2 studies for each of DVDs/videos, electronic/total media exposure, and inactive video games, and 1 study for mobile phone and internet use. Findings for these other screen exposures were mixed (unfavorable and null) and suggest no benefits and some potential for harm. Although it seems intuitive that different types of screens may exert different effects (e.g., interacting on video-chat versus passive screen use), research on children’s use of such technologies lags behind their adoption [130]; this is a substantial research gap. Importantly, screen-based behaviors are used as a proxy for sedentary
behavior; however, it is uncertain whether children are actually sedentary while using screens in this age group, and there may be screen-related health effects that are independent of the “lack of movement” [131, 132]. Notwithstanding these limitations, the present findings indicate that less screen-based sedentary behavior is better for optimal health in the early years of life.

Other sedentary behavior exposures were less frequently examined, and findings were mixed. In general, reading [110, 117, 121, 124] and storytelling [117, 124] were favorably associated with cognitive development, while various types of time spent seated (e.g., in a car seat, high chair, or stroller) had mixed unfavorable and null associations with indicators of adiposity and motor development [45, 81, 82, 91]. Only one study assessed time in the supine position and observed an age-dependent effect, where time spent supine before 6 months of age was not associated with gross motor performance, but greater time in the supine position after age 6 months was associated with worse gross motor performance [93]. Overall, there was a paucity of data regarding the relationships between other types of sedentary behaviors and health indicators. If children are spending ~7 hours of the day in sedentary pursuits [15], and ~2 hours of these are occupied by screen-time [15], this leaves an additional 5 hours that are unaccounted for. Other types of sedentary behaviors are thus highly understudied, and this is an important research gap.

Most studies examined the duration of sedentary behaviors in relation to health indicators, with only three studies specifically examining the impact of patterns of behavior (i.e., breaks, frequency). Specifically, there was no association between accelerometer-derived sedentary time in 30 minute bouts and indicators of adiposity and motor development [40], or between the frequency of playing computer games and adiposity indicators [82], but there were favorable associations between the frequency of parents reading or storytelling and child
cognitive development [121]. These findings are consistent with those of studies that examined sedentary behavior duration, however it remains difficult to draw conclusions regarding patterns of sedentary behavior for optimal health in the early years.

**Strengths, limitations, and future directions**

Strengths of this review include the use of a comprehensive search strategy that was developed and peer-reviewed by librarians with expertise in systematic reviews, as well as inclusion of all study designs and a broad range of health indicators that represent various dimensions of health. Rigorous methodological standards were used in this review, including application of the GRADE framework to guide the review process and assess the quality of the evidence [27]. This systematic review is the first to our knowledge to synthesize the evidence regarding the relationships between objectively- and subjectively-measured sedentary behavior across the most comprehensive range of health indicators in children in the early years of life.

In terms of limitations, sample size restrictions were imposed for feasibility reasons and to maximize generalizability, but it is possible that studies with smaller sample sizes may have provided additional insight. Further, because of heterogeneity in the measurement of sedentary behavior and health indicators, meta-analyses were not possible and all studies were weighted equally in the narrative synthesis. The direction of associations (i.e., unfavorable, null, favorable) was based on statistical significance; clinical significance was not considered.

Although an abundance of evidence was synthesized in this review, several limitations of this area of research were identified that remain to be addressed. As mentioned, data were limited regarding the relationships between sedentary behavior and four relevant health indicators (two or fewer studies for each of bone and skeletal health, cardiometabolic health,
fitness, and risks/harms); TV time was the primary sedentary exposure, with few studies examining “other” types of screens (e.g., tablets, mobile phones) or sedentary behaviors (e.g., reading, puzzles); and objective measures of total sedentary time were only employed in cross-sectional studies. Although adiposity was the most commonly measured health indicator (60 studies), direct measures of adiposity were used in only two studies [78, 82] while the remainder used surrogate measures such as BMI. Only one randomized controlled study was included in the present review, and the quality of the evidence ranged from “very low” to “moderate” across the study designs and health indicators. There is a need for high-quality studies with strong designs to better establish the magnitude of effects, the nature of dose-response gradients if applicable, to assess cause-and-effect relationships, and to examine potential subgroup differences (e.g., based on age, sex, or socioeconomic status). When RCTs are not possible due to the inherent challenges of research in this age group, quasi-experimental or longitudinal designs that use validated sedentary behavior measures and outcome measures that are sensitive enough to detect changes are recommended.

Across the health indicators, the most common reason for downgrading the quality of evidence was due to the serious risk of bias associated with sedentary behavior measures with no known psychometric properties. Consequently, development and use of reliable and valid subjective measures of sedentary behavior are needed. Defining and measuring sedentary behavior in young children, particularly in non-ambulatory infants, remains a challenge. For instance, infants in the supine position may be vigorously moving arms and legs, and thus being “active”, but existing questionnaire-based measures do not capture this. Future research using inclinometers, which can more accurately capture postures [133], as well as limb-worn devices, will help to address the challenges associated with quantifying sedentary behaviors in the early
Finally, the question of whether different types of sedentary behavior “content” (e.g. educational versus recreational TV programming) exert different health effects was beyond the scope of this review, and remains an important area for future work.

Conclusions

This systematic review synthesized findings from 96 studies with ~200,000 participants in 33 countries around the world; the quality of the evidence ranged from “very low” to “moderate”. In summary, the findings demonstrate that in the early years (0 to 4 years), total sedentary time may have a negligible impact on health, but the quality of that time is important, with screen-based and seated/supine sedentary behaviors likely to have no benefit and potential for harm, and interactive non-screen based activities such as reading with caregivers having favorable health effects. These findings continue to support the importance of minimizing screen time for disease prevention and health promotion in the early years [2, 9], and also highlight the potential benefits of interactive non-screen based sedentary behaviors such as reading and storytelling. Additional research using valid and reliable measures and high-quality study designs is needed to more definitively establish the relationships between sedentary behaviors and health indicators, and to provide insight into the appropriate dose (durations, patterns, type) of sedentary behavior for optimal health in the early years.
**List of abbreviations**

BMI, body mass index; GRADE, Grading of Recommendations, Assessment, Development and Evaluation; PRISMA, Preferred Reporting Items for Systematic Reviews and Meta-Analyses; RCT, randomized controlled trial; SB, sedentary behavior; TV, television

**Declarations**

**Authors’ contributions**

VJP, CEG and MST were responsible for the initiation, conceptualization, and design of the systematic review. VJP, CEG, XJ and SA were responsible for data collection and extraction and risk of bias assessment. VJP and CEG were responsible for the GRADE analysis and interpretation of data. VJP was the primary author of the manuscript. All authors (VJP, CEG, XJ, SA, VC, GF, GSG, JJR, MS, MST) were responsible for revising the manuscript critically for important intellectual content. All authors read and approved the final manuscript.

**Ethics approval and consent to participate**

Not applicable.

**Consent for publication**

Not applicable.

**Competing interests**

No competing interests were disclosed by authors.

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Living and Obesity Research Group at the Children’s Hospital of Eastern Ontario Research Institute, and the Public Health Agency of Canada. Valerie Carson is supported by a Canadian Institutes of Health Research New Investigator Salary Award. Guy Faulkner is supported by a Chair Award in Applied Public Health funded by the Public Health Agency of Canada in partnership with the Canadian Institutes of Health Research. The authors wish to acknowledge the work of Linda Slater for peer review of the search strategies, Alejandra Jaramillo Garcia and Véronique Dorais for methodological consultation, and Nick Barrowman and Katie Gunnell for statistical consultation.

Figure legends

Figure 1. PRISMA flow diagram for the identification, screening, eligibility and inclusion of studies. *Note that the numbers for each health indicator do not sum to the total number of included studies because more than one health indicator was reported in some studies.
Table 1. The relationship between sedentary behavior and adiposity.

<table>
<thead>
<tr>
<th>No of participants (No. of studies)</th>
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<th>Quality Assessment</th>
<th>Absolute Effect</th>
<th>Quality</th>
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<td></td>
<td>Risk of bias</td>
<td>Inconsistency</td>
<td>Indirectness</td>
</tr>
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<td>Randomized trial</td>
<td>Serious risk of bias</td>
<td>No serious inconsistency</td>
<td>No serious indirectness</td>
</tr>
<tr>
<td>32699 (13)</td>
<td>Longitudinal</td>
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<td>No serious inconsistency</td>
<td>No serious indirectness</td>
</tr>
<tr>
<td>1242 (2)</td>
<td>Case-Control</td>
<td>Serious risk of bias</td>
<td>No serious inconsistency</td>
<td>No serious indirectness</td>
</tr>
<tr>
<td>94191</td>
<td>Cross-</td>
<td>Serious risk</td>
<td>No serious</td>
<td>No serious</td>
</tr>
</tbody>
</table>

The range of mean ages at time of exposure measurement was ~0.75 to 4.95 years; the oldest mean age at follow-up was 15.5 years. Data were collected by randomized trial, case-control, cross-sectionally, and up to 12 years of follow-up. Adiposity measures were: BMI (absolute, z-score, SD score, percentile); fat mass index, lean mass index, trunk fat mass index; % body fat (measured using DXA); skinfold ratio (triceps skinfold thickness to subscapular skinfold thickness); sum of skinfolds; waist-to-height ratio; waist-to-hip ratio; weight-for-height (z-score); waist circumference (absolute, z-score for age); weight status (CDC, IOTF, or WHO cut-points; Flemish reference data; French reference standards; Rolland Cachera reference curves; United Kingdom reference standards in 1999); total fat mass (SD score); lean mass (SD score).
<table>
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<tr>
<th>(47)</th>
<th>sectional of bias</th>
<th>inconsistency</th>
<th>indirectness</th>
<th>imprecision</th>
</tr>
</thead>
</table>

Sedentary time 30 min bouts (accelerometer derived):
1/1 studies reported null associations [40]

Total sedentary time (accelerometer-derived):
10/11 studies reported null associations [37-40, 47, 53, 60, 75, 78, 80]
1/11 studies reported mixed unfavorable and null associations [77]

Screen-based sedentary behaviors:

Computer (duration):
3/4 studies reported null associations [63, 67, 79]
1/4 studies reported mixed unfavorable and null associations [71]

Screen time (duration):
6/18 studies reported unfavorable associations [32, 33, 46, 50, 59, 73]
10/18 studies reported null associations [44, 52, 57, 58, 62, 64, 65, 71, 72, 79]
2/18 studies reported mixed unfavorable and null associations [41, 61]

TV time (duration):
5/22 studies reported unfavorable associations [33, 55, 66, 67, 71]
11/22 studies reported null associations [31, 42, 43, 49, 50, 56, 60, 63, 69, 75, 76]
5/22 studies reported mixed unfavorable and null associations [48, 51, 54, 68, 79]
1/22 studies reported mixed null and favorable associations [74]
1/22 studies reported mixed unfavorable, null, and favorable associations [70]

Using the internet (duration):
1/1 studies reported null associations [69]

Video games (duration):
1/1 studies reported unfavorable associations [69]

Watching DVDs/videos (duration):
1/1 studies reported null associations [69]

Other sedentary behaviors:

Sedentary quiet play (duration):
1/1 studies reported mixed unfavorable and null associations [79]

Time in baby seats (duration):
1/1 studies reported null associations [45]

Using books (duration):
1/1 studies reported null associations [69]

Note. BMI, Body Mass Index; CDC, Centers for Disease Control and Prevention; IOTF, International Obesity Task Force; WHO, World Health Organization
Development; Reilly et al. 2005 [81] and Leary et al. 2015 [82] reported data from the Avon Longitudinal Study of Parents and Children (ALSPAC); Gooze et al. 2011 [84] and Flores and Lin 2013 [83] reported data from the Early Childhood Longitudinal Study-Birth Cohort (ECLS-B); and Fuller-Tyszkiewicz et al. 2012 [54] and Wheaton et al. 2015 [85] reported data from the Longitudinal Study of Australian Children (LSAC). Results are presented separately and participants are counted only once.

36 Serious risk of bias. Questionable validity and reliability of the exposure measure [33, 45, 54, 81-90]. Data were reported as missing, but amount and reasons were not provided [89]. Height and weight data were incomplete without explanation for 23% of the analyzed sample and 60.7% of the original cohort [81]. Possible selective reporting; differences between included and excluded participants were reported for confounding variables but not exposure variables without explanation [82]. BMI at age 3 yr was analyzed, but was not reported in the purpose or methods [88]. Did not account for potentially important confounding variables or mediating factors: sugar sweetened beverage consumption and sleep were assessed but not accounted for [33]; diet was not measured or included in the analysis [45]; adjusted for physical activity [89]; of the potential child and family confounders that were assessed, potential confounders were included or omitted from analyses based on the authors’ determination of what was “likely to be linked to our predictor or outcome variables,” without providing a basis for that determination [89]. Data were pooled from the control and experimental groups of a messaging-based obesity prevention intervention study [33].

The quality of evidence from the longitudinal studies was downgraded from “low” to “very low” because of a serious risk of bias that diminished the level of confidence in the observed effects.

Includes 13 longitudinal studies [33, 45, 54, 81-90] from 9 unique samples. Pagani et al. 2010 [90] and Fitzpatrick et al. 2012 [89] reported data from the Quebec Longitudinal Study of Child Development; Reilly et al. 2005 [81] and Leary et al. 2015 [82] reported data from the Avon Longitudinal Study of Parents and Children (ALSPAC); Gooze et al. 2011 [84] and Flores and Lin 2013 [83] reported data from the Early Childhood Longitudinal Study-Birth Cohort (ECLS-B); and Fuller-Tyszkiewicz et al. 2012 [54] and Wheaton et al. 2015 [85] reported data from the Longitudinal Study of Australian Children (LSAC). Results are presented separately and participants are counted only once.

Includes 2 case-control studies [35, 36].

Serious risk of bias. Questionable validity and reliability of the 1-day physical activity recall questionnaire [36]. Potentially inappropriate statistical analysis: investigators dichotomized participants by category of TV viewing of ≥1 hr/day or <1 hr/day based on exploratory bivariate analyses that showed 1 hr to be the duration most related to children’s weight status [35].

The quality of evidence from the case-control studies was downgraded from “low” to “very low” because of a serious risk of bias that diminished the level of confidence in the observed effects.


Serious risk of bias. Potentially inappropriate sampling technique: participants were a non-representative convenience sample [66]; sampling deviated from protocol and specific deviations were not documented [57]. Potentially inappropriate measurement tools were used: questionable validity and reliability of the exposure measure [31-33, 41, 43-46, 49-51, 54-62, 64-76] and outcome measure [65]; questionable validity of exposure measure [42, 52, 63, 79]; poor reliability of exposure measure [42]; height and weight were obtained by parent-report [44, 70]; options for 2-3 hr and 4-5 hr were missing from the Likert-type scale used to assess screen time [74]; applied accelerometry cut-points were not validated for the age group of interest [47]. Potential attrition bias: amount of unexplained missing exposure or outcome data is unknown [42, 50] or ranged from 14% to 67% [39, 40, 42, 43, 59, 60, 69, 71, 73, 74, 76], and reason for missing may be related to the true outcome of interest [40, 43, 46, 71]. Potential selective reporting bias: statistics for non-significant relationships were not reported [48, 64], authors decided post-hoc not to report analyses with continuous exposure variables [59]; only final model was reported [44]; results for correlations described in the methods section were not reported [62]; composite outcomes were presented without individual components; results for categorical screen time and total screen time described in the methods section were not reported [32]; outcomes from pooled hierarchical linear regression and variance information of included results were not reported [70]. Did not account for potentially important confounding variables or mediating factors: diet [43, 45, 46, 50, 58, 60, 63, 64, 67, 71, 72, 77, 80]; sugar sweetened beverage consumption and sleep [33]. Controlled for physical activity [59, 61, 66, 78]. Sleep during the day was considered sedentary time [40].

The quality of evidence from the cross-sectional studies was downgraded from “low” to “very low” because of a serious risk of bias that diminished the level of confidence in the observed effects.

Includes one randomized controlled trial [34].
Table 2. The relationship between sedentary behavior and motor development.

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<th>No of participants (No. of studies)</th>
<th>Design</th>
<th>Risk of bias</th>
<th>Inconsistency</th>
<th>Indirectness</th>
<th>Imprecision</th>
<th>Other</th>
<th>Absolute Effect</th>
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<tr>
<td>3413 (3)</td>
<td>Longitudinal</td>
<td>Serious risk of bias</td>
<td>No serious inconsistency</td>
<td>No serious indirectness</td>
<td>No serious imprecision</td>
<td>None.</td>
<td>Screen-based sedentary behaviors:</td>
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<td>2/3 studies reported null associations [88, 91]</td>
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<td>1/3 studies reported mixed unfavorable and null associations [92]</td>
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<td>Time in a baby carrier/sling (duration):</td>
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<td>Time in a car seat (duration):</td>
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<td>Time in a high chair or other chair (duration):</td>
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<td>1/1 studies reported null associations [91]</td>
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<td>681 (4)</td>
<td>Cross-sectional</td>
<td>Serious risk of bias</td>
<td>No serious inconsistency</td>
<td>No serious indirectness</td>
<td>No serious imprecision</td>
<td>None.</td>
<td>Objectively-measured sedentary time:</td>
<td>VERY LOW&lt;sup&gt;d&lt;/sup&gt;</td>
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<td>Sedentary time 30 min bouts (accelerometer-derived):</td>
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<td>1/1 studies reported null associations [40]</td>
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<td>Total sedentary time (accelerometer-derived):</td>
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<td>1/2 studies reported null associations [40]</td>
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<td>1/2 studies reported mixed unfavorable and null associations [37]</td>
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<td>Screen-based sedentary behaviors:</td>
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<td>1/1 studies reported unfavorable associations [94]</td>
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<td>Time in supine position (duration):</td>
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<td>1/1 studies reported mixed unfavorable and null associations [93]</td>
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</tbody>
</table>

a Includes 3 longitudinal studies [88, 91, 92] from 3 unique samples.

b Serious risk of bias. Questionable validity and reliability of exposure measure [88, 91, 92].

c The quality of evidence from longitudinal studies was downgraded from “low” to “very low” because of a serious risk of bias that diminished the level of confidence in the observed effects.

d Includes 4 cross-sectional studies [37, 40, 93, 94] from 4 unique samples.

e Serious risk of bias. Questionable validity and reliability of exposure measure [93, 94]; large amount (30.9%) of unexplained missing data and pattern of nonresponse indicates reason for missing data may have been related to the outcome of interest [40]; sleep during the day was included in sedentary time exposure [40].

f The quality of evidence from cross-sectional studies was downgraded from “low” to “very low” because of a serious risk of bias that diminished the level of confidence in the observed effects.
Table 3. The relationship between sedentary behavior and psychosocial health.

<table>
<thead>
<tr>
<th>No of participants (No. of studies)</th>
<th>Design</th>
<th>Risk of bias</th>
<th>Inconsistency</th>
<th>Indirectness</th>
<th>Imprecision</th>
<th>Other</th>
<th>Absolute Effect</th>
<th>Quality</th>
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<tbody>
<tr>
<td>412 (1)</td>
<td>Randomized trial</td>
<td>Serious risk of bias</td>
<td>No serious inconsistency</td>
<td>No serious indirectness</td>
<td>No serious imprecision</td>
<td>None</td>
<td>Screen time was significantly lower in the intervention vs control group at 2, 6 and 9 months post-intervention. Aggressive and delinquent behaviors were not different between the intervention and control groups at baseline, but were significantly lower in the intervention vs control group at 9-months post-intervention [34].</td>
<td>MODERATE</td>
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<tr>
<td>13301 (9)</td>
<td>Longitudinal</td>
<td>Serious risk of bias</td>
<td>No serious inconsistency</td>
<td>No serious indirectness</td>
<td>No serious imprecision</td>
<td>None</td>
<td>Screen-based sedentary behaviors: Time e-gaming or on a computer (duration): 1/1 studies reported mixed unfavorable and null associations [96] TV time (duration): 2/9 studies reported unfavorable associations [95, 103] 5/9 studies reported mixed unfavorable and null associations [90, 92, 96, 97, 99] 1/9 studies reported null associations [100] 1/9 studies reported mixed null and favorable associations [102]</td>
<td>VERY LOW</td>
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<tr>
<td>9429 (7)</td>
<td>Cross-sectional</td>
<td>Serious risk of bias</td>
<td>No serious inconsistency</td>
<td>No serious indirectness</td>
<td>No serious imprecision</td>
<td>None</td>
<td>Objectively-measured sedentary time: Total sedentary time (accelerometer-derived): 1/1 studies reported null associations [104] Screen-based sedentary behaviors: TV time (duration): 2/6 studies reported unfavorable associations [101, 103] 2/6 studies reported null associations [100, 106] 1/6 studies reported mixed unfavorable and null associations [105] 1/6 studies reported mixed null and favorable associations [98]</td>
<td>VERY LOW</td>
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</table>

Note. BASC-2, Behavior Assessment System for Children; BPI, Behavior Problems Index; CBCL, Child Behavior Checklist; CTQ, Child Temperament Questionnaire; KINDL, Questionnaire for Measuring Health-Related Quality of Life in Children and Adolescents-Revised Version; MIT-SEA, Modified Infant-Toddler Social and Emotional Assessment; SBQ, Social Behavior Questionnaire; SDQ, Strengths and Difficulties Questionnaire.

a Includes one randomized controlled trial [34].
b Serious risk of bias. Unclear if allocation was adequately concealed prior to group assignment; group allocation was adequately concealed from control, but not intervention group during the study; knowledge of outcome of interest was not prevented and outcome measurement is likely to have been influenced by lack of blinding; baseline data were not reported making it impossible to determine if baseline imbalances existed between groups [34].
Screen time was significantly lower in the intervention vs control group at 2, 6 and 9 month follow-up post-intervention (mean ± SD: 2 month: 39.48 ± 16.36 vs 86.64 ± 21.63 min/day; 6 month: 24.72 ± 4.45 vs 84.95 ± 14.77 min/day; 9 month: 21.15 ± 6.12 vs 93.96 ± 18.84 min/day; all p < 0.001).

Intervention: 3 printed materials and interactive CDs and one counselling call, intending to decrease screen time; 8 week duration. Control: Usual care; unaware of counselling interventions.

The quality of evidence from the randomized trial was downgraded from “high” to “moderate” because of a serious risk of bias in the single RCT that diminished the level of confidence in the observed effects.

Includes 9 longitudinal studies [90, 92, 95-97, 99, 100, 102, 103] from 6 unique samples. Verlinden et al. 2012 [99] and 2014 [97] reported data from the Generation R Study; and Pagani et al. 2010 [90] and 2013 [92] and Watt et al. 2015 [95] reported data from the Quebec Longitudinal Study of Child Development (QLSCD). Results are presented separately and participants are counted only once.

Serious risk of bias. Questionable validity and reliability of television duration exposure measure [90, 92, 97, 99, 100, 102, 103]; questionable validity and reliability of television duration exposure measure on weekdays only [96]; poor reliability of outcome measures for responsibility [102] and emotional symptoms, conduct problems, peer problems and prosocial behavior [100]; large amount of unexplained missing data and pattern of nonresponse indicates reason for missing data may have been related to the outcome of interest [97]; complete results were not reported for all relationships examined [99].

The quality of evidence from longitudinal studies was downgraded from “low” to “very low” because of a serious risk of bias that diminished the level of confidence in the observed effects.

Includes 7 cross-sectional studies [98, 100, 101, 103-106] from 7 unique samples.

Serious risk of bias. Questionable validity and reliability of television duration exposure measure [98, 100, 101, 103, 105, 106]; poor reliability of outcome measures for emotional symptoms, conduct problems, peer problems and prosocial behavior [100]; small amount (218/4020) of unexplained missing outcome data at 3 year follow-up [92].

The quality of evidence from cross-sectional studies was downgraded from “low” to “very low” because of a serious risk of bias that diminished the level of confidence in the observed effects.
Table 4. The relationship between sedentary behavior and cognitive development.

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<tr>
<th>No of participants (No. of studies)</th>
<th>Design</th>
<th>Risk of bias</th>
<th>Inconsistency</th>
<th>Indirectness</th>
<th>Imprecision</th>
<th>Other</th>
<th>Absolute Effect</th>
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<td></td>
<td></td>
<td>Risk of bias</td>
<td>Inconsistency</td>
<td>Indirectness</td>
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<td>Absolute Effect</td>
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<td>8927 (11)</td>
<td>Longitudinal a</td>
<td>Serious risk of bias b</td>
<td>No serious inconsistency</td>
<td>No serious indirectness</td>
<td>No serious imprecision</td>
<td>None</td>
<td>Screen-based sedentary behaviors:</td>
<td>VERY LOW c</td>
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<td>Electronic media exposure (duration):</td>
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<td>1/1 studies reported unfavorable associations [112]</td>
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<td>Parents reading (frequency):</td>
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<td>5/10 studies reported unfavorable associations [90, 92, 100, 120, 121]</td>
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<td>4/10 studies reported null associations [88, 102, 113, 122]</td>
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<td>1/10 studies reported mixed unfavorable, null, and favorable associations [119]</td>
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<td>166 (1)</td>
<td>Case-Control d</td>
<td>Serious risk of bias e</td>
<td>No serious inconsistency</td>
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<td>No serious imprecision</td>
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<td>1/1 studies reported unfavorable associations [116]</td>
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<td>9330 (16)</td>
<td>Cross-sectional f</td>
<td>Serious risk of bias b</td>
<td>No serious inconsistency</td>
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<td>No serious imprecision</td>
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<td>Objectively-measured sedentary time:</td>
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<td>Total sedentary time (accelerometer-derived):</td>
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<td>1/8 studies reported mixed unfavorable and null associations [118]</td>
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longitudinal relationships were reportedly collected but not reported in the results [115]; the methods section of one study indicated that bivariate analysis would be performed, but included variables and the results of the analysis were not reported [121].

missing data and pattern of nonresponse indicates reason for missing data may have been related to the outcome of interest; incomplete reporting of exposure [109] and outcome [90, 110]; questionable validity and/or reliability of the outcome measure [109, 110]; unknown amount [109, 117] or between 28% and 60% [121, 124] of unexplained

*Includes 11 longitudinal studies [88, 90, 92, 100, 102, 112, 113, 119-122] from 8 unique samples. Tomopoulos et al. 2010 [112] reported data from the Bellevue Project for Early Language, Literacy, and Education Success (BELLE); McKeen et al. 2015 [121] reported data from the Early Language in Victoria Study (ELVS); Pagani et al. 2010 [90] and 2013 [92] reported data from the Quebec Longitudinal Study of Child Development (QLSCD); Schmidt et al. 2009 [88] reported data from Project Viva; and Foster and Watkins 2010 [113], Christakis et al. 2004 [120] and Zimmerman and Christakis 2005 [119] reported data from the National Longitudinal Survey of Youth, Children, and Young Adults (NLSY-Child). Results are presented separately and participants are counted only once.

Serious risk of bias. Questionable validity and reliability of television duration exposure measure in all studies [88, 90, 92, 100, 102, 112, 113, 119-122]; poor reliability of Attention Problems subscale of the Child Behavior Checklist (α = 0.59) [102]; possible reporting bias, because the relationship between TV exposure and BMI at age 3 yr was analyzed despite not being described in the methods section [88]; two studies had unexplained missing data (34 and 40% missing) and the pattern of nonresponse indicates the reason for missing data may have been related to the outcome of interest [112, 121]; data were reported incompletely for the relationship between TV exposure and reading achievement [90]; the methods section of one study indicated that bivariate analysis would be performed, but included variables and the results of the analysis were not reported [121].

The quality of evidence from longitudinal studies was downgraded from “low” to “very low” because of a serious risk of bias that diminished the level of confidence in the observed effects.

*Includes 1 case-control study [116].

Serious risk of bias. Exposure measure was described in poor detail; questionable validity and reliability of television duration exposure measure; the Denver II Scale is useful for detecting severe developmental problems but has been criticized as being unreliable for predicting less severe or specific problems; the regression model that predicted developmental delay from a co

Serious risk of bias. Potentially inappropriate sampling technique resulted in a sample with higher income and education than the overall population from which it was recruited [117, 124]; questionable validity and reliability of the exposure measure [90, 106-109, 111, 115, 117, 121, 122, 124, 134]; questionable validity of exposure measure [94]; validation study showed overestimation of TV time exposure measure [110]; questionable validity and/or reliability of the outcome measure [109, 110]; unknown amount [109, 117] or between 28% and 60% [121, 124] of unexplained missing data and pattern of nonresponse indicates reason for missing data may have been related to the outcome of interest; incomplete reporting of exposure [109] and outcome [90, 110]; longitudinal relationships were reportedly collected but not reported in the results [115]; the methods section of one study indicated that bivariate analysis would be performed, but included variables and the results of the analysis were not reported [121].
The quality of evidence from longitudinal studies was downgraded from “low” to “very low” because of a serious risk of bias that diminished the level of confidence in the observed effects.
Table 5. The relationship between sedentary behavior and bone and skeletal health.

<table>
<thead>
<tr>
<th>No of participants (No. of studies)</th>
<th>Design</th>
<th>Quality Assessment</th>
<th>Absolute Effect</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Risk of bias</td>
<td>Inconsistency</td>
<td>Indirectness</td>
</tr>
<tr>
<td>1512 (1)</td>
<td>Cross-sectional</td>
<td>Serious risk of bias</td>
<td>No serious inconsistency</td>
<td>No serious indirectness</td>
</tr>
</tbody>
</table>

After adjusting for MVPA, accelerometer-derived sedentary time was no longer significantly associated with bone stiffness index (SI) in preschool children ($\beta = -0.37; R^2 = 19\%; p = 0.28)$ [125].

**Screen-based sedentary behaviors:**

There was no association between parent-reported screen time and SI ($\beta = -0.04; R^2 = 18.4\%; p = 0.50$) [125].

The mean age was 4.4 years. Data were collected cross-sectionally. Bone and skeletal health were assessed objectively using quantitative ultrasound.

Note. IDEFICS, Identification and prevention of dietary- and lifestyle-induced health effects in children and infants; MVPA, moderate-to-vigorous physical activity; SI, bone stiffness index.

*a* Includes 1 cross-sectional study that reported data from the IDEFICS sample [125].

*b* Serious risk of bias. Study participants were selected by “judgment sample”; questionable validity and reliability of subjective and objective exposure measures, and of quantitative ultrasound for measurement of bone stiffness in children [125].

*c* Serious imprecision. It was not possible to estimate the precision of the findings since the study did not provide a measure of variability in the results.

*d* The quality of evidence from the cross-sectional study was downgraded from “low” to “very low” because of: (1) a serious risk of bias that diminished the level of confidence in the observed effects, and (2) serious imprecision.
Table 6. The relationship between sedentary behavior and cardiometabolic health.

<table>
<thead>
<tr>
<th>No of participants (No. of studies)</th>
<th>Design</th>
<th>Risk of bias</th>
<th>Inconsistency</th>
<th>Indirectness</th>
<th>Imprecision</th>
<th>Absolute Effect</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>276 (1)</td>
<td>Cross-sectional</td>
<td>Serious risk of bias</td>
<td>No serious inconsistency</td>
<td>No serious indirectness</td>
<td>No serious imprecision</td>
<td>Screen-based sedentary behaviors: Watching TV for ≥2 hr/day was not associated with <strong>high blood pressure</strong> (compared to &lt;2 hr/day, Prevalence Ratio = 0.9, 95% CI: 0.5, 1.4, p=0.568) [126].</td>
<td>VERY LOWc</td>
</tr>
</tbody>
</table>

*a* Includes 1 cross-sectional study [126].

*b* Serious risk of bias. Unknown reliability and validity of the exposure measure [126].

*c* The quality of evidence from the cross-sectional study was downgraded from “low” to “very low” because of a serious risk of bias that diminished the level of confidence in the observed effects.
Table 7. The relationship between sedentary behavior and fitness.

<table>
<thead>
<tr>
<th>No of participants (No. of studies)</th>
<th>Design</th>
<th>Quality Assessment</th>
<th>Absolute Effect</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Risk of bias</td>
<td>Inconsistency</td>
<td>Indirectness</td>
</tr>
<tr>
<td>1314 (2)</td>
<td>Longitudinal</td>
<td>Serious risk of bias</td>
<td>No serious inconsistency</td>
<td>Serious indirectness</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: The mean age at exposure measurement ranged from ~29 to 53 months (~2.4 to 4.4 yr). Data were collected longitudinally up to 8 years of follow-up. Fitness was assessed as: lower body explosive strength (standing long jump) and fitness level (parent-report level relative to other children).

\[a\] Includes 2 longitudinal studies [89, 90] from 1 unique sample (QLSCD).

\[b\] Serious risk of bias. Questionable reliability and validity of the exposure [89, 90] and outcome [90] measures; large unexplained loss to follow-up and unclear if included participants differed from missing participants [89]; controlled for physical activity [89, 90].

\[c\] Serious indirectness. Differences between outcomes of included studies and those of interest; only one study reported a measure of lower-body musculoskeletal fitness (lower-body strength assessed by standing long jump performance) [89], and one study reported an indirect measure of physical fitness [90]. No studies reported direct measures of total body musculoskeletal or cardiovascular fitness.

\[d\] The quality of evidence from the longitudinal studies was downgraded from “low” to “very low” because of: 1) a serious risk of bias that diminished the level of confidence in the observed effects, and 2) indirectness of the comparisons being assessed.
<table>
<thead>
<tr>
<th>Health Indicator</th>
<th>Number of Studies</th>
<th>Quality of Evidence</th>
<th>Summary of Findings: Number of studies reporting unfavorable / null / favorable associations with at least 1 health indicator measure by SB type*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Adiposity                | 60                | Very low to moderate| **Objectively-measured sedentary time:**
Sedentary time in 30 min bouts (accelerometer-derived): null (1)
Total sedentary time (accelerometer-derived): unfavorable (1), null (12)

**Screen-based sedentary behaviors:**
Computer (duration, frequency): unfavorable (1), null (6)
Internet (duration): null (1)
Total screen time (duration): unfavorable (9), null (14)
TV time (duration): unfavorable (20), null (24), favorable (2)
Video games (duration): unfavorable (1)
Other screens (DVDs/videos; duration): unfavorable (1), null (1)

**Other sedentary behaviors:**
Reading (duration): null (1)
Sitting (baby seats, car, sedentary quiet play; duration): unfavorable (2), null (4), favorable (1) |
| Motor Development        | 7                 | Very low            | **Objectively-measured sedentary time:**
Sedentary time in 30 min bouts (accelerometer-derived): null (1)
Total sedentary time (accelerometer-derived): unfavorable (1), null (2)

**Screen-based sedentary behaviors:**
TV time (duration): unfavorable (2), null (3)

**Other sedentary behaviors:**
Sitting (baby carrier/sling, car seat, high chair/other chair, playpen, stroller; duration): null (1), favorable (1)
Supine position (duration): unfavorable (1), null (1) |
| Psychosocial Health      | 15                | Very low to moderate| **Objectively-measured sedentary time:**
Total sedentary time (accelerometer-derived): null (1)

**Screen-based sedentary behaviors:**
Computer (duration): unfavorable (1), null (1)
Total screen time (duration): unfavorable (1)
TV time (duration): unfavorable (9), null (11), favorable (2)

**Other sedentary behaviors:**
Screen time (duration): null (1) |
| Cognitive Development    | 25                | Very low            | **Objectively-measured sedentary time:**
Total sedentary time (accelerometer-derived): null (1)

**Screen-based sedentary behaviors:**
Computer (yes, no): null (1)
Mobile phone use (yes, no): unfavorable (1)
Total screen time (duration): unfavorable (1)
TV time (duration): unfavorable (11), null (10), favorable (1)
Video games (duration): null (1)
Other screens (total or electronic media exposure; duration): unfavorable (2), null (1)

**Other sedentary behaviors:**
Reading (duration, frequency): null (2), favorable (3)
Storytelling with parents (frequency): null (2), favorable (2) |
| Important                |                   |                     |                                                                                                                                 |
| Bone and Skeletal Health | 1                 | Very low            | **Screen-based sedentary behaviors:**
Screen time (duration): null (1)

**Objectively-measured sedentary time:**
<table>
<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Level</th>
<th>Screen-based sedentary behaviors:</th>
<th>Total sedentary time (accelerometer-derived):</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiometabolic Health</td>
<td>1</td>
<td>Very low</td>
<td>TV time (duration): null (1)</td>
<td></td>
</tr>
<tr>
<td>Fitness</td>
<td>2</td>
<td>Very low</td>
<td>TV time (duration): unfavorable (2)</td>
<td></td>
</tr>
<tr>
<td>Risks / harms</td>
<td>0</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

*Note that the number of studies reporting unfavorable / null / favorable associations does not sum to the total number of studies for a given indicator since some studies reported mixed associations. N/A, not applicable.
Additional files

Additional File 1: Search strategies

Additional File 2: Supplementary Tables S1-S7
References


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