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 ≤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

Description of studies

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

= 44), 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]

(Supplementary Table S3). 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].

Cognitive development

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

566 expressive language development in infants and toddlers aged ~6 months to 1.3 years, but not
567 with total language development in toddlers aged ~1.4 to 2.3 years [124].

568 The relationships between TV time and cognitive development in toddlers and
569 preschoolers were examined in eight cross-sectional studies; unfavorable associations were
570 reported in 3/8 studies [94, 108, 123], null associations in 4/8 studies [100, 114, 115, 121], and
571 mixed unfavorable and null associations in 1/8 studies [118] (see Table S4 for statistics).
572 Specifically, TV time was unfavorably associated with language development or capacity in 2/5
573 studies [94, 108] (Supplementary Table S4). TV time was unfavorably associated with delayed
574 cognitive development [94], and executive function [123] (Supplementary Table S4). TV time
575 was not associated with hyperactivity-inattention in toddlers [100], and was unfavorably
576 associated with teacher-reported but not parent-reported attention-deficit/hyperactivity disorder
577 (ADHD) symptoms in preschoolers [118] (Supplementary Table S4).

578 Regarding other sedentary behaviors, the relationships between reading with parents and
579 cognitive development indicators in infants, toddlers, and preschoolers were examined in three
580 cross-sectional studies [110, 117, 124], two of which analyzed the same dataset in different ways
581 [117, 124]; reading with parents was favorably associated with language development percentile
582 in both infants and toddlers [117], but was not associated with absolute language development in
583 toddlers (not analyzed in infants) [124]. Reading with parents was favorably associated with
584 absolute receptive language development, but not expressive language development, in infants
585 [124]. In the third study, reading with parents was not associated with executive function in
586 preschoolers [110]. Storytelling with parents was favorably associated with language
587 development percentile in infants [117]. In toddlers, storytelling was favorably associated with
588 absolute language development [124], but not language development percentile [117].

589 Storytelling with parents was favorably associated with absolute receptive language development
590 but not expressive language development in infants [124] (Supplementary Table S4).

591

592 **Important (secondary) health indicators**

593 **Bone and skeletal health**

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

599 **Cardiometabolic health**

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

605 **Fitness**

606 The relationship between sedentary behavior and fitness in toddlers and preschoolers was
607 examined in two longitudinal studies (no studies in infants; see Table 7 and Supplementary Table
608 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

677 behavior; however, it is uncertain whether children are actually sedentary while using screens in
678 this age group, and there may be screen-related health effects that are independent of the "lack of
679 movement" [131, 132]. Notwithstanding these limitations, the present findings indicate that less
680 screen-based sedentary behavior is better for optimal health in the early years of life.

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

694 Most studies examined the duration of sedentary behaviors in relation to health
695 indicators, with only three studies specifically examining the impact of patterns of behavior (i.e.,
696 breaks, frequency). Specifically, there was no association between accelerometer-derived
697 sedentary time in 30 minute bouts and indicators of adiposity and motor development [40], or
698 between the frequency of playing computer games and adiposity indicators [82], but there were
699 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,

722 fitness, and risks/harms); TV time was the primary sedentary exposure, with few studies
723 examining "other" types of screens (e.g., tablets, mobile phones) or sedentary behaviors (e.g.,
724 reading, puzzles); and objective measures of total sedentary time were only employed in cross-
725 sectional studies. Although adiposity was the most commonly measured health indicator (60
726 studies), direct measures of adiposity were used in only two studies [78, 82] while the remainder
727 used surrogate measures such as BMI. Only one randomized controlled study was included in
728 the present review, and the quality of the evidence ranged from "very low" to "moderate" across
729 the study designs and health indicators. There is a need for high-quality studies with strong
730 designs to better establish the magnitude of effects, the nature of dose-response gradients if
731 applicable, to assess cause-and-effect relationships, and to examine potential subgroup
732 differences (e.g., based on age, sex, or socioeconomic status). When RCTs are not possible due
733 to the inherent challenges of research in this age group, quasi-experimental or longitudinal
734 designs that use validated sedentary behavior measures and outcome measures that are sensitive
735 enough to detect changes are recommended.

736 Across the health indicators, the most common reason for downgrading the quality of
737 evidence was due to the serious risk of bias associated with sedentary behavior measures with no
738 known psychometric properties. Consequently, development and use of reliable and valid
739 subjective measures of sedentary behavior are needed. Defining and measuring sedentary
740 behavior in young children, particularly in non-ambulatory infants, remains a challenge. For
741 instance, infants in the supine position may be vigorously moving arms and legs, and thus being
742 "active", but existing questionnaire-based measures do not capture this. Future research using
743 inclinometers, which can more accurately capture postures [133], as well as limb-worn devices,
744 will help to address the challenges associated with quantifying sedentary behaviors in the early

745 years. Finally, the question of whether different types of sedentary behavior "content" (e.g.
746 educational versus recreational TV programming) exert different health effects was beyond the
747 scope of this review, and remains an important area for future work.

748 **Conclusions**

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

762

763

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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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.

Tables

Table 1. The relationship between sedentary behavior and adiposity.

No of partici-pants (No. of studies)	Design	Quality Assessment					Absolute Effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other		
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); weight-for-age (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).								
412 (1)	Randomized trial[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None	**Screen time**[c] was significantly lower in the intervention vs control group at 2, 6 and 9 months post-intervention[d]. **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].	MODERATE[e]
32699 (13)	Longitudinal[f]	Serious risk of bias[g]	No serious inconsistency	No serious indirectness	No serious imprecision	None	**Screen-based sedentary behaviors:** Computer(duration): **1/1 studies** reported null associations [85] Computer games (frequency): **1/1 studies** reported null associations [82] Screen time (duration): **2/3 studies** reported unfavorable associations [33, 84] **1/3 studies** reported null associations [87] TV time (duration): **6/10 studies** reported unfavorable associations [33, 54, 81, 83, 88, 90] **1/10 studies** reported null associations [86] **3/10 studies** reported mixed unfavorable and null associations [82, 85, 89] Watching DVDs (duration): **1/1 studies** reported unfavorable associations [83] **Other sedentary behaviors:** Time in baby seats (duration): **1/1 studies** reported mixed unfavorable, null and favorable associations [45] Time in the car (duration): **2/2 studies** reported null associations [81, 82]	VERY LOW[h]
1242 (2)	Case-Control[i]	Serious risk of bias[j]	No serious inconsistency	No serious indirectness	No serious imprecision	None	**TV time** [35, 36] and **total sedentary time** [36] were not different between children with **overweight/obese** (case group) or **normal weight** (control group) status, but watching **TV for ≥1 hr/day** was unfavorably associated with having **overweight status** (OR = 1.71, 95% CI: 1.07, 2.75, p = 0.02) [35].	VERY LOW[k]
94191	Cross-	Serious risk	No serious	No serious	No serious	None	**Objectively-measured sedentary time:**	VERY

(47)	sectional[l]	of bias[m]	inconsistency	indirectness	imprecision		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]	LOW[n]

Note. BMI, Body Mass Index; CDC, Centers for Disease Control and prevention; IOTF, International Obesity Task Force; WHO, World Health Organization

[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; unclear if height and weight were directly measured or proxy-reported; baseline data were not reported making it impossible to determine if baseline imbalances existed between groups [34].
[c] Screen time was significantly lower in the intervention vs control group at 2 mo, 6 mo and 9 mo follow-up post-intervention (mean ± SD: 2 mo: 39.48 ± 16.36 vs 86.64 ± 21.63 min/day; 6 mo: 24.72 ± 4.45 vs 84.95 ± 14.77 min/day; 9 mo: 21.15 ± 6.12 vs 93.96 ± 18.84 min/day; all $p < 0.001$).
[d] Intervention: 3 printed materials and interactive CDs and one counselling call intended to decrease screen time; 8 week duration. Control: Usual care; unaware of counselling interventions.
[e] The quality of evidence from the randomized trial was downgraded from "high" to "moderate" because of a serious risk of bias that diminished the level of confidence in the observed effects.

[f] 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.
[g] 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].
[h] 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.

[i] Includes **2 case-control studies** [35, 36].
[j] 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].
[k] 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.

[l] Includes **47 cross-sectional studies** [31-33, 37-80] from **40 unique samples**. Williams et al. 2008 [37], Byun et al. 2011 [39], and Byun et al. 2013 [38] reported data from the Children's Activity and Movement in Preschool Study (CHAMPS); Sijtsma et al. 2013 [45] and Sijtsma et al. 2015 [46] reported data from the Groningen Expert Center for Kids with Obesity (GECKO) Drenthe birth cohort; Manios et al. 2009 [48], Kourlaba et al. 2009 [49] and van Stralen et al. 2012 [50] reported data from the Growth, Exercise and Nutrition Epidemiological Study in preSchoolers (GENESIS); Mendoza et al. 2007 [71] reported data from the National Health and Nutrition Examination Survey (NHANES) 1999 to 2002, Fulton et al. 2009 [72] from NHANES 1999 to 2006, and Twarog et al. 2015 [73] from NHANES 2008 to 2012; Taverno Ross et al. 2013 [76] and Espana-Romero et al. 2013 [77] reported data from the Study of Health and Activity in Preschool Environments (SHAPES); Brown et al. 2010 [55] and Fuller-Tyszkiewicz et al. 2012 [54] reported data from LSAC; Dolinsky et al. 2011 [53] and Boling Turer et al. 2013 [45] reported data from Kids and Adults Now: Defeat Obesity! (KAN-DO). Results are presented separately and participants are counted only once.
[m] 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, 66, 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].
[n] 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.

Table 2. The relationship between sedentary behavior and motor development.

No of partici-pants (No. of studies)	Design	Quality Assessment					Absolute Effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other		
Participant ages at time of exposure measurement ranged from ~4 mo (0.3 yr) to 3-4 years; the oldest mean age at follow-up was 5.4 years. Data were collected cross-sectionally and up to 3 years of follow-up. Motor development indicators were assessed by parent-report unless otherwise indicated; specific indicators were: age at first sitting, age at first crawling, age at first walking, locomotion/locomotor skills (assessed by a "test of gross motor development" or CHAMPS Motor Skill Protocol), motor skill development (assessed by the PDMS-2 or CHAMPS Motor Skill Protocol), motor skills (assessed by a "neurological optimality score"), object control (assessed by a "test of gross motor development", or CHAMPS Motor Skill Protocol), and visual-motor abilities (assessed by the WRAVMA test).								
3413 (3)	Longitudinal [a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None.	**Screen-based sedentary behaviors:** TV time (duration): **2/3 studies** reported null associations [88, 91] **1/3 studies** reported mixed unfavorable and null associations [92] **Other sedentary behaviors:** Time in a baby carrier/sling (duration): **1/1 studies** reported null associations [91] Time in a car seat (duration): **1/1 studies** reported mixed null and favorable associations [91] Time in a high chair or other chair (duration): **1/1 studies** reported null associations [91] Time in a playpen (duration): **1/1 studies** reported null associations [91] Time in a stroller (duration): **1/1 studies** reported null associations [91]	VERY LOW[c]
681 (4)	Cross-sectional[d]	Serious risk of bias[e]	No serious inconsistency	No serious indirectness	No serious imprecision	None.	**Objectively-measured sedentary time:** Sedentary time 30 min bouts (accelerometer-derived): **1/1 studies** reported null associations [40] Total sedentary time (accelerometer-derived): **1/2 studies** reported null associations [40] **1/2 studies** reported mixed unfavorable and null associations [37] **Screen-based sedentary behaviors:** TV time (duration): **1/1 studies** reported unfavorable associations [94] **Other sedentary behaviors:** Time in supine position (duration): **1/1 studies** reported mixed unfavorable and null associations [93]	VERY LOW[f]

Note. CHAMPS, Children's Activity and Movement in Preschool Study; PDMS-2, Peabody Developmental Motor Scales-second edition; WRAVMA, Wide-Range Assessment of Visual Motor Ability.

[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.

No of partici-pants (No. of studies)	Design	Quality Assessment					Absolute Effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other		
The range of mean ages at time of exposure measurement was ~1 to 4.3 years; the oldest mean age at follow-up was ~12 years. Data were collected by randomized trial, cross-sectionally, and up to 9.5 years of follow-up. Psychosocial health measures were: aggression toward a sibling (assessed by the Aggressive Sibling Social Behavior Scale); aggressive behaviors/aggression, delinquent behaviors, total behavior problems, externalizing problems, internalizing problems, emotional reactivity, anxious or depressed symptoms, and attention problems (assessed by the CBCL or Japanese CBCL); attentional problems (assessed by the hyperactivity subscale of the BPI); attention problems and hyperactivity (assessed by the BASC-2); bullying (assessed by unpublished questionnaire); cooperation, assertion, responsibility, self-control, and total social skills (assessed by the Social Skills Rating System); emotional symptoms/problems, conduct problems, hyperactivity-inattention, peer-problems, and prosocial behavior (assessed using the SDQ); self-esteem, emotional well-being, family functioning, and social networks (assessed using the KINDL^{R}); social-emotional competence (assessed by the MIT-SEA); soothability, sociability, and emotionality (assessed by the CTQ); victimization, anxiety, physical aggression, and prosocial behavior (assessed by the SBQ); and risk of being a bully, victim, or bully-victim (assessed by unpublished questionnaire).								
412 (1)	Randomized trial[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None	**Screen time**[c] was significantly lower in the intervention vs control group at 2, 6 and 9 months post-intervention[d]. **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].	MODERATE[e]
13301 (9)	Longitudinal[f]	Serious risk of bias[g]	No serious inconsistency	No serious indirectness	No serious imprecision	None	**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]	VERY LOW[h]
9429 (7)	Cross-sectional[i]	Serious risk of bias[j]	No serious inconsistency	No serious indirectness	No serious imprecision	None	**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]	VERY LOW[k]

Note. BASC-2, Behavior Assessment System for Children; BPI, Behavior Problems Index; CBCL, Child Behavior Checklist; CTQ, Child Temperament Questionnaire; KINDL^{R}, 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].

[c] 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 $p < 0.001$).
[d] 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.
[e] 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.

[f] 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.
[g] 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].
[h] 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.

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

No of partici-pants (No. of studies)	Design	Quality Assessment					Absolute Effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other		
The range of mean ages at time of exposure measurement was ~0.5 to 4.4 years; the oldest age range at follow-up was 9 to 10 years. Data were collected cross-sectionally and up to 8 years of follow-up. Cognitive development indicators were: ADHD symptoms (assessed by checklists based on the DSM-IV); attentional problems (assessed by the BPI); attention span (assessed by the CTQ); classroom engagement (assessed by a Classroom Engagement Scale, and an unpublished questionnaire); cognitive ability (assessed by the Imitation Sorting Task); cognitive development (assessed by BSID-II, BSID-III); cognitive inhibitory control (assessed by the Animal Stroop Task); executive function (assessed as a composite of cognitive inhibitory control and working memory capacity; the BASC-2; four tasks: grass/snow, whisper, backward digit span, tower); language development (total), auditory comprehension, expressive communication (assessed by ASQ, PLS-4, CELF-P2, CELF-4, CDI, K-ASQ, Thai CLAMS, medical diagnosis and developmental assessment with Denver-II test); mathematical success (assessed as relative to the class distribution); mathematics, reading recognition, reading comprehension (assessed by the PIAT); number knowledge (assessed by NKT); receptive and total vocabulary (assessed by PPVT); short-term memory (assessed by the Memory for Digit Span of the WISC); speech disorders (assessed by the Chuturik test and Child Behavior Checklist by Achenbach, conversation with parents, and clinical examination); and working memory capacity (assessed using the Animal Stroop Task and K-ABC number recall test).								
8927 (11)	Longitudinal [a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None	**Screen-based sedentary behaviors:** Electronic media exposure (duration): **1/1 studies** reported unfavorable associations [112] **Other sedentary behaviors:** Parents reading (frequency): **1/1 studies** reported favorable associations [121] TV time (duration): **5/10 studies** reported unfavorable associations [90, 92, 100, 120, 121] **4/10 studies** reported null associations [88, 102, 113, 122] **1/10 studies** reported mixed unfavorable, null, and favorable associations [119]	VERY LOW[c]
166 (1)	Case-Control[d]	Serious risk of bias[e]	No serious inconsistency	No serious indirectness	No serious imprecision	None	**Screen-based sedentary behaviors:** TV time: **1/1 studies** reported unfavorable associations [116]	VERY LOW[f]
9330 (16)	Cross-sectional[g]	Serious risk of bias[h]	No serious inconsistency	No serious indirectness	No serious imprecision	None	**Objectively-measured sedentary time:** Total sedentary time (accelerometer-derived): **1/1 studies** reported null associations [104] **Screen-based sedentary behaviors:** Computer use (yes, no): **1/1 studies** reported null associations [109] Mobile phone use (yes, no): **1/1 studies** reported unfavorable associations [109] TV time (duration): **3/8 studies** reported unfavorable associations [94, 108, 123] **4/8 studies** reported null associations [100, 114, 115, 121] **1/8 studies** reported mixed unfavorable and null associations [118]	VERY LOW[i]

							Total media exposure (duration): **1/1 studies** reported mixed null and unfavorable associations [124] Video games (duration): **1/1 studies** reported null associations [107] **Other sedentary behaviors:** Reading with parents (duration, frequency): **1/3 studies** reported null associations [110] **1/3 studies** reported favorable associations [117] **1/3 studies** reported mixed null and favorable associations [124] Screen time (duration): **1/1 studies** reported unfavorable associations [111] Storytelling with parents (frequency): **2/2 studies** reported mixed null and favorable associations [117, 124]	

Note. ADHD, Attention-Deficit/Hyperactivity Disorder; ASQ, Ages and Stages Questionnaire; BASC-2, Behavior Assessment System for Children; BSID-II and BSID-III, Bayley Scales of Infant Development-second and third editions; BPI, Behavioral Problems Index; CDI, Communicative Development Inventory; CELF-P2, Clinical Evaluation of Language Fundamentals-Preschool; CELF-4, Clinical Evaluation of Language Fundamentals Fourth Edition; CLAMS, Clinical Linguistic Auditory Milestone Scale; CTQ, Child Temperament Questionnaire; DSM-IV, Diagnostic and Statistical Manual of Mental Disorders-4; K-ABC, Kaufman Assessment Battery for Children; K-ASQ, Korean-Ages and Stages Questionnaire, NKT, Number Knowledge Test; PIAT, Peabody Individual Achievement Test; PLS-4, Preschool Language Scale-4; PPVT, Peabody Picture Vocabulary Test; WISC, Wechsler Intelligence Scale for Children

[a] 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); McKean 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.

[b] 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 ($\alpha = 0.59$) [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].

[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 **1 case-control study** [116].

[e] 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 composite of "age of onset of TV viewing" and "TV viewing >2 hr/day" was not pre-specified in the methods and composite variables were not combined in analyses with other outcomes [2126].

[f] The quality of evidence from the case-control 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.

[g] Includes **16 cross-sectional studies** [90, 94, 100, 104, 107-111, 114, 115, 117, 118, 121, 123, 124]. Zimmerman et al. 2007 [117] and Ferguson and Donnellan 2014 [124] reported data from the same sample. Results are presented separately and participants are counted only once.

[h] 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].

[i] 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.

No of partici-pants (No. of studies)	Design	Quality Assessment				Absolute Effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
The mean age was 4.4 years. Data were collected cross-sectionally. Bone and skeletal health were assessed objectively using quantitative ultrasound.							
1512 (1)	Cross-sectional[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	Serious imprecision[c]	**Objectively-measured sedentary time:** After adjusting for MVPA, accelerometer-derived **sedentary time** was no longer significantly associated with **bone stiffness index (SI)** in preschool children (β=-0.37; R^2=19%; p=0.28) [125]. **Screen-based sedentary behaviors:** There was no association between parent-reported **screen time** and **SI** (β=-0.04; R^2=18.4%; p=0.50) [125].	VERY LOW[d]

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.

No of partici-pants (No. of studies)	Design	Quality Assessment				Absolute Effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
The mean age was 3.1 years. Data were collected cross-sectionally. Cardiometabolic health was assessed using an objective measure of blood pressure.							
276 (1)	Cross-sectional[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	**Screen-based sedentary behaviors:** Watching **TV** for ≥2 hr/day was not associated with **high blood pressure** (compared to <2 hr/day, Prevalence Ratio = 0.9, 95% CI: 0.5, 1.4, p=0.568) [126].	VERY LOW[c]

[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.

No of partici-pants (No. of studies)	Design	Quality Assessment				Absolute Effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
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).							
1314 (2)	Longitudinal [a]	Serious risk of bias[b]	No serious inconsistency	Serious indirectness[c]	No serious imprecision	**Screen-based sedentary behaviors:** **Higher TV time** (hr/day) at age ~29 mo was unfavorably associated with **standing long jump performance** (cm) at age 97.8 mo (B=-0.361; 95% CI: -0.576, -0.145; p<0.001) [89] and **physical fitness level** (scale from -2 to 2) in Grade 4 (β=-0.09, SE=0.0004; B=-0.01, 95% CI: -0.002, -0.02; p<0.01) [90]. A greater increase in **TV time** (hr/week) between age ~29 and ~53 months was unfavorably associated with **standing long jump performance** (cm) at age 97.8 months (B=-0.285; 95% CI: -0.436,-0.134; p<0.01) [89] and **physical fitness level** (scale from -2 to 2, relative to other children) in Grade 4 (β = -0.10, SE = 0.0003, p<0.01) [90].	VERY LOW[d]

[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 8. High-level summary of findings by health indicator

Health Indicator	Number of Studies	Quality of Evidence	Summary of Findings: Number of studies reporting unfavorable / null / favorable associations with at least 1 health indicator measure by SB type*
Critical			
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)
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:**

			Total sedentary time (accelerometer-derived): null (1)
Cardiometabolic Health	1	Very low	**Screen-based sedentary behaviors:** TV time (duration): null (1)
Fitness	2	Very low	**Screen-based sedentary behaviors:** TV time (duration): unfavorable (2)
Risks / harms	0	N/A	N/A

*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

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