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REVIEW

Combinations of physical activity, sedentary behaviour and sleep: relationships with health indicators in school-aged children and youth[1]

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Abstract: The purpose of this systematic review was to determine how combinations of physical activity (PA), sedentary behaviour (SB), and sleep were associated with important health indicators in children and youth aged 5–17 years. Online databases (MEDLINE, EMBASE, SPORTdiscus, CINAHL, and PsycINFO) were searched for relevant studies examining the relationship between time spent engaging in different combinations of PA, SB, and sleep with the following health indicators: adiposity, cardiometabolic biomarkers, physical fitness, emotional regulation/psychological distress, behavioural conduct/pro-social behaviour, cognition, quality of life/well-being, injuries, bone density, motor skill development, and self-esteem. PA had to be objectively measured, while sleep and SB could be objectively or subjectively measured. The quality of research evidence and risk of bias for each health indicator and for each individual study was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework. A total of 13 cross-sectional studies and a single prospective cohort study reporting data from 36 560 individual participants met the inclusion criteria. Children and youth with a combination of high PA/high sleep/low SB had more desirable measures of adiposity and cardiometabolic health compared with those with a combination of low PA/low sleep/high SB. Health benefits were also observed for those with a combination of high PA/high sleep (cardiometabolic health and adiposity) or high PA/low SB (cardiometabolic health, adiposity and fitness), compared with low PA/low sleep or low PA/high SB. Of the 3 movement behaviours, PA (especially moderate- to vigorous-intensity PA) was most consistently associated with desirable health indicators. Given the lack of randomized trials, the overall quality of the available evidence was low.

Key words: physical activity, sedentary behaviour, sleep, adiposity, cardiometabolic health, fitness.

Résumé : Cette analyse documentaire systématique a pour objectif de déterminer de quelle façon les effets combinés de l'activité physique (« PA »), des comportements sédentaires (« SB ») et du sommeil sont associés à d'importants indicateurs de santé chez des enfants et des jeunes âgés de 5 à 17 ans. On cherche dans les bases de données en ligne (MEDLINE, EMBASE, SPORTdiscus, CINAHL et PsycINFO) les études pertinentes traitant de la relation entre le temps passé à différentes combinaisons de PA, SB et du sommeil et les indicateurs de santé suivants : adiposité, biomarqueurs cardiométaboliques, condition physique, contrôle émotif/détresse psychologique, comportement/comportement prosocial, cognition, qualité de vie/bien-être, blessures, densité osseuse, développement des habiletés motrices et estime de soi. Il faut une mesure objective de PA, mais on peut avoir une mesure objective ou subjective de SB et du sommeil. On évalue par la méthode *Grading of Recommendations Assessment, Development, and Evaluation* (« GRADE ») la qualité des données probantes et le risque de biais de chaque indicateur de santé et de chaque étude individuelle. Au total, 13 études transversales et une seule étude prospective de cohorte présentant des données de 36 560 participants distincts sont conformes aux critères d'inclusion. Les enfants et les jeunes avec une combinaison de PA élevé/sommeil élevé/SB faible présentent plus de mesures souhaitables d'adiposité et de santé cardiométabolique comparativement à ceux avec une combinaison de PA faible/sommeil faible/SB élevé. On observe aussi des bienfaits sanitaires chez les enfants et les jeunes avec une combinaison PA élevé/sommeil élevé (santé cardiométabolique et adiposité) ou PA élevé/SB faible (santé

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cardiométabolique, adiposité et condition physique) comparativement à ceux avec PA faible/sommeil faible ou PA faible/SB élevé. Parmi les trois comportements kinésiques, PA (particulièrement la PA d'intensité modérée à vigoureuse) est régulièrement associée à des indicateurs de santé souhaitables. À cause du manque d'essais aléatoires, la qualité globale des données probantes disponibles est faible. [Traduit par la Rédaction]

Mots-clés : activité physique, comportement sédentaire, sommeil, adiposité, santé cardiométabolique, condition physique.

Introduction

Over the past decade an increasing number of studies have highlighted the independent health benefits of high physical activity (PA), low sedentary behaviour (SB), and sufficient sleep among school-aged children (Cappuccio et al. 2008; Janssen and LeBlanc 2010; Tremblay et al. 2011). Together, these behaviours span the breadth of the movement continuum (Chaput et al. 2014*a*). These findings have led some to suggest that optimal health may be attained among those with certain combinations of movement behaviours (e.g., high PA/high sleep/low SB) (Chaput et al. 2014*a*; Saunders et al. 2014), and to question whether some intermediate combinations may be more beneficial than others (e.g., high PA/high SB vs low PA/low SB) (Ekelund et al. 2012). Researchers have recently begun to compare the health impacts of specific combinations of these movement behaviours, but this evidence has yet to be systematically reviewed or synthesized. Canada is in the process of creating comprehensive movement behaviour guidelines for school-aged children (Chaput et al. 2014*a*). To create evidence-based guidelines and interventions aimed at improving the health of children, it is critical to understand which combinations of PA, SB, and sleep are most strongly associated with physical, mental, and social health. Thus, the purpose of this systematic review was to determine how combinations of different levels of PA, SB, and sleep were associated with health indicators among children and youth aged 5–17 years.

Materials and methods

This systematic review was prospectively registered with PROSPERO (www.crd.york.ac.uk/PROSPERO/; ID: CRD42015015493), and follows the PRISMA guidelines for the transparent reporting of systematic reviews (Moher et al. 2009). This review was performed in parallel with 3 other reviews, synthesizing the current evidence linking physical activity (Poitras et al. 2016), sedentary behaviour (Carson et al. 2016), and sleep (Chaput et al. 2016) with health indicators individually in school-aged children and youth. These 4 reviews were conducted to inform Canadian movement behaviour guidelines for school-aged children and youth (Chaput et al. 2014*a*). Given the scope of these guidelines and large volume of research on each behaviour, it was not feasible to synthesize information on all of the above topics in a single review.

Inclusion criteria

This review targeted apparently healthy school-aged children and youth aged 5–17 years. Study participants were required to have a mean age of 5–17.99 years for at least 1 exposure measurement point, although follow-up measures of health indicators could occur past this age limit. Studies were excluded if they reported exclusively on populations with a clinical diagnosis, or if the behaviour (i.e., PA, SB, and/or sleep) was not measured during the age limits for at least 1 time point.

Studies were eligible for inclusion if they reported any combinations of PA, SB, and sleep. These combinations could not include any other health behaviours (e.g., diet), although such behaviours could be included as covariates in regression analyses. The comparator group had to report some combination of PA, SB, and/or sleep that was different from the intervention/exposure group. Only objective measures of PA (e.g., accelerometry, heart rate monitors, pedometers, arm bands, etc.) were included in this review, while objective and subjective measures were included for both SB and sleep. The decision to restrict to objective measures of PA was made to allow the comparison of *all* intensities of PA (e.g., light-, moderate-, and vigorous-intensity PA), whereas subjective measures of PA typically focus exclusively on moderate- to vigorous-intensity PA (MVPA). Studies assessing PA as total energy expenditure only (e.g., via doubly labelled water or indirect calorimetry) were excluded from this review. Throughout this review, the terms light-intensity physical activity (LPA) and MVPA are used when discussing studies that examined specific exercise intensities. The term PA is used when discussing studies that did not investigate intensity (e.g., studies that simply report steps/day) or when discussing groups of studies including some combination of total PA, LPA, and MVPA. We included all study designs. Observational studies (e.g., cross-sectional, prospective or retrospective cohorts, and case-control studies) were required to have a minimum sample size of 300 participants; randomized controlled trials and other intervention studies were required to have at least 30 participants in the intervention group. For intervention and longitudinal studies, any follow-up length was allowed. There were no other exclusion criteria.

Health indicators

Prior to the search process, health indicators of relevance to movement behaviour guidelines for school-aged children and youth were identified by a 26-member expert group, each with expertise in 1 or more of PA, SB, or sleep, in accordance with the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework (Guyatt et al. 2011*a*). Critical health indicators included measures of adiposity, cardiometabolic biomarkers, physical fitness, emotional regulation/psychological distress, behavioural conduct/pro-social behaviour, cognition, quality of life/well-being, and injuries. Important indicators included bone density, motor skill development, and self-esteem. These health outcomes were standardized with those included in the 3 parallel reviews (Carson et al. 2016; Chaput et al. 2016; Poitras et al. 2016), as well as with reviews performed to inform previous Canadian movement guidelines (Janssen and LeBlanc 2010; Tremblay et al. 2011).

Search strategy

The electronic search strategy was developed in consultation with a librarian with expertise in systematic reviews (Margaret Sampson) and peer reviewed by a second librarian (Linda Slater). The present review was performed in parallel with 3 other systematic reviews in school-aged children, examining the health benefits of PA, SB, and sleep, respectively, which are described in detail elsewhere (Carson et al. 2016; Chaput et al. 2016; Poitras et al. 2016). Briefly, these parallel reviews performed detailed searches of MEDLINE, EMBASE, PsycINFO SPORTDiscus, and CINAHL (for the sleep review only). The full search strategies are available in Supplementary File S1.[2] All articles screened into these other systematic reviews were manually screened to determine eligibility for inclusion in the present review. Further, a new search was performed using the CINAHL database (EbscoHost) on June 2, 2015. This new search targeted combinations of 2 or more movement behaviours.

[2]Supplementary data are available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/apnm-2015-0626.

No date, language, or study design limits were applied (Appendix A1). This additional search was performed to ensure that no relevant PA or SB papers were missed, as the reviews on those topics did not include a search of the CINAHL database. Collaborators were also invited to nominate their own relevant accepted or in-press publications, or those in their libraries. No forward or backward tracking was employed for this review.

Study selection and data collection

Bibliographic records were extracted from the CINAHL interface and imported into Reference Manager Software (Thompson Reuters, San Francisco, Calif., USA). Articles identified as potentially relevant during the screening process of the other 3 systematic reviews (Carson et al. 2016; Chaput et al. 2016; Poitras et al. 2016) were also added to the database for de-duplication. Titles and abstracts of potentially relevant articles were screened by 2 independent reviewers using DistillerSR software (Evidence Partners, Ottawa, Ont., Canada). Potentially eligible articles were obtained for full-text review, which was performed by 2 independent reviewers. Any discrepancies between reviewers were decided by consensus, or by a third reviewer if required. Data extraction was completed by 1 reviewer and checked by another for accuracy. Information was extracted regarding study characteristics (e.g., first author, publication year, study design, country, number of participants, age), type and measure of behaviour (i.e., PA, SB, sleep), and health indicators and results. Reviewers were not blinded to the authors or journals when extracting data.

Quality assessment

The overall quality of research evidence for each health indicator was assessed using the GRADE framework (Balshem et al. 2011). This included assessments of risk of bias (Guyatt et al. 2011*e*), imprecision (Guyatt et al. 2011*b*), inconsistency (Guyatt et al. 2011*d*), and indirectness (Guyatt et al. 2011*c*). GRADE does not have an official tool for assessing quality in observational studies, but does recommend the types of characteristics to consider for the cohort of studies reporting the indicator of interest related to the research question. For risk of bias, this included selection bias (i.e., failure to apply appropriate eligibility criteria), performance bias (e.g., flawed measurement of exposure or outcome), selective reporting bias, and attrition bias (i.e., incomplete follow-up), and other biases (e.g., inadequate control for key confounders). For imprecision, this focused on whether the findings were sufficiently precise to support a recommendation (Guyatt et al. 2011*b*). For inconsistency, we considered all studies reporting the outcome, and examined whether there were differences in the direction of effect that could not be explained by differences in methodology or participant population (Guyatt et al. 2011*d*). And for indirectness, we considered all studies reporting the outcome, and examined whether studies included the populations, interventions, comparators, or outcomes of interest (Guyatt et al. 2011*c*). Factors positively and negatively affecting the quality of individual studies were recorded by 1 reviewer, and reviewed by another. Across all studies reporting a health indicator of interest, we evaluated the quality of the evidence for that indicator. Following the GRADE framework, the quality of evidence ratings began as high when summarizing evidence from randomized controlled trials (RCTs) and low for all other study designs. The quality of evidence was downgraded for any health indicator if there were limitations because of risk of bias, inconsistency, indirectness, imprecision, or other factors. If there were no serious overall quality of evidence limitations identified, all studies could be upgraded based on large effect sizes, while nonrandomized studies could be upgraded based on dose–response evidence, and cross-sectional studies could be upgraded based on a gradient of higher exposure with higher/lower outcome. Overall quality of evidence for each study design within each health indicator was evaluated by 1 reviewer and verified by the larger review team. Quality assessments using GRADE should be interpreted in the light of the outcome explored and the kind of study designs that are possible. For example, it would not be ethical to deprive children of sleep or physical activity, so some kinds of RCTs are not possible, placing increased focus on studies using observational designs.

Data synthesis

Meta-analyses were planned for results that were sufficiently homogeneous in terms of statistical, clinical, and methodological characteristics. However, it was determined that a meta-analysis was not possible because of high levels of heterogeneity for the above characteristics across studies, and a narrative synthesis was performed for each health indicator instead.

Results

Description of studies

A total of 489 unique citations were eligible for inclusion (134 from CINAHL, 352 identified during the screening process of the 3 parallel systematic reviews, and 3 nominated by the research team) (Fig. 1). After title and abstract review, 71 papers remained and were retrieved for full-text review. Of those, 57 articles were excluded for failing to include a combination of movement behaviours ($n = 50$); failing to assess the relationship between movement behaviours and the predefined health indicators ($n = 2$); having fewer than 300 participants for observational studies ($n = 2$) or 30 participants for intervention studies ($n = 1$); failing to report data related to indicators or outcomes of interest ($n = 2$); having participants outside the target age group ($n = 1$); and subjective measurement of PA ($n = 1$). Some studies were excluded for multiple reasons.

After screening, 14 studies reporting data from 9 different datasets met all inclusion criteria (See Table 1). These papers presented results from 36 560 individual participants from 20 countries. Hjorth et al. (2014*a*) employed a longitudinal design with a 200-day follow-up, while all other studies employed cross-sectional designs. All studies were published in 2008 or later, with participants ranging from 4–18 years of age (the mean age was between 5.0 and 17.9 years). Of the 14 included studies, 10 reported on adiposity (Aggio et al. 2015; Chaput et al. 2014*b*; De Bourdeaudhuij et al. 2013; Ekelund et al. 2012; Herman et al. 2014; Hjorth et al. 2014*b*; Katzmarzyk et al. 2015; Laurson et al. 2008, 2014; Loprinzi et al. 2015), 3 on cardiometabolic risk factors (de Moraes et al. 2013; Ekelund et al. 2012; Hjorth et al. 2014*a*), and 3 on cardiorespiratory or musculoskeletal fitness (Aggio et al. 2015; Martinez-Gomez et al. 2011; Santos et al. 2014). Two papers (Aggio et al. 2015; Ekelund et al. 2012) reported on more than 1 indicator. We did not identify any papers reporting the relationship between combinations of movement behaviours and emotional regulation/psychological distress, behavioural conduct/pro-social behaviour, cognition, quality of life/well-being, or injuries.

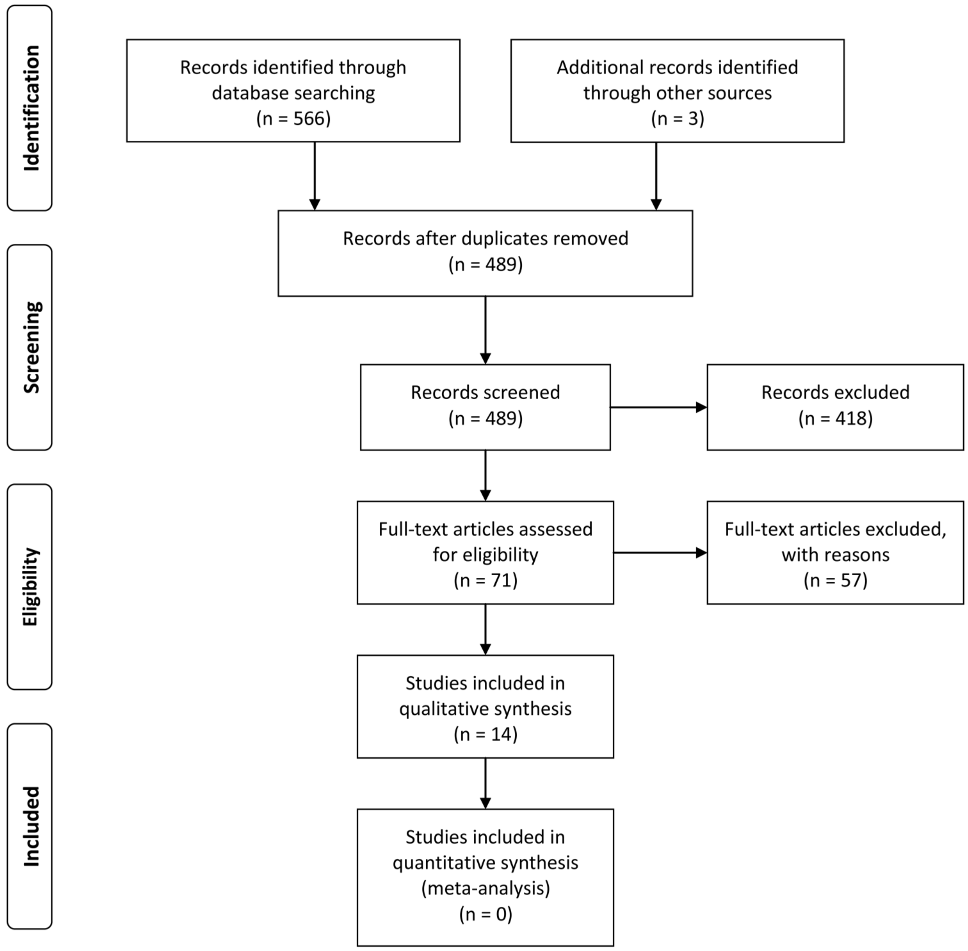
Measurement of movement behaviours

PA was measured with pedometers in 2 studies (Laurson et al. 2008, 2014), while the rest used accelerometers. SB was objectively measured using accelerometers in 12 studies (Aggio et al. 2015; Chaput et al. 2014*b*; De Bourdeaudhuij et al. 2013; de Moraes et al. 2013; Ekelund et al. 2012; Martinez-Gomez et al. 2011; Herman et al. 2014; Hjorth et al. 2014*a*, 2014*b*; Katzmarzyk et al. 2015; Loprinzi et al. 2015; Santos et al. 2014), and self-reported in 4 studies (Herman et al. 2014; Hjorth et al. 2014*b*; Laurson et al. 2008, 2014). Two studies (Herman et al. 2014; Hjorth et al. 2014*b*) included both self-reported and objective measures of SB. Sleep was objectively measured in 3 studies (Chaput et al. 2014*b*; Hjorth et al. 2014*a*, 2014*b*), and self-reported in 1 study (Laurson et al. 2014).

Adiposity

Adiposity was reported in 10 cross-sectional studies, representing 7 unique datasets, and 30 746 individual participants (Aggio

Fig. 1. PRISMA flow diagram for the identification, screening, eligibility, and inclusion of studies.



et al. 2015; Chaput et al. 2014*b*; De Bourdeaudhuij et al. 2013; Ekelund et al. 2012; Herman et al. 2014; Hjorth et al. 2014*b*; Katzmarzyk et al. 2015; Laurson et al. 2008, 2014; Loprinzi et al. 2015) (Table 2). Mean ages from individual studies ranged from 9.3–11.6 years. Three studies (Chaput et al. 2014*b*; Hjorth et al. 2014*b*; Laurson et al. 2014) assessed combinations of all 3 movement behaviours; 1 examined steps/day (Laurson et al. 2014), while the others (Chaput et al. 2014*b*; Hjorth et al. 2014*b*) focused on MVPA. All 3 of these studies reported that individuals with a combination of high PA/low SB/high sleep had lower adiposity and/or risk of overweight than those with a combination of low PA/high SB/low sleep. One study (Laurson et al. 2014) also reported that in comparison with meeting all 3 recommended guidelines for steps/day, screen time, and sleep, meeting 2, 1, or none of the guidelines was associated with 2.6 (95% confidence interval (CI): 1.1–6.5), 4.7 (95% CI: 1.9–11.3), and 8.2 (95% CI: 3.2–32.1) times increased odds of obesity, respectively.

Eight studies (Aggio et al. 2015; De Bourdeaudhuij et al. 2013; Ekelund et al. 2012; Herman et al. 2014; Hjorth et al. 2014*b*; Katzmarzyk et al. 2015; Laurson et al. 2008; Loprinzi et al. 2015) assessed different combinations of PA and SB. All 8 studies reported that individuals with a combination of high PA/low SB had lower measures of adiposity and/or reduced prevalence of overweight/obesity than those with low PA/high SB. Of these, 4 studies (De Bourdeaudhuij et al. 2013; Ekelund et al. 2012; Katzmarzyk et al. 2015; Laurson et al. 2008) found that for at least 1 subgroup of participants, those with a high PA tended to have lower levels of adiposity when compared with those with low PA, regardless of their level of SB. Two studies (Aggio et al. 2015; Loprinzi et al. 2015) used isotemporal substitution analysis to estimate the impact of replacing 60 min of SB with LPA or MVPA, or vice versa. Both studies reported that replacing 60 min/day of SB or LPA with MVPA was associated with 4%–5% lower body fat percentage in children but not adolescents. Replacing SB with LPA was not associated with adiposity in either age group.

One study (Hjorth et al. 2014*b*) assessed different combinations of sleep, MVPA, self-reported screen time, and accelerometer-derived sedentary time. In comparison with children in the high sleep/high MVPA group, they reported that those in the low sleep/low MVPA group had a 2.17 kg/m^2 higher fat mass index. However, there were no significant differences in fat mass index between the high sleep/low SB and low sleep/high SB groups, irrespective of whether SB was assessed as self-reported screen time or as accelerometer derived sedentary time.

Given the observational nature of the cohort of papers on adiposity, the quality rating for this health indicator began as low, according to the GRADE protocol. These papers showed no serious risk of bias, inconsistency, indirectness, or imprecision and therefore the evidence was not downgraded from the initial rating of low quality.

Cardiometabolic health

The relationship between movement behaviours and risk factors for the metabolic syndrome and cardiovascular disease was assessed in 1 longitudinal study with a 200-day follow-up (Hjorth et al. 2014*a*) in 632 Danish children aged 8–11 years (Table 3). In comparison with children who increased their MVPA and sleep and reduced their SB, children who *reduced* their MVPA and sleep while *increasing* their SB had a 3.31 unit increase in their metabolic

Table 1. Characteristics of included studies.

Authors	Year	Design	Location	Age range, y	Mean age, y	*N*	PA measure	Sleep measure	SB measure	Outcome
Laurson et al. 2014[a]	2014	X-Sectional	United States	7–12		674	Pedometer	Questionnaire	Computer + video game time	Adiposity
Laurson et al. 2008[a]	2008	X-Sectional	United States		9.7	709	Pedometer		Screen time	Adiposity
Herman et al. 2014	2014	X-Sectional	Canada	8–10		534	Accelerometer		Screen time + accelerometer	Adiposity
De Bourdeaudhuij et al. 2013	2013	X-Sectional	Belgium, Greece, Hungary, the Netherlands, and Switzerland		11.6	766	Accelerometer		Accelerometer	Adiposity
Ekelund et al. 2012[b]	2012	X-Sectional	Australia, Brazil, United Kingdom, Switzerland, Denmark, Estonia, Switzerland, Scotland, Norway, Portugal, and United States	4–18		20 871	Accelerometer		Accelerometer	Adiposity + CMB
Martinez-Gomez et al. 2011[c]	2011	X-Sectional	Austria, Belgium, France, Germany, Greece, Hungary, Italy, Spain, and Sweden		14.7	1808	Accelerometer		Accelerometer	CRF
Santos et al. 2014	2014	X-Sectional	Portugal	10–18		2506	Accelerometer		Accelerometer	CRF
Hjorth et al. 2014a[d]	2014	Longitudinal	Denmark		10.0	632	Accelerometer	Accelerometer	Accelerometer	CMB
Chaput et al. 2014b[e]	2014	X-Sectional	Canada		10.0	507	Accelerometer	Accelerometer	Accelerometer	Adiposity
Hjorth et al. 2014b[d]	2014	X-Sectional	Denmark		10.0	785	Accelerometer	Accelerometer	Accelerometer + questionnaire	Adiposity
de Moraes et al. 2013[c]	2013	X-Sectional	Austria, Belgium, France, Germany, Greece, Hungary, Italy, Spain, and Sweden		14.8	3308	Accelerometer		Accelerometer	CMB
Loprinzi et al. 2015[b]	2015	X-Sectional	United States	6–17		2644	Accelerometer		Accelerometer	Adiposity
Aggio et al. 2015	2015	X-Sectional	United Kingdom		9.3	353	Accelerometer		Accelerometer	Adiposity + MSK
Katzmarzyk et al. 2015[e]	2015	X-Sectional	Australia, Brazil, Canada, China, Colombia, Finland, India, Kenya, Portugal, South Africa, United Kingdom, and United States	9–11	10.4	6539	Accelerometer		Accelerometer	Adiposity

Note: Studies with the same postscript used the same underlying dataset for at least a portion of the included participants. CMB, cardiometabolic health; CRF, cardiorespiratory fitness; MSK, musculoskeletal fitness.

Table 2. GRADE table showing association between combinations of movement behaviours and body composition in school-aged children and youth.

No. of studies	Design	Quality assessment					No. of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
10[a]	Cross-sectional[b]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	None	30 746	***SB+PA+SLEEP*** (Laurson et al. 2014; Chaput et al. 2014*b*; Hjorth et al. 2014*b*) 3/3 studies reported higher markers of adiposity and/or prevalence of overweight/obesity among those with high PA/low SB/high sleep compared with low PA/high SB/low sleep. Hjorth et al. (2014*a*) reported that these associations were significant when using accelerometer-derived sedentary time, but not self-reported screen time. Chaput et al. (2014*b*) also reported higher body fat and waist-to-height ratio in the low PA/low SB/high sleep group, when compared with the high PA/low SB/high sleep group. Laurson et al. (2014) reported that in comparison with meeting recommended guidelines for steps/day, screen time, and sleep, meeting 2, 1, or 0 of the guidelines was associated with increased odds of obesity in a dose response fashion ***PA+SB*** (Laurson et al. 2008; Ekelund et al. 2012; De Bourdeaudhuij et al. 2013; Herman et al. 2014; Hjorth et al. 2014*b*; Loprinzi et al. 2015; Katzmarzyk et al. 2015) 6/6 studies focusing on children reported that those with high PA/low SB had lower measures of adiposity and/or reduced prevalence of overweight/obesity than those with low PA/high SB. 3/6 studies in children (Laurson et al. 2008, De Bourdeaudhuij et al. 2013, Katzmarzyk et al. 2015) found that categories with high PA tended to have lower levels of adiposity when compared with those with low PA, irrespective of SB Studying both children and adolescents, Ekelund et al. (2012) found high levels of MVPA were beneficially associated with waist circumference irrespective of SB levels, while Loprinzi et al. (2015) reported no differences in BMI, waist circumference, or skinfolds across MVPA and SB categories in adolescents Isotemporal substitution models were used to compare the impact of substituting MVPA, LPA, or SB in children and youth (Loprinzi et al. 2015) and children (Aggio et al. 2015). 2/2 studies reported that replacing 60 min/d of SB or LPA with MVPA was associated with lower markers of adiposity in children (but not adolescents). Replacing SB with LPA was not associated with markers of adiposity in either age group ***PA+SLEEP*** (Hjorth et al. 2014*b*) 1/1 study reported lower fat mass index in the high sleep/high MVPA group when compared with low sleep/low MVPA ***SB+SLEEP*** (Hjorth et al. 2014*b*) 1/1 study reported no differences for low sleep/high screen time vs high sleep/low screen time, or low sleep/high sedentary time vs high sleep/low sedentary time Because of heterogeneity in study design, presentation of data, and measures of body composition, a meta-analysis was not possible	Low

Note: Mean ages ranged from 9.3–11.6 years, all data collection was cross-sectional. Sedentary behaviour assessed via accelerometer and self-reported screen time. Physical activity was assessed via accelerometer and pedometer. Sleep was assessed via self-report questionnaire and accelerometer. Adiposity was assessed via measured height and weight, waist circumference, waist-to-height ratio, body fat % (bio-electrical impedance and dual-energy X-ray absorptiometry scans) and skinfolds. BMI, body mass index; GRADE, Grading of Recommendations Assessment, Development, and Evaluation; LPA, light-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; PA, physical activity; SB, sedentary behaviour.

[a]Two studies (Laurson et al. 2008, 2014) used data from the SWITCH intervention. Two studies used data from the International Study of Childhood Obesity, Lifestyle, and the Environment (ISCOLE) study, although one (Chaput et al. 2014*b*) used only the Canadian data, while one (Katzmarzyk et al. 2015) used data from 12 countries. Two studies used the National Health and Nutrition Examination Survey (NHANES) survey, although one (Loprinzi et al. 2015) used only the NHANES, while another (Ekelund et al. 2012) combined the NHANES with other data from the International Children's Accelerometry Database (ICAD) database. Participants in Loprinzi et al. (2015) Chaput et al. (2014*b*)), and Laurson et al. (2014) have not been included in "Number of Participants" column to avoid double-counting of the same individuals.

[b]Includes 10 cross-sectional studies: Laurson et al. (2008, 2014), Ekelund et al. (2012), De Bourdeaudhuij et al. (2013), Herman et al. (2014), Chaput et al. (2014*b*), Hjorth et al. (2014*b*), Loprinzi et al. (2015), Aggio et al. (2015), Katzmarzyk et al. (2015).

Table 3. GRADE table showing association between combinations of movement behaviours and metabolic syndrome/cardiovascular disease risk factors in school-aged children and youth.

No. of studies	Design	Quality assessment					No of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
1	Longitudinal[a]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	None	632	***PA+SB+SLEEP*** (Hjorth et al. 2014*a*) In comparison with those with increased SB/decreased sleep/decreased MVPA, those with decreased SB/increased sleep/increased MVPA had 3.3 unit reduction in metabolic syndrome score over 200-d follow-up ***PA+SB*** (Hjorth et al. 2014*a*) Decreased SB/increased MVPA was associated with lower metabolic syndrome score over 200-d follow-up when compared with increased SB/decreased MVPA ***PA+SLEEP*** (Hjorth et al. 2014*a*) Increased sleep/increased MVPA was associated with lower metabolic syndrome score over 200-d follow-up when compared with decreased sleep/decreased MVPA ***SB+SLEEP*** (Hjorth et al. 2014*a*) Increased sleep/decreased SB was associated with lower metabolic syndrome score over 200-d follow-up when compared with the decreased sleep/increased SB	Low
2	Cross-sectional[b]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	None	24 179	***PA+SB*** (Ekelund et al. 2012; de Moraes et al. 2013) Ekelund et al. (2012) found that higher tertiles of MVPA were associated with lower SBP, fasting insulin, and fasting TGs, and higher values of HDL cholesterol across tertiles for sedentary time. Sedentary tertiles were unrelated to these risk factors after adjusting for time spent MVPA de Moraes et al. (2013) reported higher SBP in females with high MVPA/high SB vs low MVPA/high SB. They found no other associations between behaviour combinations and SBP in females or males, and no associations between movement combinations and DBP in either sex Because of heterogeneity in study design, presentation of data, and measures of risk factors, a meta-analysis was not possible	Low

Note: Ages ranging from 4–18 years, data collection cross-sectionally and longitudinally up to 200 day follow-up. Sedentary behaviour, MVPA, and sleep assessed via accelerometer. Systolic, diastolic, and mean arterial blood pressure, fasting insulin, TGs, HDL-cholesterol, and homeostatic model assessment of insulin resistance were directly measured. DBP, diastolic blood pressure; GRADE, Grading of Recommendations Assessment, Development, and Evaluation; HDL, high-density lipoprotein; LPA, light-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; PA, physical activity; SB, sedentary behaviour; SBP, systolic blood pressure; TG, triglyceride.

[a]Includes 1 longitudinal study: Hjorth et al. (2014*a*).

[b]Includes 2 cross-sectional studies: Ekelund et al. (2012), de Moraes et al. (2013).

syndrome score (calculated as the sum of z scores for waist circumference mean arterial pressure, homeostasis model of assessment insulin resistance, triglycerides, and high-density lipoprotein (HDL) cholesterol) over the 200-day follow-up. Similarly, in comparison with those who showed beneficial changes in any 2 movement behaviours (e.g., increased MVPA, increased sleep, or reduced sedentary time), children who demonstrated deleterious changes in any 2 behaviours experienced significant increases in metabolic syndrome score over the 200-day follow-up.

Two cross-sectional studies (Ekelund et al. 2012; de Moraes et al. 2013) examined the relationship between movement behaviours and cardiometabolic risk factors in 24 179 children and youth from 18 countries. One study (Ekelund et al. 2012) found that those in higher tertiles of MVPA had lower systolic blood pressure, fasting insulin and fasting triglycerides, and higher values of HDL cholesterol across tertiles of SB. SB was unrelated to these risk factors after adjusting for time spent in MVPA. In contrast, the other study (de Moraes et al. 2013) reported higher systolic blood pressure in females with high MVPA/high SB versus low MVPA/high SB. They found no other associations between movement combinations and systolic or diastolic blood pressure in either sex.

Because of the observational design of the cohort of studies examining cardiometabolic risk factors, this evidence began with a low-quality rating. These papers showed no serious risk of bias, inconsistency, indirectness, or imprecision and were therefore not downgraded from the initial rating of low quality.

Cardiorespiratory fitness

Two cross-sectional studies involving 4314 children and adolescents aged 10–18 years (Martinez-Gomez et al. 2011; Santos et al. 2014) examined combinations of movement behaviours associations with cardiorespiratory fitness (Table 4). Both studies reported that participants in both the high MVPA/low SB and low MVPA/low SB groups had higher odds of having a high cardiorespiratory fitness compared with those with low MVPA/high SB, although in 1 study (Martinez-Gomez et al. 2011) this was observed in females only. Both studies also reported higher maximal oxygen uptake in the high MVPA/low SB group, compared with the low MVPA/high SB group, although 1 study (Martinez-Gomez et al. 2011) observed this in females only.

Musculoskeletal fitness

One cross-sectional study of 353 participants employed isotemporal substitution models to estimate the impact of replacing 60 min of SB with LPA or MVPA, or vice versa, on musculoskeletal fitness (Aggio et al. 2015). The estimates from the isotemporal substitution models suggested that replacing 60 min/day of SB with MVPA was associated with a 16-cm longer horizontal jump distance, and a 4.7-cm greater sit and reach flexibility score. There was no influence on grip strength when replacing SB or LPA with MVPA, or on any indicator when replacing SB with LPA.

The evidence related to cardiorespiratory and musculoskeletal fitness began with a low-quality rating because of the observational design of the relevant papers. These papers showed no serious risk of bias, inconsistency, indirectness, or imprecision and were therefore not downgraded from the initial rating of low quality.

Discussion

The purpose of this systematic review was to determine how combinations of different levels of PA, SB, and sleep were associated with health indicators in children and youth aged 5–17 years. Children and youth with a combination of high PA/high sleep/low SB (best combination) had favourable measures of adiposity and cardiometabolic health, when compared with those with a combination of low PA/low sleep/high SB (worst combination). We also observed that high PA/high sleep (cardiometabolic health and

Table 4. GRADE table showing association between combinations of movement behaviours and fitness in school-aged children and youth.

No. of studies	Design	Quality assessment: Risk of bias	Inconsistency	Indirectness	Imprecision	Other	No of participants	Absolute effect	Quality
3	Cross-sectional[a]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	None	4667	***PA+SB*** (Martinez-Gomez et al. 2011; Santos et al. 2014; Aggio et al. 2015) 2/2 studies in adolescents (Martinez-Gomez et al. 2011; Santos et al. 2014) reported that both the high MVPA/low SB and low MVPA/low SB groups had higher odds of having high cardiorespiratory fitness compared with those with low MVPA/high SB, although in 1 study (Martinez-Gomez et al. 2011) this was seen in females only. 2/2 studies reported higher $\dot{V}O_{2max}$ in the high MVPA/low SB group compared with the low MVPA/high SB group, although 1 study (Martinez-Gomez et al. 2011) saw this only in females Isotemporal substitution models were used in one study in children (Aggio et al. 2015). Replacing 60 min/d of SB or LPA with MVPA was associated with greater horizontal jump distance and flexibility. Replacing SB or LPA with MVPA was not associated with grip strength, and no outcomes were associated with replacing SB with LPA Because of heterogeneity in study design, presentation of data, and measures of fitness, a meta-analysis was not possible	LOW

Note: Range of mean ages 9.3–14.7 years. Data collection was cross-sectional. Sedentary behaviour and MVPA assessed via accelerometer. Cardiorespiratory fitness assessed via 20-m shuttle run. Leg power was measured via a horizontal jump test. Flexibility was determined using a sit-and-reach test. GRADE, Grading of Recommendations Assessment, Development, and Evaluation; LPA, light-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; PA, physical activity; SB, sedentary behaviour; $\dot{V}O_{2max}$, maximal oxygen uptake.

[a]Includes 3 cross-sectional studies: Martinez-Gomez et al. (2011), Santos et al. (2014), Aggio et al. (2015).

adiposity), and high PA/low SB (cardiometabolic health, adiposity, and fitness) were also associated with better health indicators when compared with the opposing combinations. High sleep/low SB was associated with more favourable markers of cardiometabolic health, but not adiposity, compared with low sleep/high SB. These findings suggest that there may be synergistic benefits to achieving optimal levels for multiple movement behaviours. This was illustrated most clearly by Laurson et al. (2014), who found that in comparison with meeting recommended guidelines for steps/day, screen time, and sleep, meeting 2, 1, or none of the guidelines was associated with higher odds of obesity in a graded fashion.

Our results also suggest that among the 3 movement behaviours, health benefits were most consistently associated with high levels of PA, and especially MVPA. Four of 8 studies comparing combinations of PA and SB reported that individuals with high PA tended to have lower levels of adiposity when compared with those with low PA, regardless of their level of SB (De Bourdeaudhuij et al. 2013; Ekelund et al. 2012; Katzmarzyk et al. 2015; Laurson et al. 2008). For example, 2 isotemporal substitution studies suggested that replacing 60 min/day of SB or LPA with MVPA would be associated with favourable changes in markers of adiposity (Aggio et al. 2015; Loprinzi et al. 2015) and better musculoskeletal fitness in children (Aggio et al. 2015), whereas replacing SB with LPA was not projected to result in any benefits for either health indicator. However, it should be noted that these were the only 2 studies to investigate LPA specifically. Taken together, these findings suggest that optimal health improvements are likely to be seen by replacing SB with MVPA, and warrant investigation via well-controlled intervention studies.

Areas for future research

The present review identified several important research gaps in the published literature. First, we were unable to identify any studies examining the relationship between combinations of objectively measured PA and objectively or subjectively measured SB and sleep with bone density, motor skill development, or any psycho-social outcomes. Aside from adiposity, we identified few papers examining *any* health indicator. Thus, at present it remains unclear how different combinations of PA, SB, and sleep relate to these important health indicators in the school-aged population.

Further, the majority of studies compared only the best and worst combinations of behaviours (e.g., high PA/high sleep/low SB vs low PA/low sleep/high SB), without directly comparing intermediate combinations. Thus, while children and youth with the combination of high PA/high sleep/low SB are likely healthier than those with low PA/low sleep/high SB, it is unclear how they compare to children with low PA/high sleep/low SB, or other intermediate combinations. Another approach could compare the health of children meeting guidelines for 1, 2, or all 3 movement behaviours, as done by Laurson et al. (2014). However, in that study, the authors simply examined the benefits of meeting 1 or more guideline, with all guidelines being treated as equivalent. To date, no one has examined whether meeting the guidelines for specific behaviours (e.g., sleep vs PA vs SB) have similar associations with health indicators in school-aged children and youth. Finally, only 4 studies (representing 3 separate datasets) looked at combinations of all 3 movement behaviours, with the majority of included studies focusing on only 2 behaviours (typically PA and SB).

The available evidence suggests that optimal health benefits may come from replacing SB with MVPA. However, these findings are based on cross-sectional observational studies. Longitudinal and intervention studies are needed to better clarify the benefits of replacing time in 1 movement behaviour with time in another, and also to determine the potential impacts to time-use and behavioural compensation (e.g., diet) in response to such an intervention. Future studies may also benefit from including both objective and subjective measures of movement behaviours, as this may provide more relevant information than studies using one or the other and allow for more direct comparisons with existing literature (Saunders et al. 2014). Finally, novel statistical approaches (e.g., compositional analyses) may also help to better identify the optimal combination of movement behaviours, while avoiding issues of collinearity that are encountered with conventional regression models (Chastin et al. 2015).

Strengths and limitations

The present systematic review has several strengths and limitations. This review employed a rigorous and systematic methodology, which was prospectively registered using PROSPERO (CRD42015015493), and followed the PRISMA guidelines (Moher et al. 2009) and GRADE methodology (Higgins and Green 2011). The search strategy was developed in consultation with a research librarian with expertise in systematic review methodologies (Margaret Sampson). Despite the comprehensive search process, we did not investigate grey or other unpublished literature, which may have resulted in some relevant studies being left out. However, grey literature is itself limited by being poorly indexed, poorly reported, and the risk of changes in results from abstract to full publication; therefore, we do not believe that inclusion of grey literature would have materially changed our findings. Consistent with the other reviews done in parallel with the present review, only studies including objective measures of PA were included. This inclusion criterion may have excluded some relevant studies from the current analysis, in particular those addressing psycho-social health indicators. Finally, the strength of our conclusions is limited by the small number of included studies and total lack of intervention studies assessing movement behaviours during the full 24-h period.

Conclusions

Our findings suggest that school-aged children and youth characterized by high PA/high sleep/low SB generally have more desirable measures of adiposity and cardiometabolic health, when compared with those with a combination of low PA/low sleep/high SB. Further, those with high PA/high sleep, and high PA/low SB are also likely to experience health benefits, when compared with low PA/low sleep, or low PA/high SB. Optimal health benefits may come from replacing SB with MVPA, although this requires investigation in intervention studies. However, the overall quality of the available research evidence is low. Longitudinal and intervention studies, and those using novel statistical methodologies, are needed to better clarify these relationships and to determine the potential health benefits of various combinations of movement behaviours.

Conflict of interest statement

Michelle E. Kho received an honorarium for methodological input to guideline development. Travis J. Saunders has received research and/or in-kind support from StepsCount, Pacific Rim Wellness, and Ergotron. The other authors declare that they have no conflicts of interest.

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References

Aggio, D., Smith, L., and Hamer, M. 2015. Effects of reallocating time in different activity intensities on health and fitness: a cross sectional study. Int. J. Behav. Nutr. Phys. Act. **12**(1): 83. doi:10.1186/s12966-015-0249-6. PMID:26104041.

Balshem, H., Helfand, M., Schünemann, H.J., Oxman, A.D., Kunz, R., Brozek, J., et al. 2011. GRADE guidelines: 3. Rating the quality of evidence. J. Clin. Epidemiol. **64**(4): 401–406. doi:10.1016/j.jclinepi.2010.07.015. PMID:21208779.

Cappuccio, F.P., Taggart, F.M., Kandala, N.-B., Currie, A., Peile, E., Stranges, S., and Miller, M.A. 2008. Meta-analysis of short sleep duration and obesity in children and adults. Sleep, **31**(5): 619–626. PMID:18517032.

Carson, V., Hunter, S., Kuzik, N., Gray, C.E., Poitras, V.J., Chaput, J.-P., et al. 2016. Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update. Appl. Physiol. Nutr. Metab. **41**: This issue. doi:10.1139/apnm-2015-0630.

Chaput, J.-P., Carson, V., Gray, C.E., and Tremblay, M.S. 2014*a*. Importance of all movement behaviors in a 24 hour period for overall health. Int. J. Environ. Res. Public. Health **11**(12): 12575–12581. doi:10.3390/ijerph111212575.

Chaput, J.-P., Leduc, G., Boyer, C., Bélanger, P., LeBlanc, A.G., Borghese, M.M., and Tremblay, M.S. 2014*b*. Objectively measured physical activity, sedentary time and sleep duration: independent and combined associations with adiposity in canadian children. Nutr. Diabetes, **4**(6): e117. doi:10.1038/nutd.2014.14.

Chaput, J.-P., Gray, C.E., Poitras, V.J., Carson, V., Gruber, R., Olds, T., et al. 2016. Systematic review of the relationships between sleep duration and health indicators in school-aged children and youth. Appl. Physiol. Nutr. Metab. **41**: This issue. doi:10.1139/apnm-2015-0627.

Chastin, S.F.M., Palarea-Albaladejo, J., Dontje, M.L., and Skelton, D.A. 2015. Combined effects of time spent in physical activity, sedentary behaviors and sleep on obesity and cardio-metabolic health markers: a novel compositional data analysis approach. PLoS ONE, **10**(10): e0139984. doi:10.1371/journal.pone.0139984. PMID:26461112.

De Bourdeaudhuij, I., Verloigne, M., Maes, L., Van Lippevelde, W., Chinapaw, M.J.M., te Velde, S.J., et al. 2013. Associations of physical activity and sedentary time with weight and weight status among 10- to 12-year-old boys and girls in Europe: a cluster analysis within the ENERGY project. Pediatr. Obes. **8**(5): 367–375. doi:10.1111/j.2047-6310.2012.00117.x. PMID:23239600.

de Moraes, A.C.F., Carvalho, H.B., Rey-López, J.P., Gracia-Marco, L., Beghin, L., Kafatos, A., et al. 2013. Independent and combined effects of physical activity and sedentary behavior on blood pressure in adolescents: gender differences in two cross-sectional studies. PLoS ONE, **8**(5): e62006. doi:10.1371/journal.pone.0062006. PMID:23650506.

Ekelund, U., Luan, J., Sherar, L.B., Esliger, D.W., Griew, P., and Cooper, A. 2012. Moderate to vigorous physical activity and sedentary time and cardiometabolic risk factors in children and adolescents. JAMA, **307**(7): 704–712. doi:10.1001/jama.2012.156. PMID:22337681.

Guyatt, G.H., Oxman, A.D., Kunz, R., Atkins, D., Brozek, J., Vist, G., et al. 2011*a*. GRADE guidelines: 2. Framing the question and deciding on important outcomes. J. Clin. Epidemiol. **64**(4): 395–400. PMID:21194891.

Guyatt, G.H., Oxman, A.D., Kunz, R., Brozek, J., Alonso-Coello, P., Rind, D., et al. 2011*b*. GRADE guidelines 6. Rating the quality of evidence—imprecision. J. Clin. Epidemiol. **64**(12): 1283–1293. doi:10.1016/j.jclinepi.2011.01.012. PMID:21839614.

Guyatt, G.H., Oxman, A.D., Kunz, R., Woodcock, J., Brozek, J., Helfand, M., et al. 2011*c*. GRADE guidelines: 8. Rating the quality of evidence—indirectness. J. Clin. Epidemiol. **64**(12): 1303–1310. doi:10.1016/j.jclinepi.2011.04.014. PMID:21802903.

Guyatt, G.H., Oxman, A.D., Kunz, R., Woodcock, J., Brozek, J., Helfand, M., et al. 2011*d*. GRADE guidelines: 7. Rating the quality of evidence—inconsistency. J. Clin. Epidemiol. **64**(12): 1294–1302. doi:10.1016/j.jclinepi.2011.03.017. PMID:21803546.

Guyatt, G.H., Oxman, A.D., Vist, G., Kunz, R., Brozek, J., Alonso-Coello, P., et al. 2011*e*. GRADE guidelines: 4. Rating the quality of evidence—study limitations (risk of bias). J. Clin. Epidemiol. **64**(4): 407–415. doi:10.1016/j.jclinepi.2010.07.017. PMID:21247734.

Herman, K.M., Sabiston, C.M., Mathieu, M.-E., Tremblay, A., and Paradis, G. 2014. Sedentary behavior in a cohort of 8- to 10-year-old children at elevated risk of obesity. Prev. Med. **60**: 115–120. doi:10.1016/j.ypmed.2013.12.029. PMID:24398174.

Higgins, J., and Green, S. (*Editors*). 2011. Cochrane Handbook for Systematic Reviews of Interventions. Version 5.1.0 [updated March 2011]. The Cochrane Collaboration. Available from www.cochrane-handbook.org. [Accessed 19 October 2015.]

Hjorth, M.F., Chaput, J.-P., Damsgaard, C.T., Dalskov, S.-M., Andersen, R., Astrup, A., et al. 2014*a*. Low physical activity level and short sleep duration are associated with an increased cardio-metabolic risk profile: a longitudinal study in 8-11 year old Danish children. PLoS ONE, **9**(8): e104677. doi:10.1371/journal.pone.0104677. PMID:25102157.

Hjorth, M.F., Chaput, J.-P., Ritz, C., Dalskov, S.-M., Andersen, R., Astrup, A., et al. 2014*b*. Fatness predicts decreased physical activity and increased sedentary time, but not vice versa: support from a longitudinal study in 8- to 11-year-old children. Int. J. Obes. **38**(7): 959–965. doi:10.1038/ijo.2013.229. PMID:24304596.

Janssen, I., and LeBlanc, A.G. 2010. Systematic review of the health benefits of physical activity and fitness in school-aged children and youth. Int. J. Behav. Nutr. Phys. Act. **7**(1): 40. doi:10.1186/1479-5868-7-40. PMID:20459784.

Katzmarzyk, P.T., Barreira, T.V., Broyles, S.T., Champagne, C.M., Chaput, J.-P., Fogelholm, M., et al. 2015. Physical activity, sedentary time, and obesity in an international sample of children. Med. Sci. Sports Exerc. **47**(10): 2062–2069. doi:10.1249/MSS.0000000000000649. PMID:25751770.

Laurson, K.R., Eisenmann, J.C., Welk, G.J., Wickel, E.E., Gentile, D.A., and Walsh, D.A. 2008. Combined influence of physical activity and screen time recommendations on childhood overweight. J. Pediatr. **153**(2): 209–214. doi:10.1016/j.jpeds.2008.02.042. PMID:18534231.

Laurson, K.R., Lee, J.A., Gentile, D.A., Walsh, D.A., and Eisenmann, J.C. 2014. Concurrent associations between physical activity, screen time, and sleep duration with childhood obesity. ISRN Obes. **2014**: ID 204540. doi:10.1155/2014/204540. PMID:24734210.

Loprinzi, P.D., Cardinal, B.J., Lee, H., and Tudor-Locke, C. 2015. Markers of adiposity among children and adolescents: implications of the isotemporal substitution paradigm with sedentary behavior and physical activity patterns. J. Diabetes Metab. Disord. **14**(1): 46. doi:10.1186/s40200-015-0175-9. PMID:26034720.

Martinez-Gomez, D., Ortega, F.B., Ruiz, J.R., Vicente-Rodriguez, G., Veiga, O.L., Widhalm, K., et al. 2011. Excessive sedentary time and low cardiorespiratory fitness in European adolescents: the HELENA study. Arch. Dis. Child. **96**: 240–246. doi:10.1136/adc.2010.187161. PMID:21220264.

Moher, D., Liberati, A., Tetzlaff, J., and Altman, D.G. 2009. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA Statement. Ann. Intern. Med. **151**(4): 264–269. doi:10.7326/0003-4819-151-4-200908180-00135. PMID:19622511.

Poitras, V.J., Gray, C.E., Borghese, M.M., Carson, V., Chaput, J.-P., Janssen, I., et al. 2016. Systematic review of the relationships between objectively-measured physical activity and health indicators in school-aged children and youth. Appl. Physiol. Nutr. Metab. **41**: This issue. doi:10.1139/apnm-2015-0663.

Santos, R., Mota, J., Okely, A.D., Pratt, M., Moreira, C., Coelho-e-Silva, M.J., et al. 2014. The independent associations of sedentary behaviour and physical activity on cardiorespiratory fitness. Br. J. Sports Med. **48**: 1508–1512. doi:10.1136/bjsports-2012-091610. PMID:23410883.

Saunders, T.J., Chaput, J.-P., and Tremblay, M.S. 2014. Sedentary behaviour as an emerging risk factor for cardiometabolic diseases in children and youth. Can. J. Diabetes, **38**(1): 53–61. doi:10.1016/j.jcjd.2013.08.266.

Tremblay, M., LeBlanc, A., Kho, M., Saunders, T., Larouche, R., Colley, R., et al. 2011. Systematic review of sedentary behaviour and health indicators in school-aged children and youth. Int. J. Behav. Nutr. Phys. Act. **8**(1): 98. doi:10.1186/1479-5868-8-98. PMID:21936895.

Appendix A

Fig. A1. Cumulative Index to Nursing and Allied Health Literature (CINAHL) search strategy.

S1 (MH "Exercise+")
S2 (MH "Therapeutic Exercise+")
S3 (MH "Motor Activity+")
S4 (MH "Physical Activity")
S5 (MH "Physical Education and Training+")
S6 (MH "Sports+")
S7 (MH "Play and Playthings+")
S8 TX sport$ or bicycl$ or swim$ or walk$ or run$ or jog$
S9 TX physic* N2 activ*
S10 TX aerobic N2 activ* OR aerobic N2 train*
S11 S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10)
S12 sedentar*
S13 chair time or desk time or car time or automobile time or auto time or bus time or indoor time or in-door time or screen time or computer time
S14 low energy expenditure
S15 computer game* or video game* or television or tv
S16 electronic game* or gaming
S17 screen based entertainment or screen-based entertainment
S18 texting or text messag* or app or apps or mobile applications
S19 smartphone* or smart phone* or cell phone* or mobile phone* or small screen*
S20 social media or Facebook or Youtube or Twitter or Snapchat or Instagram or Pinterest or Skype or Vine
S21 bed rest
S22 sitting
S23 physical* N2 inactivit*
S24 S12 OR S13 OR S14 OR S15 OR S16 OR S17 OR S18 OR S19 OR S20 OR S21 OR S22 OR S23
S25 (MH "Sleep") OR (MH "Sleep Deprivation")
S26 TX sleep N2 duration
S27 (MH "Sleep Apnea Syndromes+") AND TI ((apnea or apnoea))
S28 (S25 or S26) not S27
S29 S11 and S24 and S28