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Systematic Review of the Relationships Between Objectively Measured Physical Activity and Health Indicators in School-Aged Children and Youth

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REVIEW

Systematic review of the relationships between objectively measured physical activity and health indicators in school-aged children and youth[1]

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Abstract: Moderate-to-vigorous physical activity (MVPA) is essential for disease prevention and health promotion. Emerging evidence suggests other intensities of physical activity (PA), including light-intensity activity (LPA), may also be important, but there has been no rigorous evaluation of the evidence. The purpose of this systematic review was to examine the relationships between objectively measured PA (total and all intensities) and health indicators in school-aged children and youth. Online databases were searched for peer-reviewed studies that met the a priori inclusion criteria: population (apparently healthy, aged 5–17 years), intervention/exposure/comparator (volumes, durations, frequencies, intensities, and patterns of objectively measured PA), and outcome (body composition, cardiometabolic biomarkers, physical fitness, behavioural conduct/pro-social behaviour, cognition/academic achievement, quality of life/well-being, harms, bone health, motor skill development, psychological distress, self-esteem). Heterogeneity among studies precluded meta-analyses; narrative synthesis was conducted. A total of 162 studies were included (204 171 participants from 31 countries). Overall, total PA was favourably associated with physical, psychological/social, and cognitive health indicators. Relationships were more consistent and robust for higher (e.g., MVPA) versus lower (e.g., LPA) intensity PA. All patterns of activity (sporadic, bouts, continuous) provided benefit. LPA was favourably associated with cardiometabolic biomarkers; data were scarce for other outcomes. These findings continue to support the importance of at least 60 min/day of MVPA for disease prevention and health promotion in children and youth, but also highlight the potential benefits of LPA and total PA. All intensities of PA should be considered in future work aimed at better elucidating the health benefits of PA in children and youth.

Key words: physical activity, body composition, cardiometabolic biomarkers, fitness, behavioural conduct, bone health, academic achievement, quality of life, well-being, children.

Résumé : L'activité physique d'intensité moyenne à vigoureuse (« MVPA ») est essentielle à la prévention des maladies et à la promotion de la santé. D'après de récentes données, l'activité physique (« PA ») pratiquée à d'autres intensités telles que légères (« LPA ») s'avère aussi importante, mais il n'y a pas d'évaluation rigoureuse de ces faits. Cette analyse documentaire systématique a pour objectif d'examiner la relation entre l'activité physique mesurée objectivement (totale et à chacune des intensités) et des indicateurs de la santé chez des enfants et des jeunes d'âge scolaire. On a cherché dans des bases de données en ligne pour identifier des études révisées par des pairs et présentant a priori les critères d'inclusion suivants : population (apparemment en santé, sujets âgés de 5 à 17 ans), intervention/exposition/comparateur (volume, durée, fréquence, intensité et types de mesure objective de PA) et le résultat (composition corporelle, biomarqueurs cardiométaboliques, condition physique, comportement/comportement prosocial, cognition/réussite scolaire, qualité de vie/bien-être, préjudices, santé osseuse, développement des habiletés motrices, détresse psychologique, estime de soi). L'hétérogénéité des études ne permet pas la méta-analyse; une synthèse descriptive est réalisée. L'analyse regroupe 162 études (204 171 participants de 31 pays). Globalement, l'activité physique totale est favorablement associée aux indicateurs de santé physique, psychologique/sociale et cognitive. Les relations sont plus

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uniformes et plus robustes pour des intensités plus élevées (p. ex. MVPA) vs plus basses (p. ex. LPA). Toutes les modalités d'activité (sporadique, ponctuelle, continue) procurent des bienfaits. LPA est associée favorablement aux biomarqueurs cardiométaboliques; il y a peu de données au sujet des autres résultats. Ces observations appuient encore la thèse de l'importance d'effectuer au moins 60 min/jour de MVPA pour la prévention des maladies et la promotion de la santé chez les enfants et les jeunes; elles soulignent aussi les bienfaits potentiels de LPA et de PA totale. Les prochains travaux devraient prendre en compte toutes les intensités de PA pour mieux élucider les bienfaits sanitaires de PA chez les enfants et les jeunes. [Traduit par la Rédaction]

Mots-clés : activité physique, composition corporelle, biomarqueurs cardiométaboliques, condition physique, comportement, santé osseuse, réussite scolaire, qualité de vie, bien-être, enfant.

Introduction

Physical activity (PA) is vital to the physical, psychological/social, and cognitive health of school-aged children and youth (Janssen and LeBlanc 2010; Tremblay et al. 2010*b*). In this regard, the *Canadian Physical Activity Guidelines for Children and Youth* (Tremblay et al. 2010*b*, 2011), and many other guidelines around the world (e.g., Australia (Okely et al. 2012), USA (US Department of Health and Human Services 2008), and World Health Organization (WHO 2010)), recommend that children and youth spend a minimum of 60 min each day in moderate- to vigorous-intensity physical activity (MVPA). The current Canadian guidelines are based on a systematic review of the relationships between PA and health indicators in school-aged children and youth, which supported the importance of MVPA (Janssen and LeBlanc 2010; Tremblay et al. 2010*b*, 2011). While the significance of MVPA cannot be overstated, this research and messaging approach has resulted in a narrow focus on 1 h of the 24-h period (<5% of each day), and emerging evidence suggests that all intensities of PA (including light-intensity physical activity; LPA) may be important for health promotion and disease prevention (Carson et al. 2013).

There are currently no PA guidelines that include recommendations regarding LPA. Indeed, none of the synthesized studies that informed the current Canadian guidelines specifically examined the relationships between LPA and health indicators (Janssen and LeBlanc 2010). This research gap may be due to the historical focus on MVPA (Tremblay et al. 2010*a*; Marshall and Ramirez 2011) and the widespread use of subjective assessments of PA (Reilly et al. 2008; Adamo et al. 2009; Janssen and LeBlanc 2010; Trost et al. 2011), which cannot accurately capture LPA (e.g., various incidental activities accumulated throughout the day) (Hamilton et al. 2004; Tremblay et al. 2007). This is unfortunate, as studies from Canada and the United States indicate that children and youth spend ~4–6 h/day in LPA (Matthews et al. 2008; Troiano et al. 2008; Colley et al. 2011; Chaput et al. 2014), and emerging research suggests that spending more waking hours in LPA compared with sedentary pursuits may provide some health benefits (Hamilton et al. 2004; Tremblay et al. 2007, 2010*a*; Spittaels et al. 2012).

Since the previous systematic review, an abundance of new literature with objective measures of PA has been published. However, despite the current widespread use of accelerometers and growing body of evidence, there has not been a rigorous scientific evaluation of the relationship between different intensities of objectively measured PA, including LPA, and health indicators among children and youth. Consequently, a systematic review of the current literature regarding the volume, duration, frequency, intensity, and patterns of objectively measured PA is needed.

Therefore, the purpose of this study was to perform a systematic review that examined the relationships between objectively measured PA (overall (total PA; e.g., accelerometer counts/min, sum of minutes at all intensities, steps/day) and by intensity (light, moderate, moderate-to-vigorous, vigorous)) and relevant health indicators in children and youth aged 5–17 years. An additional aim was to examine the associations between various patterns of PA (sporadic PA and bouts of PA as well as adherence to current PA guidelines (e.g., 60 min of MVPA each day)) and health indicators.

Materials and methods

Protocol and registration

This systematic review was registered with the International Prospective Register of Systematic Reviews (PROSPERO; registration no. CRD42015015488; available from www.crd.york.ac.uk/PROSPERO/display_record.asp?ID=CRD42015015488), and was conducted following the PRISMA statement for reporting systematic reviews and meta-analyses (Moher et al. 2009).

Eligibility criteria

The participants, interventions, comparisons, outcomes and study design (PICOS) framework (Schardt et al. 2007) was followed to identify key study concepts in the research question a priori and to facilitate the searching process.

Population

Apparently healthy children and youth (including those with overweight and obesity) with a mean age of 5–17 years and/or in grades kindergarten–12.

Intervention (exposure)

Various volumes, durations, frequencies, intensities (i.e., light, moderate, moderate to vigorous, vigorous; LPA, MPA, MVPA, and VPA, respectively) and patterns of objectively measured total PA. Studies were included if they reported objective PA measures (accelerometer, heart rate monitor, pedometer, arm band).

Comparison

Various volumes, durations, frequencies, intensities, and patterns of objectively measured total PA. A comparison or control group was not required but was used when available to compare effects.

Outcome

Eleven health indicators were chosen by expert consensus among a 27-member group with expertise in movement behaviours in children and youth. Consideration was given to the literature (previous reviews) and a recognition of the importance of including relevant measures from a range of holistic health indicators (i.e., physical, psychological/social, and cognitive health). Seven health indicators were identified as *critical* (primary) health indicators by expert consensus: (*i*) body composition, (*ii*) cardiometabolic biomarkers (i.e., metabolic syndrome and cardiovascular disease risk factors), (*iii*) physical fitness, (*iv*) behavioural conduct/pro-social behaviour, (*v*) cognition/academic achievement, (*vi*) quality of life/well-being, and (*vii*) harms (i.e., injuries). Four health indicators were identified as *important* (secondary): (*i*) bone health, (*ii*) motor skill development, (*iii*) psychological distress, and (*iv*) self-esteem.

Study design

All study designs were considered. For longitudinal studies, any follow-up length was allowed as long as the exposure was measured before follow-up at least once between ages 5–17 years.

Randomized controlled trials (RCTs) and nonrandomized intervention studies were required to have at least 30 participants in the intervention group. Observational studies were required to have a minimum sample size of 300 participants. If an intervention study targeted PA but did not demonstrate a significant effect of the intervention on PA, it was treated as an observational study (minimum sample size requirement of 300 participants) and cross-sectional relationships between objectively measured PA and health indicators (at baseline) were extracted where possible. For feasibility reasons related to the large number of studies examining body composition, cross-sectional studies that examined body composition were required to have a minimum sample size of 1000 participants.

In terms of study-report characteristics, studies were screened if they were published in English or could be translated using Google Translate (Google Inc.; Balk et al. 2012). Published peer-reviewed original manuscripts and in-press manuscripts were eligible for inclusion. Grey literature and conference abstracts were excluded.

Information sources and search strategy

The electronic search strategy was created by a research librarian with expertise in systematic review searching and peer-reviewed by a second research librarian. The following databases were searched using the Ovid interface: MEDLINE (1946 to January 19, 2015), EMBASE (1980 to 2015 week 3), and PsycINFO (1806 to January week 2, 2015). SPORTDiscus was searched using the EBSCOhost interface (1949 to January 21, 2015). No language or study design limits were applied. The search strategies are presented in Supplementary Material A[2].

Bibliographic records were extracted as text files from the Ovid and EBSCO interfaces and imported into Reference Manager Software (version 11; Thompson Reuters, San Francisco, Calif., USA), where duplicate references were systematically removed. At this stage, study collaborators were invited to submit additional relevant accepted and in-press papers, and the reference sections of relevant reviews were scanned for papers potentially missed by the search. Titles and abstracts of potentially relevant articles were imported to DistillerSR (Evidence Partners; Ottawa, Ont., Canada) where they were screened against inclusion criteria independently by 2 reviewers. Exclusion by both reviewers was required for a study to be excluded at level 1; all other studies passed to level 2 for 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 by a third reviewer if needed.

Data extraction

Data extraction forms were created by the study coordinators, and reviewed and piloted by study collaborators (including methodological experts) and the reviewers. Extraction was completed in DistillerSR by 1 reviewer and exported to Excel (Microsoft Corp.) to be 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 (first author, publication year, study design, country, sample size, age, and sex of participants); PA characteristics (volume, duration, frequency, intensity, pattern and measure and/or description of PA intervention); health indicators (measure); results (e.g., risk ratio, difference in means); and confounders (e.g., sleep, sedentary behaviour). The results from fully adjusted models were extracted when studies presented multiple models. Study findings were considered statistically significant at $p < 0.05$.

Risk of bias and evidence 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 risk of bias assessment tool (Higgins et al. 2011). Papers from RCTs and nonrandomized intervention studies were screened for potential sources of bias for the overall study (i.e., selection bias (random sequence generation and allocation concealment), reporting bias (selective reporting)); for each main outcome (i.e., performance bias (blinding of participants, personnel, and outcome assessors), detection bias (blinding of outcome assessment), and attrition bias (incomplete outcome data)); and for "other" sources of bias. Observational studies were screened for potential sources of bias for the overall study (i.e., selection bias (appropriate sampling), performance bias (flawed measurement of exposure), attrition bias (incomplete follow-up, high loss to follow-up), and selective reporting bias (selective/incomplete outcome reporting)) for each main outcome (i.e., detection bias (flawed measurement of outcome)), and for other sources of bias.

The quality of evidence (i.e., the level of confidence that the estimates of effect are correct) for each health indicator by each type of study design was assessed using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework (Guyatt et al. 2011*a*). According to the GRADE framework, which categorizes evidence quality into 4 groups ("high", "moderate", "low", or "very low"), evidence quality ratings start at high for randomized studies and low for all other experimental and observational studies. The quality of evidence is downgraded if there are limitations across studies because of serious risk of bias, inconsistency of relative treatment effects, indirectness, imprecision, or other factors. If there is no cause to downgrade, the quality of evidence can be upgraded if there is a large effect size, a dose–response gradient, or if all plausible confounders would decrease an apparent treatment effect (Guyatt et al. 2011*b*). Overall quality of evidence for each study design within each health indicator was evaluated by 1 reviewer and verified by the larger review team, including 3 systematic review methodology experts. Because of the inherent challenges of research that involves objective PA measures, the review team decided 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.

Synthesis of results

Meta-analyses were planned if data could be meaningfully pooled (i.e., if sufficiently homogeneous in terms of statistical, clinical, and methodological characteristics). Narrative syntheses structured around the intensity (e.g., LPA, MPA, MVPA, VPA) and amount (e.g., duration, frequency) of PA and the health indicator were conducted if meta-analyses were not possible.

Results

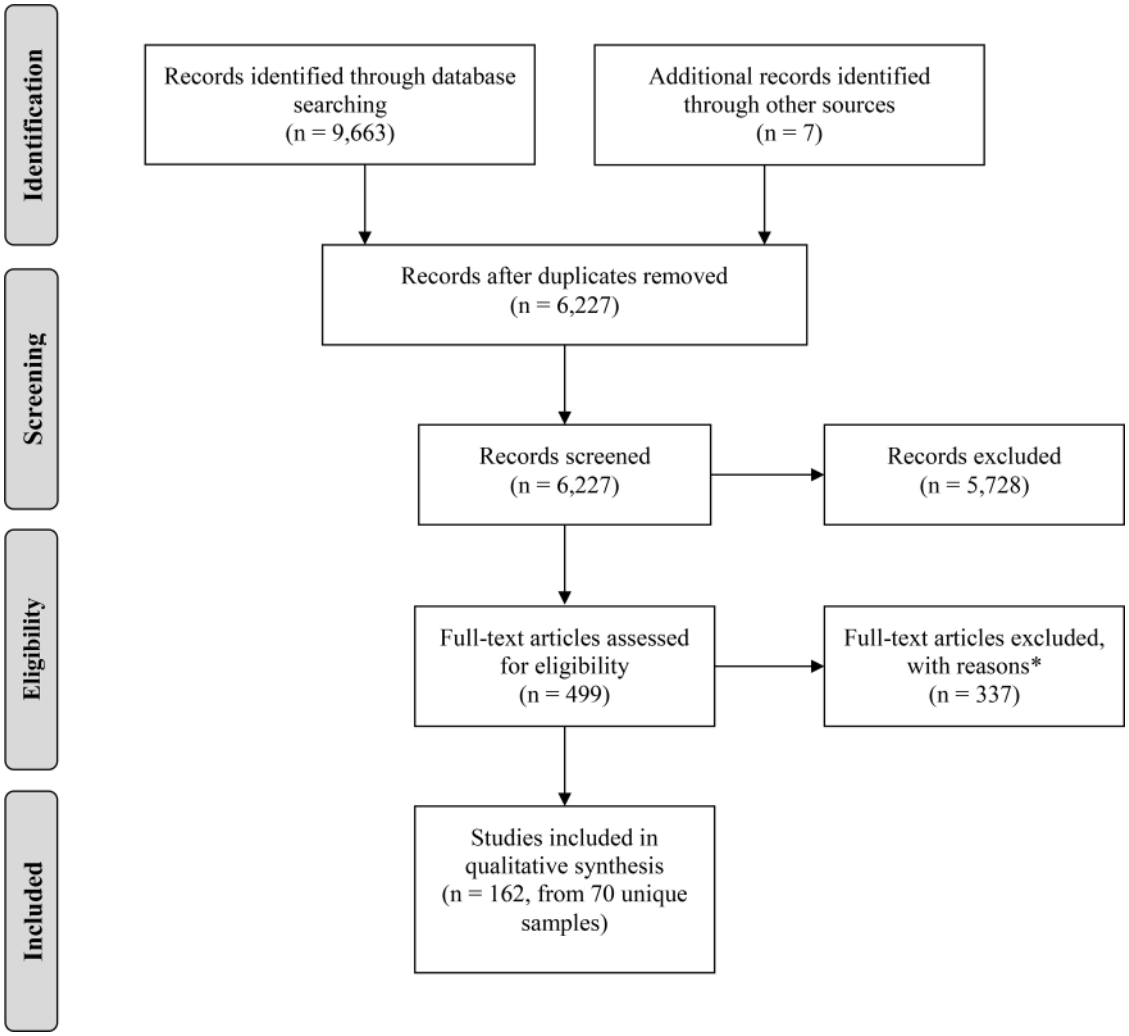
Description of studies

A total of 9663 records were identified through database searches, 1 was identified from reference list searches, and 6 were accepted or in-press publications nominated by collaborators. After de-duplication, 6227 records remained. A total of 499 records remained after screening titles and abstracts, and 162 studies (from 70 unique samples) were identified as meeting inclusion criteria after full-text screening (see Fig. 1 for reasons for exclusions).

Important study characteristics and results of the individual 162 included studies are presented in Supplementary Tables S1–S10 (Supplementary Material B[2]) and summarized in Tables 1–11. Data across studies involved 204 171 participants (85 532 from 70 unique

[2]Supplementary data are available with the article through the journal Web site at http://nrcresearchpress.com/doi/suppl/10.1139/apnm-2015-0663.

Fig. 1. PRISMA flow diagram for the identification, screening, eligibility, and inclusion of studies. *, Reasons for exclusion included: study did not assess the relationship between physical activity (PA) and a relevant health indicator (n = 90); sample size (n = 81); PA was included only as a covariate or outcome and not as the exposure (n = 66); an intervention study that did not target PA (n = 31); no objective measure of PA (n = 29); study participants not within appropriate age range (n = 17); not original research (e.g., review; n = 13); special population (n = 4); could not obtain full-text (n = 3); non-English language article that could not be translated by Google Translate (n = 2); and duplicate paper discovered during data extraction (n = 1). Some studies were excluded for multiple reasons.



samples), ranging from 31 (Rowland et al. 1996) to 7495 (Tudor-Locke et al. 2011) participants. Included studies were conducted in 31 different countries, and mean baseline age ranged from 5.1 to 17.7 years. Sixteen studies used an experimental design; 8 studies used a randomized design, and 8 studies used a nonrandomized design. The remaining 146 studies used observational designs, including longitudinal (n = 33) and cross-sectional (n = 123) components (i.e., cross-sectional design, or cross-sectional analyses within a longitudinal study).

Quality of evidence

Overall, the quality of evidence ranged from very low to moderate. The most common reasons for downgrading the quality of evidence were (*i*) serious risk of bias that reduced the level of confidence in the observed effects, and (*ii*) indirectness of the interventions and comparisons being assessed. Common sources of bias included reasons for and/or amount of missing data not reported, large proportion of missing exposure/outcome data, and unknown validity/reliability of outcome measures. Regarding indirectness, no intervention studies directly compared different durations and intensities of PA. 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 1–10.

Data synthesis

Meta-analyses could not be performed because of heterogeneity in measurement of PA and health indicators. Narrative syntheses are presented for all included studies. "Mixed findings" refer to mixed positive, null, and/or negative results. Unless otherwise stated, results did not differ by sex or age. Within each health indicator, results are presented first by study design and then by intensity of PA (i.e., total PA, followed sequentially by VPA, MVPA, MPA, and LPA). Because of the large number of included studies, the reader is referred to the results Tables (Tables 1–10) for references in cases where 7 or more papers are cited.

Critical (primary) health indicators

Body composition

Adiposity

Seventy-two studies examined the relationships between PA and measures of adiposity (see Table 1 and Supplementary

Table 1. The relationship between physical activity and body composition.

No. of participants (no. of studies)	Design	Quality assessment				Absolute effect[a]	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
2085 (7)	Randomized trials[b]	Serious risk of bias[c]	No serious inconsistency	Serious indirectness[d]	No serious imprecision	**2/7 studies** reported improved adiposity for intervention vs control at post-test (Gutin et al. 1999; Eather et al. 2013); **3/7 studies** reported mixed favourable and null findings (Verstraete et al. 2007; Kriemler et al. 2010; Ford et al. 2013). **1/7 studies** had no intervention effects (Finkelstein et al. 2013); **1/7 studies** reported that significant favourable effects in Kriemler et al. (2010) were null at 3-y follow-up (Meyer et al. 2014). Favourable effects for %BF, but not FM, remained at 15-wk follow-up for Ford et al. (2013)[e]	LOW[f]
1174 (6)	NRT[g]	Serious risk of bias[h]	No serious inconsistency	Serious indirectness[i]	No serious imprecision	**5/6 studies** reported null effects of PA intervention on adiposity outcomes (Rowland et al. 1996; Pangrazi et al. 2003; Williams and Warrington 2011; Huang et al. 2012; Duncan et al. 2012) **1/6 studies** reported lower odds of overweight/obesity half way through (1 y) a school/afterschool-based **total PA** intervention program, at post-test (2 y) and at 2-y follow-up (Sigmundova and Sigmund 2012)	VERY LOW[j]
11 629 (14)	Longitudinal[k]	Risk of bias[l]	No serious inconsistency	No serious indirectness	No serious imprecision	**Total PA:** **1/7 studies** reported favourable associations (Janz et al. 2005); **2/7 studies** reported mixed favourable and null associations (Riddoch et al. 2009; White and Jago 2012); **4/7 studies** reported null associations (Butte et al. 2007*a*; Basterfield et al. 2012; Hjorth et al. 2014*a*, 2014*b*) **VPA:** **2/3 studies** reported favourable associations (total and bouts, Janz et al. 2005; dose-response trend, Carson et al. 2014); **1/3 studies** reported null associations (Butte et al. 2007*a*) **MVPA:** **2/7 studies** reported favourable associations (Janz et al. 2009; Mitchell et al. 2013); **2/7 studies** reported mixed favourable and null associations (Riddoch et al. 2009; Hjorth et al. 2014*b*); **3/7 studies** reported null associations (Stevens et al. 2007; Hallal et al. 2012; Hjorth et al. 2014*a*) **MPA:** **2/2 studies** reported null associations (total and bouts, Janz et al. 2005; Butte et al. 2007*a*) **LPA:** **2/3 studies** reported null associations (Butte et al. 2007*a*; Treuth et al. 2009); **1/3 studies** reported an unfavourable association, with evidence of dose–response gradient (Carson et al. 2014) ***FFM:*** **Total PA: 1/1 studies** reported mixed favourable and null associations (Stevens et al. 2004).	VERY LOW[m]

Table 1 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment				Absolute effect[a]	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
57 696 (48)	Cross-sectional[n]	Serious risk of bias[o]	Serious inconsistency[p]	No serious indirectness	No serious imprecision	**Meeting/not meeting guidelines (≥60 min/d MVPA):** **2/3 studies** reported favourable associations (Steele et al. 2009; Martinez-Gomez et al. 2010*b*); **1/3 studies** reported null associations (Mendoza et al. 2012) **Total PA:** **9/22 studies** reported favourable associations (Duncan et al. 2008; Riddoch et al. 2009; Steele et al. 2009; Belcher et al. 2010; Ferrar and Olds 2010; Owen et al. 2010; Mark and Janssen 2011; Ekstedt et al. 2013; Manios et al. 2013) **8/22 studies** reported mixed favourable and null associations (Andersen et al. 2006; Duncan et al. 2006; Ness et al. 2007; Ortega et al. 2007; Dollman et al. 2010; Ruiz et al. 2011; Tudor-Locke et al. 2011; Jimenez-Pavon et al. 2013*c*) **3/22 studies** reported null associations (Ekelund et al. 2006; Hands et al. 2009; Martinez-Gomez et al. 2012) **1/22 studies** reported mixed favourable, null, and unfavourable associations (Jimenez-Pavon et al. 2013*a*) **1/22 studies** reported mixed null and unfavourable associations (Hands and Parker 2008) **VPA:** **10/15 studies** reported favourable associations (Ekelund et al. 2004; Lohman et al. 2006; Steele et al. 2009; Martinez-Gomez et al. 2010*b*; Mark and Janssen 2011; Sayers et al. 2011; Chung et al. 2012; Martinez-Gomez et al. 2012; Jimenez-Pavon et al. 2013*a*; Katzmarzyk et al. 2015*b*). **4/15 studies** reported mixed favourable and null associations (Ortega et al. 2007; Belcher et al. 2010; Kelly et al. 2010; Jimenez-Pavon et al. 2013*c*) **1/15 studies** reported mixed null and unfavourable associations (Ortega et al. 2010) **MVPA:** **20/30 studies** reported favourable associations (Ekelund et al. 2004; Lohman et al. 2006; Ness et al. 2007; Stevens et al. 2007; Mark and Janssen 2009; Riddoch et al. 2009; Steele et al. 2009; Belcher et al. 2010; Martinez-Gomez et al. 2010*b*; Holman et al. 2011; Grydeland et al. 2012; Lawman et al. 2012; Carson et al. 2013; Ekstedt et al. 2013; Jimenez-Pavon et al. 2013*a*; Taverno Ross et al. 2013; da Silva et al. 2014; Young et al. 2014; Katzmarzyk et al. 2015*a*, 2015*b*) **6/30 studies** reported mixed favourable and null associations (Kelly et al. 2010; Peart et al. 2011; Ruiz et al. 2011; Mendoza et al. 2012; St George et al. 2013; Jimenez-Pavon et al. 2013*c*) **3/30 studies** reported null associations (Hurtig-Wennlof et al. 2007; Ortega et al. 2007; Martinez-Gomez et al. 2012) **1/30 studies** reported mixed null and unfavourable associations (Ortega et al. 2010)	VERY LOW[q]

Table 1 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment				Absolute effect[a]	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
						2 studies examined *sporadic MVPA* (i.e., 1–4 min bouts) and associations were favourable (Mark and Janssen 2009; Holman et al. 2011) **3 studies** examined *bouts of MVPA* and associations were favourable (**2/3 studies;** Holman et al. 2011; da Silva et al. 2014) or mixed (favourable and null; **1/3 studies;** Mark and Janssen 2009) **MPA:** **2/10 studies** reported favourable associations (Mark and Janssen 2011; Chung et al. 2012) **2/10 studies** reported mixed favourable and null associations (Belcher et al. 2010; Jimenez-Pavon et al. 2013*c*) **5/10 studies** reported null associations (Ortega et al. 2007; Steele et al. 2009; Sayers et al. 2011; Martinez-Gomez et al. 2012; Jimenez-Pavon et al. 2013*a*) **1/10 studies** reported mixed null and unfavourable associations (Ortega et al. 2010) **No studies** reported only unfavourable associations **LPA:** **1/9 studies** reported favourable associations (Mark and Janssen 2011) **2/9 studies** reported mixed favourable and null associations (Treuth et al. 2009; Kwon et al. 2011) **3/9 studies** reported null associations (Ekelund et al. 2004; Sayers et al. 2011; Carson et al. 2013) **3/9 studies** reported mixed null and unfavourable associations (Steele et al. 2009; Jimenez-Pavon et al. 2013*a*, 2013*c*)	
						FFM: **Total PA:** **1/2 studies** reported favourable associations (Ness et al. 2007); **1/2 studies** reported mixed favourable and null associations (Jimenez-Pavon et al. 2013*a*) **VPA:** **2/4 studies** reported favourable associations (Jimenez-Pavon et al. 2013*a*; Sayers et al. 2011); **2/4 studies** reported mixed null and unfavourable associations (Lohman et al. 2006, 2008) **MVPA:** **1/4 studies** reported null associations (Jimenez-Pavon et al. 2013*a*); **3/4 studies** reported mixed null and unfavourable associations (Lohman et al. 2006, 2008; Taverno Ross et al. 2013) **MPA:** **2/2 studies** reported null associations (Jimenez-Pavon et al. 2013*a*; Sayers et al. 2011)	

Table 1 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment				Absolute effect[a]	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
						LPA: **1/2 studies** reported favourable associations (Sayers et al. 2011); **1/2 studies** reported mixed unfavourable (boys) and null (girls) associations (Jimenez-Pavon et al. 2013*a*)	

Note: The range of mean ages was 6.9 to 11.3 years. Data were collected by randomized trial, nonrandomized intervention trial, cross-sectionally, and up to 3 years of follow-up. Body composition markers were BMI (absolute, percentile, *z* score, conditional *z* score velocity), weight status (CDC, IOTF, or WHO cut-points), sum of SF, body mass, WC, %BF, FM, FM index, FFM, FFM index, ponderal index, and trunk fat. Outcomes were measured objectively in all but one instance. ACT, Active by Choice Today trial; ALSPAC, Avon Longitudinal Study of Parents and Children; %BF, percent body fat; BMI, body mass index; CDC, Centers for Disease Control and Prevention; CTRL, control group; EYHS, European Youth Heart Study; FFM, fat free mass; FM, fat mass; HELENA, Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study; INT, intervention group; IOTF, International Obesity Task Force; ISCOLE, International Study of Childhood Obesity, Lifestyle and the Environment; KISS, Kinder-Sportstudie; LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; NHANES, National Health and Nutrition Examination Survey; NRT, nonrandomized trial; OPUS, Optimal well-being, development and health for Danish children through a healthy New Nordic Diet School Meal Study; PA, physical activity; RCT, randomized controlled trial; SF, skinfold; TAAG, Trial of Activity for Adolescent Girls; VPA, vigorous-intensity physical activity; WC, waist circumference; WHO, World Health Organization.

[a]Absolute effects are in relation to adiposity-specific indicators unless otherwise stated (i.e. in relation to FFM).

[b]Includes **6 RCT studies** (Verstraete et al. 2007; Kriemler et al. 2010; Finkelstein et al. 2013; Eather et al. 2013; Ford et al. 2013; Meyer et al. 2014) from **5** unique samples, and **1 modified randomized crossover study** (Gutin et al. 1999). Kriemler et al. 2010 and Meyer et al. 2014 both report data from the KISS study. Results are reported separately and participants are only counted once.

[c]Serious risk of bias. Performance bias: randomization was reported, but the method by which sibling pairs were further randomized beyond the initial randomization was not described and it is plausible that siblings discussed and detected group assignment (Finkelstein et al. 2013). Detection bias: 6-min walk test assessors were not blinded to group assignment; pedometers were open for INT, but sealed for CTRL, which could have influenced the outcome; missing pedometer data were disproportionately high in controls relative to intervention group (18.1% vs 6.1%), likely because of incentives for wear time offered to the intervention group only (Finkelstein et al. 2013). Selective reporting: %BF from BodPod (Life Measurement Instruments, Concord, Calif., USA) was not available at follow up and reasons were not described. Many analyses were only reported for subsamples with no explanation. Sequence generation: unclear how the subsample of children who had objective PA measures was selected (Ford et al. 2013).

[d]Serious indirectness. Differences in intervention: studies examined various types of PA programs and provided indirect evidence bearing on the potential effectiveness of different intensities and durations of PA. Indirect comparisons: different durations and intensities of PA were not compared within individual studies.

[e]MVPA (but not total PA) was significantly greater in the intervention vs control group at post-intervention (post 9-month intervention group difference of ~11 min/day) (Kriemler et al. 2010); there was a trend toward higher levels of total PA (but not MVPA) in the intervention vs control group at 3-year follow-up (Cohen's $d = 0.35$, $p = 0.06$; not significant) (Meyer et al. 2014).

[f]The quality of the evidence from randomized studies was downgraded from "high" to "low" because of (*i*) a serious risk of bias in 2 studies that diminished the level of confidence in the observed effects, and (*ii*) serious indirectness of the interventions and the comparisons being assessed.

[g]Includes **3 nonrandomized controlled intervention studies** (Rowland et al. 1996; Pangrazi et al. 2003; Sigmundova and Sigmund 2012) and **3 single-group intervention studies** (Williams and Warrington 2011; Duncan et al. 2012; Huang et al. 2012).

[h]Serious risk of bias. Allocation concealment: group assignment was based on completion of intervention or drop-out, with drop-outs serving as CTRL. Attrition bias: the large amount of missing data was likely related to the outcome of interest (Williams and Warrington 2011). Other source of bias: there was no CTRL group (Duncan et al. 2012; Huang et al. 2012). Attrition bias: analysis did not control for clustering by class order/number and change scores were not compared with a reference group (Huang et al. 2012). Allocation concealment was not described. Performance bias: no blinding attempted. Other sources of bias: the authors reported implausibly large effect sizes for the intervention (i.e., a reduction in the proportion of obesity to 0% in INT, while the proportion doubled in CTRL) (Sigmundova and Sigmund 2012). Incomplete outcome data: dietary analysis showed there was a small increase in caloric intake in INT compared to CTRL that was not controlled for in analysis (Rowland et al. 1996).

[i]Serious indirectness. Differences in intervention: studies examined various types of PA programs and provided indirect evidence bearing on the potential effectiveness of different intensities and durations of PA. Indirect comparisons: different durations and intensities of PA were not compared within individual studies.

[j]The quality of evidence from nonrandomized intervention studies was downgraded from "low" to "very low" because of (*i*) a serious risk of bias in five studies that diminished the level of confidence in the observed effects, and (*ii*) serious indirectness of the interventions and the comparisons being assessed.

[k]Includes **14 longitudinal studies** (Stevens et al. 2004, 2007; Janz et al. 2005, 2009; Butte et al. 2007*a*; Riddoch et al. 2009; Treuth et al. 2009; Basterfield et al. 2012; Hallal et al. 2012; White and Jago 2012; Mitchell et al. 2013; Carson et al. 2014; Hjorth et al. 2014*a*, 2014*b*) from **11 unique samples**; Janz et al. 2005 and 2009 reported data from the Iowa Bone Development Study; Stevens et al. 2007 and Treuth et al. 2009 reported data from the TAAG study; Hjorth et al. 2014*a* and 2014*b* reported data from the OPUS study. Results are presented separately and participants are only counted once.

[l]Serious risk of bias. Authors reported significance at $p < 0.10$. It is unclear if data from the univariate or multivariate models are reported. Loss to follow-up not examined by fat mass index (Basterfield et al. 2012). Enrollment protocol was not adequately described. Adiposity outcomes were reportedly estimated using a "previously validated equation"; however, in the validation study BMI was a better predictor of BF than the new equation. In the overweight group, baseline PA was a significant predictor of FM and FFM but not %BF; this is concerning as %BF is a function of FM and FFM (Stevens et al. 2004). Sixty-eight percent of participants did not provide valid baseline accelerometer data or did not have complete cardiometabolic risk factor data (which included WC) at baseline and/or follow-up; reasons for missing data were not provided. Those lost to follow-up were older, heavier, and displayed lower cardiorespiratory fitness levels than completers. Conditional BMI *z* score velocity was validated with infants as cited; however, the validity and reliability with children and youth are unknown (Carson et al. 2014). Reasons for exclusions are not adequately reported (Hallal et al. 2012). Reasons for missing outcome data not clear (Riddoch et al. 2009). Only the subset that gained weight was included in the analysis ($n = 798$ out of $n = 879$), which may have affected the associations reported (Butte et al. 2007*a*).

[m]The quality of evidence from longitudinal studies was downgraded from "low" to "very low" because of serious risk of bias in 6 studies that diminished the level of confidence in the observed effects.

Table 1 (*concluded*).

[n]Includes **48 studies** (Ekelund et al. 2004, 2006; Andersen et al. 2006; Duncan et al. 2006, 2008; Lohman et al. 2006, 2008; Ness et al. 2007; Ortega et al. 2007, 2010; Stevens et al. 2007; Hurtig-Wennlof et al. 2007; Hands and Parker 2008; Hands et al. 2009; Mark and Janssen 2009; Riddoch et al. 2009; Steele et al. 2009; Treuth et al. 2009; Ferrar and Olds 2010; Martinez-Gomez et al. 2010*b*; Owen et al. 2010; Dollman et al. 2010; Kelly et al. 2010; Belcher et al. 2010; Peart et al. 2011; Holman et al. 2011; Kwon et al. 2011; Tudor-Locke et al. 2011; Ruiz et al. 2011; Sayers et al. 2011; Chung et al. 2012; Grydeland et al. 2012; Lawman et al. 2012; Martinez-Gomez et al. 2012; Mendoza et al. 2012; Barreira et al. 2013; Carson et al. 2013; Ekstedt et al. 2013; Jimenez-Pavon et al. 2013*a*, 2013*c*; Manios et al. 2013; St George et al. 2013; Taverno Ross et al. 2013; da Silva et al. 2014; Young et al. 2014; Katzmarzyk et al. 2015*a*, 2015*b*) from **18 unique samples**. **Three studies** reported data from the Australian National Children's PA and Nutrition Survey (Hands and Parker 2008; Dollman et al. 2010; Ferrar and Olds 2010); **9 studies** reported data from NHANES (Mark and Janssen 2009, 2011; Belcher et al. 2010; Holman et al. 2011; Peart et al. 2011; Chung et al. 2012; Mendoza et al. 2012; Barreira et al. 2013; Carson et al. 2013); **2 studies** reported data from the ACT Trial (Lawman et al. 2012; St George et al. 2013); **6 studies** reported data from the EYHS (Ekelund et al. 2004, 2006; Andersen et al. 2006; Hurtig-Wennlof et al. 2007; Ortega et al. 2007, 2010); **2 studies** reported data from ISCOLE (Katzmarzyk et al. 2015*a*, 2015*b*); **3 studies** reported data from ALSPAC (Ness et al. 2007; Riddoch et al. 2009; Sayers et al. 2011); **6 studies** reported data from TAAG (Lohman et al. 2006, 2008; Stevens et al. 2007; Treuth et al. 2009; Kelly et al. 2010; Young et al. 2014); **4 studies** reported data from HELENA (Martinez-Gomez et al. 2010*b*, 2012; Ruiz et al. 2011; Jimenez-Pavon et al. 2013*a*); Duncan et al. (2006) and (2008) were from the same sample; results are reported separately and participants are only counted once.

[o]Serious risk of bias. Potential confounders were not controlled for (da Silva et al. 2014; Katzmarzyk et al. 2015*b*). Reasons for missing PA and BMI data were not reported (da Silva et al. 2014). The amount of missing data/exclusions and reasons were not reported (Hurtig-Wennlof et al. 2007; Duncan et al. 2008). Risk of detection bias as participants were retained if they provided PA data for at least 1 to 7 days; 68% provided at least 5 days of PA data and 32% provided 1–4 days. PA levels were slightly higher in those with fewer days of PA data. MVPA and LPA were recorded but not reported (Owen et al. 2010). Reasons for missing data were not explained (Steele et al. 2009). Participants with missing PA data differed on some outcome measures (Andersen et al. 2006). BMI *z* score was measured and analyzed for males and females aged 5–12 years, and collected but not reported for 13–16-year olds (Dollman et al. 2010). Parent-estimated height and weight were used (Tudor-Locke et al. 2011). Thirty percent of adiposity data were missing without explanation (Jimenez-Pavon et al. 2013*c*). A large proportion of data were missing with no explanation (Ruiz et al. 2011; Sayers et al. 2011; Taverno Ross et al. 2013). FFM and FM were estimated using an equation developed specifically for the study; however, a methods paper showed the equation did not perform satisfactorily or meet the criteria for cross-validation (Taverno Ross et al. 2013). Validity and reliability of outcome measure is unknown and a reference for the equation is not provided (Young et al. 2014).

[p]Serious inconsistency. Findings for LPA were highly inconsistent. Findings for other intensities of PA consistently reported null or favourable associations between PA and adiposity outcomes. Consistency for other measures was not an issue, with consistency and strength of findings explained by varied outcome measurement and intensity of PA (stronger associations for higher intensities of PA and more precise measures of adiposity).

[q]The quality of evidence from cross-sectional studies was downgraded from "low" to "very low" because of (*i*) serious risk of bias in 14 studies that diminished the level of confidence in the observed effects, and (*ii*) serious unexplained inconsistency in the findings for LPA.

Table S1 (Supplementary Material B[2])). Seven studies used a randomized design, 6 intervention studies used a nonrandomized design, 14 studies used a longitudinal design, and 48 studies used a cross-sectional design or also reported cross-sectional findings. Measures of adiposity (e.g., body mass index (BMI), percent body fat) were assessed objectively (e.g., calculated from objectively measured height and weight, sum of skinfolds, or bioelectrical impedance) in all but 1 instance (see Table 1 for summary of measures). The quality of evidence ranged from very low to low across study designs (see Table 1 for specific details).

As summarized in Table 1, among randomized studies, increasing total PA resulted in decreased adiposity compared with a control condition for at least 1 adiposity measure in 5/7 studies (Gutin et al. 1999; Verstraete et al. 2007; Kriemler et al. 2010; Eather et al. 2013; Ford et al. 2013). In the 3 studies where associations were not uniformly favourable across all adiposity measures, there was no measure-specific pattern of null and significant findings (Verstraete et al. 2007; Kriemler et al. 2010; Ford et al. 2013). Two studies included a follow-up period. In the first, 15-week follow-up PA levels were not reported; significant intervention effects were maintained for percent body fat, but not fat mass (Ford et al. 2013). In the second, there was a trend for greater total PA (but not MVPA) in the intervention versus control group at 3-year follow-up (Cohen's $d = 0.35$, $p = 0.06$), but no difference between groups in sum of 4 skinfolds, BMI, or waist circumference (Meyer et al. 2014).

Among nonrandomized intervention studies, 1/6 studies reported lower odds of overweight or obesity for participants of a PA intervention at post-test and 2-year follow-up compared with a control group (Sigmundova and Sigmund 2012). The remaining 5/6 studies reported no effect of a PA intervention on adiposity (Rowland et al. 1996; Pangrazi et al. 2003; Williams and Warrington 2011; Duncan et al. 2012; Huang et al. 2012).

Among longitudinal studies, associations between total PA and adiposity were mixed: 3/7 studies reported at least 1 favourable association (Janz et al. 2005; Riddoch et al. 2009; White and Jago 2012), and 6/7 studies reported at least 1 null association (Janz et al. 2005; Butte et al. 2007*a*; Riddoch et al. 2009; Basterfield et al. 2012; White and Jago 2012; Hjorth et al. 2014*a*, 2014*b*). Approximately half of the longitudinal studies that examined VPA (2/3 studies; Janz et al. 2005; Carson et al. 2014) and/or MVPA (4/7 studies; Janz et al. 2009; Riddoch et al. 2009; Mitchell et al. 2013; Hjorth et al. 2014*b*) reported a favourable prospective association with at least 1 measure of adiposity. No studies reported a prospective association between MPA and adiposity (0/2 studies; Janz et al. 2005; Butte et al. 2007*a*). There was an unfavourable dose–response gradient in 1/3 studies that examined LPA, whereby higher levels of LPA were prospectively associated with greater adiposity (Carson et al. 2014), and null associations between LPA and adiposity markers were observed in 2/3 studies (Butte et al. 2007*a*; Treuth et al. 2009). When associations were not uniformly favourable across all adiposity measures, there was no measure-specific pattern of null and significant findings.

Among cross-sectional studies, total PA was favourably associated with at least 1 measure of adiposity in 18/22 studies (see Table 1 for references). VPA (14/15 studies) and MVPA (26/30 studies) were also consistently favourably associated with at least 1 adiposity measure (Table 1). For MPA, results were less uniform; 4/10 studies reported at least 1 favourable association, 1/10 studies reported at least 1 unfavourable association, and 5/10 studies reported only null associations (Table 1). Similarly, for LPA, there was no clear direction of relationship or pattern of consistent findings: 3/9 studies reported a favourable association with at least 1 indicator of adiposity (Treuth et al. 2009; Kwon et al. 2011; Mark and Janssen 2011), 3/9 studies reported at least 1 unfavourable association (Steele et al. 2009; Jimenez-Pavon et al. 2013*a*, 2013*c*), and 3/9 studies reported only null associations (Ekelund et al. 2004; Sayers et al. 2011; Carson et al. 2013). When associations were not uniformly

Table 2. The relationship between physical activity and cardiometabolic biomarkers.

No. of participants (no. of studies)	Design	Quality assessment					Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other		
502 (2)	Randomized trials[a]	No serious risk of bias	No serious inconsistency	Serious indirectness[b]	No serious imprecision	None	The intervention group had larger reductions in **TGs**, **glucose**, and **cardiometabolic disease risk score** and a greater increase in **HDL** vs the control group. **Systolic BP** and **diastolic BP** were not different between groups (Kriemler et al. 2010).[c] There were no differences in **glucose, HDL**, **TG,** or **systolic BP** or **diastolic BP** between the control and intervention groups 3 y post-intervention (Meyer et al. 2014)[c]	MODERATE[d]
31 (1)	NRT[e]	Serious risk of bias[f]	No serious inconsistency	Serious indirectness[g]	No serious imprecision	None	Aerobic training had no effect on **total cholesterol**, **HDL**, or **TG**. In boys, **LDL** decreased during the control weeks prior to the intervention (Rowland et al. 1996)[h]	VERY LOW[i]
7918 (7)	Longitudinal[j]	Serious risk of bias[k]	No serious inconsistency	No serious indirectness	No serious imprecision	None	**Meeting/not meeting guidelines:** Changes in *PA guideline adherence* over 2 y did not influence incidence of **pre-high BP** or **high-BP** (de Moraes et al. 2015)[l] **Total PA:** *Systolic BP:* null association (**2/2 studies;** Hallal et al. 2011; Knowles et al. 2013); *Diastolic BP:* associations were favourable (**1/2 studies;** Knowles et al. 2013), or mixed (favourable and null; compared with the *least active tercile,* children in the *most active tercile* of PA at age 12 y had lower diastolic BP at age 14 y; no difference between least active and intermediate terciles; **1/1 studies;** Hallal et al. 2011); *Mean arterial BP:* null association (**1/1 studies;** Hjorth et al. 2014*a*); *TG:* null association (**1/1 studies;** Hjorth et al. 2014*a*); *HDL cholesterol:* favourable association (**1/1 studies;** Hjorth et al. 2014*a*); *HOMA:* associations were null (**1/1 studies;** Hjorth et al. 2014*a*), or mixed favourable (in boys but not girls at 4-y follow-up) and null (2-y follow-up) (Telford et al. 2009); *Cardiometabolic disease risk score:* null association (**1/1 studies;** Hjorth et al. 2014*a*) **VPA:** Null associations with **systolic BP** (Carson et al. 2014) **MVPA:** *Systolic BP:* null association (**1/1 studies;** Knowles et al. 2013); *Diastolic BP:* null association (**1/1 studies;** Knowles et al. 2013); *Mean arterial BP:* null association (**1/1 studies;** Hjorth et al. 2014*a*); *TG:* null association (**1/1 studies;** Hjorth et al. 2014*a*); *HDL cholesterol:* favourable association (**1/1 studies;** Hjorth et al. 2014*a*); *HOMA:* null association (**1/1 studies;** Hjorth et al. 2014*a*); *Cardiometabolic disease risk score:* null association (**1/1 studies;** Hjorth et al. 2014*a*) **MPA:** Null associations with **systolic BP** (Carson et al. 2014) **LPA:** Null associations with **systolic BP** (Carson et al. 2014)	VERY LOW[m]

Table 2 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment					Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other		
27 571 (47)	Cross-sectional[n]	Serious risk of bias[o]	No serious inconsistency	No serious indirectness	No serious imprecision	Exposure/outcome gradient[p]	***Blood Pressure (Systolic BP, Diastolic BP, Mean Arterial BP)*** **Meeting/not meeting guidelines:** **1 study** found that *meeting PA guidelines*[q] was associated with reduced odds of having **high BP**, but no difference in odds of **pre-high BP** or **risk of high** BP (de Moraes et al. 2015). **1 study** found that *meeting PA guidelines*[q] was associated with lower **systolic BP** and **diastolic BP** (Janssen et al. 2013). **1 study** found that *meeting 10 000 steps/day* did not impact the odds of having **high BP** (Schofield et al. 2009) **Total PA:** *Hypertension:* favourable dose–response gradient (**1/1 studies;** Mark and Janssen 2008) *Diastolic hypertension:* favourable association (**1/1 studies;** Knowles et al. 2013) *Systolic hypertension:* no association (**1/1 studies;** Knowles et al. 2013) *Systolic BP:* associations were favourable (**3/8 studies;** Andersen et al. 2006; Ekelund et al. 2006; Mark and Janssen 2008), null (**4/8 studies;** Leary et al. 2008; Owen et al. 2010; Chaput et al. 2013; Knowles et al. 2013), or mixed (favourable and null; **1/8 studies;** Hurtig-Wennlof et al. 2007). Mark and Janssen (2008) found a favourable dose–response gradient *Diastolic BP:* associations were favourable (**6/8 studies;** Andersen et al. 2006; Ekelund et al. 2006; Mark and Janssen 2008; Owen et al. 2010; Chaput et al. 2013; Knowles et al. 2013), null (**1/8 studies;** Leary et al. 2008), or mixed (favourable and null; **1/8 studies;** Hurtig-Wennlof et al. 2007). Mark and Janssen (2008) found an inverse dose–response gradient *Mean arterial BP:* null association (**1/1 studies;** Hjorth et al. 2014*a*) **VPA:** *High-normal systolic BP %:* was greatest in the lowest tertile of *VPA* (**1/1 studies;** Hay et al. 2012) *BP z score:* no association (**1/1 studies;** Stabelini Neto et al. 2014) **MVPA:** *Hypertension:* the likelihood of **hypertension** decreased in a curvilinear manner with *MVPA* (**1/1 studies;** Hjorth et al. 2014*a*) *BP z score:* favourable association (**1/1 studies;** Stabelini Neto et al. 2014) *Systolic BP:* associations were favourable (**4/9 studies;** Holman et al. 2011; Colley et al. 2012; Mendoza et al. 2012; Carson et al. 2013); null (**4/9 studies;** Leary et al. 2008; Hearst et al. 2012; Chaput et al. 2013; Knowles et al. 2013); or mixed (favourable and null; **1/9 studies;** Hurtig-Wennlof et al. 2007). **1 study** found a favourable association between *sporadic MVPA* and *systolic BP* (Holman et al. 2011)	

Table 2 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment: Risk of bias	Inconsistency	Indirectness	Imprecision	Other	Absolute effect	Quality
							Diastolic BP: associations were favourable (**1/8 studies;** Chaput et al. 2013); null (**5/8 studies;** Leary et al. 2008; Colley et al. 2012; Hearst et al. 2012; Mendoza et al. 2012; Carson et al. 2013); or mixed (favourable and null; **2/8 studies;** Hurtig-Wennlof et al. 2007; Knowles et al. 2013) *Mean arterial BP:* null association (**1/1 studies;** Hjorth et al. 2014*a*) **MPA:** *BP z score:* favourable association (**1/1 studies;** Stabelini Neto et al. 2014) *Systolic BP:* null association (**1/1 studies;** Hay et al. 2012) **LPA:** *BP z score:* favourable association (**1/1 studies;** Stabelini Neto et al. 2014) *Systolic BP:* null associations (**2/2 studies;** Hay et al. 2012; Carson et al. 2013) *Diastolic BP:* favourable association (**1/1 studies;** Carson et al. 2013)	
							TG: **Meeting/not meeting guidelines:** *meeting PA guidelines*[a] had a null association with fasting **TGs** (**1/1 studies;** Janssen et al. 2013) **Total PA:** associations were favourable (**3/7 studies;** Andersen et al. 2006; Ekelund et al. 2006; Owen et al. 2010), null (**2/7 studies;** Chaput et al. 2013; Hjorth et al. 2014*a*), or mixed (favourable and null; **2/7 studies;** Wennlof et al. 2005; Hurtig-Wennlof et al. 2007) **VPA:** null association (**1/1 studies;** Stabelini Neto et al. 2014) **MVPA:** associations were favourable (**1/7 studies;** LeBlanc and Janssen 2010) or null (**6/7 studies;** Hurtig-Wennlof et al. 2007; Mendoza et al. 2012; Carson et al. 2013; Chaput et al. 2013; Hjorth et al. 2014*a*; Stabelini Neto et al. 2014) **MPA:** null association (**1/1 studies;** Stabelini Neto et al. 2014) **LPA:** null associations (**2/2 studies;** Carson et al. 2013; Stabelini Neto et al. 2014)	
							Cholesterol: **Meeting/not meeting guidelines:** *HDL cholesterol: meeting PA guidelines*[a] was favourably associated with HDL (**1/1 studies;** Janssen et al. 2013) **Total PA:** *Total cholesterol:* associations were favourable (**1/2 studies;** Andersen et al. 2006), or mixed (favourable and null; **1/2 studies;** Hurtig-Wennlof et al. 2007) *HDL cholesterol:* associations were favourable (**2/5 studies;** Chaput et al. 2013; Hjorth et al. 2014*a*) or null (**3/5 studies;** Andersen et al. 2006; Hurtig-Wennlof et al. 2007; Owen et al. 2010) **VPA:** *HDL cholesterol:* null associations (**1/1 studies;** Stabelini Neto et al. 2014)	

Table 2 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment					Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other		
							MVPA: *"High risk" cholesterol:* increased *MVPA* was associated with reduced odds (**1/1 studies;** LeBlanc and Janssen 2010) *Total cholesterol:* associations were favourable (**1/3 studies;** Hurtig-Wennlof et al. 2007) or null (**2/3 studies;** Hurtig-Wennlof et al. 2007; Mendoza et al. 2012) *HDL cholesterol:* associations were favourable (**3/7 studies;** Mendoza et al. 2012; Chaput et al. 2013; Hjorth et al. 2014*a*) or null (**4/7 studies;** Hurtig-Wennlof et al. 2007; Hearst et al. 2012; Carson et al. 2013; Stabelini Neto et al. 2014) *Non-HDL cholesterol: MVPA* (total, bouts, sporadic) was favourably associated (**1/1 studies;** Holman et al. 2011) *LDL cholesterol:* null associations (**3/3 studies;** LeBlanc and Janssen 2010; Mendoza et al. 2012; Carson et al. 2013) **MPA:** *HDL cholesterol:* null associations (**1/1 studies;** Stabelini Neto et al. 2014) **LPA:** *HDL cholesterol:* associations were null (**1/2 studies;** Stabelini Neto et al. 2014) or mixed (favourable and null; **1/2 studies;** Carson et al. 2013)	
							Insulin resistance: **Meeting/not meeting guidelines:** *HOMA: meeting PA guidelines*[q] had no impact on **HOMA** (**1/1 studies;** Janssen et al. 2013) **Total PA:** *HOMA:* associations were favourable (**5/6 studies;** Andersen et al. 2006; Rizzo et al. 2008; Sardinha et al. 2008; Owen et al. 2010; Hjorth et al. 2014*a*), or null (**1/6 studies;** Jimenez-Pavon et al. 2013*c*) *QUICKI:* null association (**1/1 studies;** Jimenez-Pavon et al. 2013*c*) **VPA:** *HOMA:* associations were favourable (**1/2 studies;** Rizzo et al. 2008) or null (**1/2 studies;** Jimenez-Pavon et al. 2013*c*) *QUICKI:* null association (**1/1 studies;** Jimenez-Pavon et al. 2013*c*) **MVPA:** *HOMA:* associations were favourable (**4/7 studies;** Rizzo et al. 2008; Sardinha et al. 2008; Henderson et al. 2014; Hjorth et al. 2014*a*), or null (**3/7 studies;** Henderson et al. 2012; Carson et al. 2013; Jimenez-Pavon et al. 2013*c*) *QUICKI:* null association (**1/1 studies;** Jimenez-Pavon et al. 2013*c*) *Matsuda score:* null association (**1/1 studies;** Henderson et al. 2012) *HOMA-%S:* favourable association (**1/1 studies;** Carson et al. 2013) *OGTT results* (AUC $I/G_{t30\ min}$ *or AUC* $I/G_{t120\ min}$)*:* null associations (**1/1 studies;** Henderson et al. 2014)	

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Table 2 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment: Risk of bias	Inconsistency	Indirectness	Imprecision	Other	Absolute effect	Quality
							MPA: *HOMA:* associations were favourable (**1/2 studies;** Rizzo et al. 2008), or null (**1/2 studies;** Jimenez-Pavon et al. 2013*c*) *QUICKI:* null association (**1/1 studies;** Jimenez-Pavon et al. 2013*c*) **LPA:** *HOMA:* associations were null (**4/4 studies;** Rizzo et al. 2008; Sardinha et al. 2008; Carson et al. 2013; Jimenez-Pavon et al. 2013*c*) *QUICKI:* null association (**1/1 studies;** Jimenez-Pavon et al. 2013*c*) *HOMA-%S:* null association (**1/1 studies;** Carson et al. 2013) ***Fasting insulin:*** **Total PA:** associations were favourable (**8/11 studies;** Brage et al. 2004*a*; Andersen et al. 2006; Ekelund et al. 2006; Butte et al. 2007*b*; Rizzo et al. 2008; Sardinha et al. 2008; Owen et al. 2010; Jimenez-Pavon et al. 2012), null (**1/11 studies;** Jimenez-Pavon et al. 2013*c*), or mixed (favourable and null; **2/11 studies;** Wennlof et al. 2005; Hurtig-Wennlof et al. 2007) **VPA:** associations were favourable (**2/4 studies;** Rizzo et al. 2008; Jimenez-Pavon et al. 2012), or null (**2/4 studies;** Butte et al. 2007*b*; Jimenez-Pavon et al. 2013*c*) **MVPA:** associations were favourable (**5/9 studies;** Rizzo et al. 2008; Sardinha et al. 2008; Henderson et al. 2012; Jimenez-Pavon et al. 2012; Carson et al. 2013), null (**2/9 studies;** Mendoza et al. 2012; Jimenez-Pavon et al. 2013*c*), or mixed (favourable and null **2/9 studies;** Butte et al. 2007*b*; Hurtig-Wennlof et al. 2007). Butte et al. 2007*b* found that 5- but not *10-min bouts of MVPA* were favourably associated with fasting insulin **MPA:** associations were favourable (**1/3 studies;** Butte et al. 2007*b*), null (**1/3 studies;** Jimenez-Pavon et al. 2013*c*), or mixed (favourable and null; **1/3 studies;** Rizzo et al. 2008) **LPA:** associations were favourable (**1/5 studies;** Butte et al. 2007*b*) or null (**4/5 studies;** Rizzo et al. 2008; Sardinha et al. 2008; Carson et al. 2013; Jimenez-Pavon et al. 2013*c*) ***Fasting glucose:*** **Total PA:** associations were favourable (**3/7 studies;** Andersen et al. 2006; Ekelund et al. 2006; Rizzo et al. 2008), null (**3/7 studies;** Brage et al. 2004*a*; Chaput et al. 2013; Jimenez-Pavon et al. 2013*c*), or mixed (favourable and null; **1/7 studies;** Hurtig-Wennlof et al. 2007) **VPA:** associations were favourable (**1/3 studies;** Rizzo et al. 2008) or null (**2/3 studies;** Jimenez-Pavon et al. 2013*c*; Stabelini Neto et al. 2014) **MVPA:** associations were favourable (**1/8 studies;** Rizzo et al. 2008), null (**6/8 studies;** Owen et al. 2010; Mendoza et al. 2012; Carson et al. 2013; Chaput et al. 2013; Jimenez-Pavon et al. 2013*c*; Stabelini Neto et al. 2014) or mixed (favourable and null; **1/8 studies;** Hurtig-Wennlof et al. 2007). **1/1 studies** found no association between *MVPA* and **2-h plasma glucose** (Carson et al. 2013)	

Table 2 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment: Risk of bias	Inconsistency	Indirectness	Imprecision	Other	Absolute effect	Quality
							MPA: associations were favourable (**1/3 studies;** Rizzo et al. 2008), or null (**2/3 studies;** Jimenez-Pavon et al. 2013*c*; Stabelini Neto et al. 2014) **LPA:** associations were null (**4/4 studies;** Rizzo et al. 2008; Carson et al. 2013; Jimenez-Pavon et al. 2013*c*; Stabelini Neto et al. 2014). **1/1 studies** found no association with **2-h plasma glucose** (Carson et al. 2013)	
							HbA1c: **Total PA:** null association (**1/1 studies;** Owen et al. 2010) **MVPA:** null association (**1/1 studies;** Mendoza et al. 2012)	
							Inflammatory markers (CRP, TNF-α, IL-6, C3, C4): **Meeting/not meeting guidelines:** Null association between *meeting PA guidelines*[r] and **CRP** (**1/1 studies;** Loprinzi et al. 2013) **Total PA:** *CRP:* null associations (**3/3 studies;** Owen et al. 2010; Martinez-Gomez et al. 2012; Loprinzi et al. 2013) *IL-6, TNF-α, C3 or C4:* null associations (**1/1 studies;** Martinez-Gomez et al. 2012) **VPA:** *CRP, IL-6, TNF-α, C3 or C4:* null associations (**1/1 studies;** Martinez-Gomez et al. 2012) **MVPA:** *CRP:* associations were favourable (increasing quartiles of *MVPA (total, bouts, sporadic)* were associated with reduced **CRP** (**1/5 studies;** Holman et al. 2011)) or null (**4/5 studies;** Martinez-Gomez et al. 2012; Mendoza et al. 2012; Carson et al. 2013; Loprinzi et al. 2013). *Bouts of MVPA* did not differ across CRP quartiles (**1/1 studies;** Loprinzi et al. 2013) *IL-6, TNF-α, C3 or C4:* null associations (**1/1 studies;** Martinez-Gomez et al. 2012) **MPA:** *CRP, IL-6, TNF-α, C3 or C4:* null associations (**1/1 studies;** Martinez-Gomez et al. 2012) **LPA:** *CRP:* null associations (**1/1 studies;** Carson et al. 2013)	
							Alanine amino transferase: **Total PA** did not differ by **ALT** status, and % of awake time spent in ***VPA***, ***MPA*** or ***LPA*** did not differ by **ALT** status (**1/1 studies;** Quiros-Tejeira et al. 2007)	
							Artery properties: **Total PA:** negative association with **PWV** (**1/1 studies;** Sakuragi et al. 2009); null association with carotid **IMT** (**1/1 studies;** Lamotte et al. 2013)	

Table 2 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment: Risk of bias	Inconsistency	Indirectness	Imprecision	Other	Absolute effect	Quality
							VPA: null associations with **IMT, carotid compliance, Young's elastic modules,** or **stiffness index** (**1/1 studies;** Ried-Larsen et al. 2013) **MVPA:** null associations with **IMT, carotid compliance, Young's elastic modules,** or **stiffness index** (**1/1 studies;** Ried-Larsen et al. 2013)	
							RPP: **Total PA, VPA, or MPA:** null associations (**1/1 studies;** Mota et al. 2012)	
							Cardiac sympathetic/parasympathetic modulation: **MVPA:** positively associated with one index of **cardiac parasympathetic modulation** (root mean square of successive differences) but not associated with another (high frequency power), and negatively associated with **sympathetic-parasympathetic balance** (**1/1 studies;** Gutin et al. 2005*b*)	
							Homocysteine: **Total PA, VPA, MVPA or MPA:** null associations (**1/1 studies;** Ruiz et al. 2007)	
							Composite Cardiometabolic Disease Risk Score: **Meeting/not meeting guidelines:** *meeting PA guidelines*[q,s] was associated with reduced **cardiometabolic risk score** (**2/2 studies;** Mendoza et al. 2012; Janssen et al. 2013); achieving 10 000 steps/d was not associated with different odds of having any number of **cardiovascular risk factors** (**1/1 studies;** Schofield et al. 2009) **Total PA:** associations were favourable (**3/7 studies;** Brage et al. 2004*b*; Ekelund et al. 2009; Jimenez-Pavon et al. 2013*b*) or null (**4/7 studies;** Rizzo et al. 2007; Schofield et al. 2009; Moreira et al. 2011; Hjorth et al. 2014*a*). **1/1 studies** found that *lower mean cadence values* were associated with larger accrued **numbers of risk factors** (Barreira et al. 2013) **VPA:** associations were favourable (**1/2 studies;** Jimenez-Pavon et al. 2013*b*) or null (**1/2 studies;** Stabelini Neto et al. 2014) **MVPA:** associations were favourable (**6/8 studies;** Ekelund et al. 2006; Nguyen et al. 2010; Carson and Janssen 2011; Holman et al. 2011; Jimenez-Pavon et al. 2013*b*; Stabelini Neto et al. 2014), null (**1/8 studies;** Hjorth et al. 2014*a*), or mixed (favourable and null; **1/8 studies;** Rey-Lopez et al. 2013). **1 study** found that the odds of a high cardiometabolic risk score decreased in a graded dose–response manner across quartiles of *sporadic MVPA* or *bout MVPA,* with similar associations for some individual cardiometabolic disease risk factors (non-HDL cholesterol, CRP, systolic BP) (Holman et al. 2011)	

Table 2 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment: Risk of bias	Inconsistency	Indirectness	Imprecision	Other	Absolute effect	Quality
							MPA: favourable associations (**2/2 studies;** Jimenez-Pavon et al. 2013*b*; Stabelini Neto et al. 2014) **LPA:** null association (**1/1 studies;** Stabelini Neto et al. 2014)	

Note: The range of mean ages was 5.1 to 17.0 years. Data were collected by randomized trial, nonrandomized intervention trial, cross-sectionally, and up to 4 years of follow-up. Cardiometabolic biomarkers assessed were BP (systolic BP, diastolic BP, mean arterial BP, pre-high BP, high BP, hypertension), blood lipids (TG, HDL, LDL, total cholesterol), insulin sensitivity/resistance (HOMA, HOMA-%S; QUICKI, Matsuda index), fasting insulin and glucose, OGTT results (2-h plasma glucose, AUC I/$G_{t30\ min}$, AUC I/$G_{t120\ min}$), HbA1c, RPP, inflammatory markers (CRP, IL-6, TNF-α, C3, C4), artery properties (PWV, carotid intima-media thickness, carotid compliance, Young's elastic modules, stiffness index), ALT, cardiac sympathetic-parasympathetic modulation, homocysteine, and composite cardiometabolic risk scores. All outcomes were measured objectively. ALT, alanine amino transferase; AUC I/$G_{t30\ min}$ and AUC I/$G_{t120\ min}$, area under the curve of the ratio of insulin to glucose at 30 and 120 min post-OGTT, respectively; BP, blood pressure; C3 and C4, complement factors 3 and 4, respectively; CHMS, Canadian Health Measures Survey; CRP, C-reactive protein; EYHS, European Youth Heart Study; HbA1c, glycosylated hemoglobin; HELENA, Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study; HDL, high-density lipoprotein cholesterol; HOMA, homeostatic model assessment insulin resistance; HOMA-%S, insulin sensitivity; IDEFICS, Identification and prevention of Dietary- and lifestyle-induced health EFfects in Children and infantS; IL-6, interleukin-6; IMT, intima media thickness; KISS, Kinder-Sportstudie; LDL, low density lipoprotein cholesterol; LOOK, Lifestyle of our Kids; LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; NHANES, National Health and Nutrition Examination Survey; NRT, nonrandomized trial; OGTT, oral glucose tolerance test; PA, physical activity; PWV, pulse wave velocity; QUALITY, QUebec Adiposity and Lifestyle InvesTigation in Youth; QUICKI, quantitative insulin sensitivity check index; RPP, rate-pressure product; sporadic MVPA, <5 consecutive minutes of moderate- to vigorous-intensity physical activity; TG, triglycerides; TNF-α, tumor necrosis factor alpha; VPA, vigorous-intensity physical activity.

[a]Includes **2 studies** (Kriemler et al. 2010; Meyer et al. 2014) from 1 cluster randomized controlled trial (KISS). Results are reported separately and participants are only counted once.

[b]Serious indirectness. Indirect comparisons: different durations and intensities of PA were not compared.

[c]MVPA (but not total PA) was significantly greater in the intervention vs control group at post-intervention (post 9-month intervention group difference of ~11 min/day) (Kriemler et al. 2010); there was a trend toward higher levels of total PA (but not MVPA) in the intervention vs control group at 3-year follow-up (Cohen's $d = 0.35$, $p = 0.06$; not significant) (Meyer et al. 2014).

[d]The quality of the evidence from the randomized study was downgraded from "high" to "moderate" because of serious indirectness of the interventions and the comparisons being assessed.

[e]Includes **1 nonrandomized intervention study** (Rowland et al. 1996).

[f]Serious risk of bias. PA outside of prescribed intervention was not controlled (e.g., sports teams/recreational programs) or measured, and it is unclear whether activity external to the intervention changed over the course of the study and/or may have influenced the results. Dietary analysis in a subset of nonrandomly selected subjects ($n = 11$) showed a decrease in caloric intake in the intervention vs control period (potentially important confounder) (Rowland et al. 1996).

[g]Serious indirectness. Indirect comparisons: different durations and intensities of PA were not compared.

[h]Training intensity estimated by heart monitor; mean heart rate during the training sessions was 174.4 (SD 10) beats/min (Rowland et al. 1996).

[i]The quality of the evidence from the nonrandomized study was downgraded from "low" to "very low" because of (*i*) serious risk of bias in the included study that diminished the level of confidence in the observed effects, and (*ii*) serious indirectness of comparisons.

[j]Includes **7 longitudinal studies** (Hallal et al. 2011; Telford et al. 2009, 2012*a*; Knowles et al. 2013; Carson et al. 2014; Hjorth et al. 2014*a*; de Moraes et al. 2015) from **6 unique samples**. **Two studies** reported data from the LOOK study (Telford et al. 2009, 2012*a*); results are reported separately and participants are only counted once.

[k]Serious risk of bias. Participants were divided into intervention (community-based healthy lifestyle promotion) and control (no treatment) groups, but possible group-effects were not considered and all analyses were reported pooled across groups (de Moraes et al. 2015). Sixty-eight percent of participants did not provide valid baseline accelerometer data or did not have complete cardiometabolic risk factor data at baseline and/or follow-up; reasons for missing data were not reported; those lost to follow-up were older, heaver, and displayed lower cardiorespiratory fitness than those included at follow-up (Carson et al. 2014). Those included in analysis represent only ~10% of the total cohort (Hallal et al. 2011).

[l]Cut-point for "meeting" PA guidelines was ≥60 min MVPA/day (de Moraes et al. 2015).

[m]The quality of the evidence from longitudinal studies was downgraded from "low" to "very low" because of serious risk of bias in 3 studies that diminished the level of confidence in the observed effects.

[n]Includes **47 cross-sectional studies** (Brage et al. 2004*a*, 2004*b*; Gutin et al. 2005*b*; Wennlof et al. 2005; Andersen et al. 2006; Ekelund et al. 2006, 2009; Hurtig-Wennlof et al. 2007; Quiros-Tejeira et al. 2007; Rizzo et al. 2007, 2008; Butte et al. 2007*b*; Ruiz et al. 2007; Leary et al. 2008; Mark and Janssen 2008; Sardinha et al. 2008; Sakuragi et al. 2009; Schofield et al. 2009; LeBlanc and Janssen 2010; Nguyen et al. 2010; Owen et al. 2010; Carson and Janssen 2011; Holman et al. 2011; Moreira et al. 2011; Colley et al. 2012; Hay et al. 2012; Hearst et al. 2012; Henderson et al. 2012; Jimenez-Pavon et al. 2012, 2013*b*, 2013*c*; Martinez-Gomez et al. 2012; Mota et al. 2012; Mendoza et al. 2012; Barreira et al. 2013; Carson et al. 2013; Chaput et al. 2013; Janssen et al. 2013; Lamotte et al. 2013; Knowles et al. 2013; Loprinzi et al. 2013; Rey-Lopez et al. 2013; Ried-Larsen et al. 2013; Henderson et al. 2014; Hjorth et al. 2014*a*; Stabelini Neto et al. 2014; de Moraes et al. 2015) from **20 unique samples**. **Two studies** reported data from the CHMS (Colley et al. 2012; Janssen et al. 2013); **12 studies** reported data from the EYHS (Brage et al. 2004*a*, 2004*b*; Wennlof et al. 2005; Andersen et al. 2006; Ekelund et al. 2006, 2009; Hurtig-Wennlof et al. 2007; Rizzo et al. 2007, 2008; Ruiz et al. 2007; Sardinha et al. 2008; Ried-Larsen et al. 2013); **5 studies** reported data from HELENA (Jimenez-Pavon et al. 2012, 2013*c*; Martinez-Gomez et al. 2012; Lamotte et al. 2013; Rey-Lopez et al. 2013); **2 studies** reported data from IDEFICS (Jimenez-Pavon et al. 2013*b*; de Moraes et al. 2015); **8 studies** reported data from NHANES (Mark and Janssen 2008; LeBlanc and Janssen 2010; Carson and Janssen 2011; Holman et al. 2011; Mendoza et al. 2012; Barreira et al. 2013; Carson et al. 2013; Loprinzi et al. 2013); **3 studies** reported data from QUALITY (Henderson et al. 2012, 2014; Chaput et al. 2013); **2 studies** reported data from Viva la Familia (Butte et al. 2007*b*; Quiros-Tejeira et al. 2007); results are reported separately and participants are only counted once.

Table 2 (*concluded*).

[o]Serious risk of bias. Participants were divided into intervention (community-based healthy lifestyle promotion) and control (no treatment) groups, but possible group-effects were not considered and all analyses were reported pooled across groups (de Moraes et al. 2015). Many studies had a large amount of missing data, or did not report sufficient information to determine the proportion of missing data (Gutin et al. 2005*b*; Andersen et al. 2006; Hurtig-Wennlof et al. 2007; Rizzo et al. 2007, 2008; Mark and Janssen 2008; Ekelund et al. 2009; LeBlanc and Janssen 2010; Carson and Janssen 2011; Holman et al. 2011; Mendoza et al. 2012; Mota et al. 2012; Carson et al. 2013; Janssen et al. 2013; Jimenez-Pavon et al. 2013*b*; Ried-Larsen et al. 2013; Stabelini Neto et al. 2014). Possible detection bias as participants were retained if they provided PA data for at least 1–7 days; 68% provided at least 5 days of PA data and at 32% provided 1–4 days; PA levels were slightly higher in those with fewer days of PA data; MVPA and LPA were recorded but not reported (Owen et al. 2010). Participants with missing data differed from those included in the analysis on some outcome measures (Andersen et al. 2006; Jimenez-Pavon et al. 2013*c*). Potential failure to adjust for relevant confounders (Barreira et al. 2013). No information provided regarding criteria for valid exposure measurement; possible detection bias (Quiros-Tejeira et al. 2007). Possible selective reporting bias (systolic BP reported in absence of diastolic BP); not possible to discern which potentially important confounders were included in the analyses (Hay et al. 2012). Possible detection bias; participants were excluded from the study if they did not wear the pedometer for >4 h in total over the full 4 days of data collection (Schofield et al. 2009).

[p]Exposure/outcome gradients were observed in **4 studies** (Andersen et al. 2006; Mark and Janssen 2008; Holman et al. 2011; Hay et al. 2012) from **3 unique samples**.

[q]Cut-point for "meeting" PA guidelines was ≥60 min MVPA/day (Janssen et al. 2013; de Moraes et al. 2015).

[r]Cut-point for "meeting" PA guidelines was ≥60 min of at least moderate-intensity PA, daily (1-min bouts) (Loprinzi et al. 2013).

[s]Cut-point for "meeting" PA guidelines was ≥60 min MVPA/day on 5 of 7 days (Mendoza et al. 2012).

[t]The quality of evidence from cross-sectional studies was downgraded from "low" to "very low" due to serious risk of bias in 24 studies that diminished the level of confidence in the observed effects.

favourable across all measures of adiposity, null and unfavourable associations were largely limited to sub-analyses of the data based on sex, age, adiposity measure/weight classification criteria, high/low fitness, and/or day of the week.

Fat free mass

Seven studies examined the relationships between PA and fat free mass (FFM) (Stevens et al. 2004; Lohman et al. 2006, 2008; Ness et al. 2007; Sayers et al. 2011; Jimenez-Pavon et al. 2013*a*; Taverno Ross et al. 2013). Measures of FFM were assessed objectively (e.g., calculated from sum of skinfolds or bioelectrical impedance, dual-energy X-ray absorptiometry; see Table 1 for summary of measures). One study used a longitudinal design, and 6 studies used a cross-sectional design.

The longitudinal study (Stevens et al. 2004) reported both favourable and null associations between total PA and FFM. Among the cross-sectional studies, 2/2 studies found at least 1 favourable association between total PA and FFM (Ness et al. 2007; Jimenez-Pavon et al. 2013*a*). There were favourable (2/4 studies; Sayers et al. 2011; Jimenez-Pavon et al. 2013*a*) or mixed (null and unfavourable; 2/4 studies; Lohman et al. 2006, 2008) associations between VPA and FFM. There were null (1/4 studies; Jimenez-Pavon et al. 2013*a*) and mixed (null and unfavourable; 3/4 studies; Lohman et al. 2006, 2008; Taverno Ross et al. 2013) associations between MVPA and FFM. MPA was not associated with FFM (0/2 studies; Sayers et al. 2011; Jimenez-Pavon et al. 2013*a*). Results for LPA were mixed; 1/2 studies found that LPA was favourably associated with FFM (Sayers et al. 2011), and 1/2 studies found that LPA was unfavourably associated with FFM in boys but not girls (Jimenez-Pavon et al. 2013*a*). When the direction of association was not uniform, mixed findings were largely limited to sub-analyses based on sex and/or outcome measurement tool.

Cardiometabolic biomarkers

Fifty-four studies examined the relationships between PA and cardiometabolic biomarkers (see Table 2 and Supplementary Table S2 (Supplementary Material B[2])). Two studies used a randomized design, 1 intervention study used a nonrandomized design, 7 studies used a longitudinal design, and 47 studies used a cross-sectional design or also reported cross-sectional findings. Composite risk scores and/or various individual risk factors (e.g., blood pressure (BP), blood lipids) were measured objectively (e.g., sphygmomanometer, blood sample analyses; see Table 2 for summary of measures). The quality of evidence ranged from very low to moderate across study designs (Table 2).

As summarized in Table 2, increasing MVPA in a randomized study resulted in larger reductions in cardiometabolic disease risk score, triglycerides, and glucose, and a greater increase in high-density lipoprotein (HDL) cholesterol in the intervention group compared with the control group (Kriemler et al. 2010). There were no between-group differences for BP (Kriemler et al. 2010) and intervention effects were no longer significant at 3-year follow-up (Meyer et al. 2014).

In the nonrandomized intervention study, a PA intervention had no effect on total cholesterol, HDL cholesterol, or triglycerides (Rowland et al. 1996).

Among the 7 longitudinal studies, total PA was favourably associated with HDL cholesterol (1/1 studies; Hjorth et al. 2014*a*) and diastolic BP (2/2 studies; Hallal et al. 2011; Knowles et al. 2013). Total PA was not associated with cardiometabolic disease risk score, mean arterial pressure, triglycerides (Hjorth et al. 2014*a*), or systolic BP (Hallal et al. 2011; Knowles et al. 2013). Total PA was not associated with the homeostatic model assessment of insulin resistance (HOMA-IR) after 200-day or 2-year follow-up (Telford et al. 2009; Hjorth et al. 2014*a*), but was associated with improved HOMA-IR 4 years after baseline assessment in boys but not girls (Telford et al. 2012*a*). A favourable prospective association was reported between MVPA and HDL cholesterol (Hjorth et al. 2014*a*);

Table 3. The relationship between physical activity and physical fitness.

No. of participants (no. of studies)	Design	Quality assessment					Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other		
1113 (6)	Randomized trials[a]	Serious risk of bias[b]	No serious inconsistency	Serious indirectness[c]	No serious imprecision	None	***Aerobic fitness:*** **2 studies** reported a favourable effect of PA interventions on aerobic fitness at post-test (Kriemler et al. 2010) and 6-mo and 2-y follow-up (Eather et al. 2013; Meyer et al. 2014); **2 studies** reported no effect (Verstraete et al. 2007; Finkelstein et al. 2013)[d] ***Muscular strength and endurance:*** **1 study** reported a favourable effect of PA interventions on upper and lower-body muscular fitness at post-test; these differences were no longer significant after 3 mo (Meinhardt et al. 2013); **1 study** reported no effect at post-test (Verstraete et al. 2007); **1 study** reported mixed favourable and null findings at 6-mo follow up (Eather et al. 2013) ***Flexibility:*** **1 study** reported no effect at post-test (Verstraete et al. 2007); **1 study** reported a favourable effect of PA on flexibility at 6-mo follow-up (Eather et al. 2013)	LOW[e]
242 (3)	NRT[f]	Serious risk of bias[g]	No serious inconsistency	Serious indirectness[h]	No serious imprecision	None	***Aerobic fitness:*** **1 study** reported no effect of PA intervention on aerobic fitness (Rowland et al. 1996); **1 study** reported a favourable effect of PA intervention for INT compared with CTRL (Dimitriou et al. 2011); and **1 study** reported no differential effect of PA intervention on aerobic fitness between INT and CTRL, however, the intervention group decreased from baseline to post-test (Shore et al. 2014) ***Muscular strength and endurance:*** **1 study** reported a favourable effect of PA intervention on upper-body strength for INT compared with CTRL (Dimitriou et al. 2011); and **1 study** reported no differential effect of PA intervention on muscular fitness; however, the control group improved upper body strength from baseline to post-test (Shore et al. 2014) ***Flexibility:*** **1 study** reported a favourable differential effect of PA intervention for INT compared with CTRL (Dimitriou et al. 2011) **1 study** reported no differential effect of a PA intervention on flexibility, and an increase from baseline to post-test for the intervention group (Shore et al. 2014)	VERY LOW[i]
315 (1)	Longitudinal[j]	No serious risk of bias	No serious inconsistency	No serious indirectness	Serious imprecision[k]	Dose–response gradient[l]	***Aerobic fitness:*** There was a favourable, dose-response gradient between **VPA** and aerobic fitness, and no association between **LPA** or **MPA** and aerobic fitness in **1 longitudinal study** (Carson et al. 2014)	VERY LOW[m]

Table 3 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment					Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other		
14 985 (28)	Cross-sectional[n]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	None	***Aerobic fitness:*** **Meeting/not meeting PA guidelines (≥60 min/day MVPA):** favourable associations (**3/3 studies;** Ortega et al. 2008; Martinez-Gomez et al. 2010*a*; Silva et al. 2013) **Total PA:** associations were favourable (**14/18 studies;** Eiberg et al. 2005; Andersen et al. 2006; Ruiz et al. 2006; Butte et al. 2007*b*; Hands et al. 2009; Schofield et al. 2009; Ruiz et al. 2011; Machado-Rodrigues et al. 2012; Martinez-Gomez et al. 2012; Hjorth et al. 2013; Lambourne et al. 2013; Hansen et al. 2014; Larouche et al. 2014; Saavedra et al. 2014) or mixed (favourable and null; **4/18 studies;** Rizzo et al. 2007; Dencker et al. 2010; Kristensen et al. 2010; Jimenez-Pavon et al. 2013*c*)[o] **VPA:** associations were favourable (**11/12 studies;** Gutin et al. 2005*a*; Ruiz et al. 2006; Butte et al. 2007*b*; Rizzo et al. 2007; Lohman et al. 2008; Martinez-Gomez et al. 2010*a*, 2012; Kristensen et al. 2010; Ottevaere et al. 2011; Hay et al. 2012; Jimenez-Pavon et al. 2013*c*) or mixed (favourable and null; **1/12 studies;** Dencker et al. 2010)[p] **MVPA:** associations were favourable (**14/16 studies;** Eiberg et al. 2005; Gutin et al. 2005*a*; Ruiz et al. 2006, 2011; Butte et al. 2007*b*; Lohman et al. 2008; Ortega et al. 2008; Martinez-Gomez et al. 2010*a*, 2012; Ottevaere et al. 2011; Machado-Rodrigues et al. 2012; Hjorth et al. 2013; Silva et al. 2013; Santos et al. 2014), or mixed (favourable in boys, null in girls; **2/16 studies;** Dencker et al. 2010; Jimenez-Pavon et al. 2013*c*).[q] *Bouts of MVPA* were favourably associated with aerobic fitness in **2/2 studies** (Eiberg et al. 2005; Butte et al. 2007*b*) **MPA:** associations were favourable (**5/9 studies;** Gutin et al. 2005*a*; Ruiz et al. 2006; Martinez-Gomez et al. 2010*a*; Dencker et al. 2010; Ottevaere et al. 2011), mixed favourable and null (**2/9 studies;** Rizzo et al. 2007; Butte et al. 2007*b*), or null (**2/9 studies;** Hay et al. 2012; Martinez-Gomez et al. 2012)[r] **LPA:** associations were favourable (**1/6 studies;** Martinez-Gomez et al. 2010*a*), mixed favourable and null (**1/6 studies;** Butte et al. 2007*b*), or null (**4/6 studies;** Dencker et al. 2010; Hay et al. 2012; Machado-Rodrigues et al. 2012; Jimenez-Pavon et al. 2013*c*) ***Muscular strength and endurance:*** **Total PA:** associations were favourable (**2/4 studies;** Martinez-Gomez et al. 2012; Larouche et al. 2014), mixed favourable and null (**1/4 studies;** Hands et al. 2009), or null (**1/4 studies;** Moliner-Urdiales et al. 2010)[s]	LOW[u]

Table 3 (*continued*).

No. of participants (no. of studies)	Design	Quality assessment					Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other		
							VPA: associations were favourable (**1/2 studies;** Martinez-Gomez et al. 2012), or mixed favourable and null (**1/2 studies;** Moliner-Urdiales et al. 2010) **MVPA:** associations were favourable (**1/3 studies;** Martinez-Gomez et al. 2012), or mixed favourable and null (**2/3 studies;** Moliner-Urdiales et al. 2010; Aggio et al. 2015)[t] **MPA:** null associations (**2/2 studies;** Moliner-Urdiales et al. 2010; Martinez-Gomez et al. 2012) **LPA:** associations were null (**1/2 studies;** Moliner-Urdiales et al. 2010), or mixed null and unfavourable (**1/2 studies;** Aggio et al. 2015)	
							Flexibility: **Total PA:** associations were mixed favourable and null (**1/2 studies;** Hands et al. 2009) or null (**1/2 studies;** Larouche et al. 2014) **MVPA:** favourable associations (**1/1 studies;** Aggio et al. 2015) **LPA:** null associations (**1/1 studies;** Aggio et al. 2015)	

Note: The range of mean ages was 6.9 to 16.0 years. Data were collected by randomized trial, cross-sectionally and up to 3.75 years of follow-up. Fitness was assessed as: aerobic fitness ($\dot{V}O_{2max}$, $\dot{V}O_{2peak}$, CRF), muscular strength and endurance, and flexibility. All outcomes were measured objectively. CoSCIS, Prospective Copenhagen School Child Interventions Study; CRF, cardiorespiratory fitness; CTRL, control group; EYHS, European Youth Heart Study; HELENA, Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study; INT, intervention group; KISS, Kinder-Sportstudie; LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; NRT, nonrandomized trial; PA, physical activity; PACER, progressive aerobic cardiovascular endurance run; RCT, randomized controlled trial; $\dot{V}O_{2max}$, maximal oxygen uptake; $\dot{V}O_{2peak}$, peak oxygen uptake; VPA, vigorous-intensity physical activity.

[a]Includes **6 RCT studies** (Verstraete et al. 2007; Kriemler et al. 2010; Eather et al. 2013; Finkelstein et al. 2013; Meinhardt et al. 2013; Meyer et al. 2014) from **5 unique samples**. Kriemler et al. 2010 and Meyer et al. 2014 both report data from the KISS Study. Results are reported separately and participants are only counted once.

[b]Serious risk of bias. Unclear method of randomization for sibling pairs; allocation concealment unlikely; missing pedometer data disproportionately high in controls relative to intervention group (18.1% vs 6.1%), likely because of incentives for wear time offered to the intervention group only; control group wore sealed pedometers while intervention group wore unsealed pedometers; 6-min walk test assessors were not blinded to group assignment (Finkelstein et al. 2013). No allocation concealment, which was likely to contaminate the control group (Meinhardt et al. 2013). Teachers of control group classes were aware of intervention arm but not its content; drop-outs were older and had higher adiposity than adherers and differences likely related to outcome of interest (Meyer et al. 2014).

[c]Serious indirectness. Differences in intervention: randomized trials examined various types of PA programs and provided indirect evidence bearing on the potential effectiveness of different intensities and durations of PA. Indirect comparisons: different durations and intensities of PA were not compared.

[d]MVPA (but not total PA) was significantly greater in the intervention vs control group at post-intervention (post 9-month intervention group difference of ~11 min/day) (Kriemler et al. 2010); there was a trend toward higher levels of total PA (but not MVPA) in the intervention vs control group at 3-year follow-up (Cohen's $d = 0.35$, $p = 0.06$; not significant) (Meyer et al. 2014).

[e]The quality of evidence from randomized studies was downgraded from "high" to "low" because of (*i*) a serious risk of bias in three studies that diminished the level of confidence in the observed effects, and (*ii*) serious indirectness of the interventions and the comparisons being assessed.

[f]Includes **1 nonrandomized controlled trial** (Shore et al. 2014), **1 community trial** (Dimitriou et al. 2011), and **1 uncontrolled trial** (Rowland et al. 1996).

[g]Serious risk of bias. No inclusion/exclusion criteria established; inadequate reporting of recruitment, allocation concealment, and blinding; large unexplained loss to follow-up (36.5% retention) and unknown if follow-up differed by group allocation (Shore et al. 2014); selective reporting bias: reported use of PACER to measure aerobic fitness but did not report in results (Dimitriou et al. 2011).

[h]Serious indirectness. Differences in intervention: nonrandomized trials examined various types of PA programs and provided indirect evidence bearing on the potential effectiveness of different intensities and durations of PA. Indirect comparisons: different durations and intensities of PA were not compared.

[i]The quality of evidence from randomized studies was downgraded from "high" to "low" because of (*i*) a serious risk of bias in 2 studies that diminished the level of confidence in the observed effects, and (*ii*) serious indirectness of the interventions and the comparisons being assessed.

[j]Includes **1 longitudinal study** (Carson et al. 2014).

[k]Serious imprecision. Wide confidence intervals for dose–response trend (Carson et al. 2014).

[l]There was a positive, dose–response gradient between VPA and aerobic fitness (Carson et al. 2014).

[m]The quality of evidence from the longitudinal study was downgraded from "low" to "very low" because of imprecision (wide confidence intervals), and because of this limitation was not upgraded for the dose–response trend.

Table 3 (*concluded*).

[n]Includes **28 cross-sectional studies** (Eiberg et al. 2005; Gutin et al. 2005*a*; Andersen et al. 2006; Ruiz et al. 2006, 2011; Butte et al. 2007*b*; Rizzo et al. 2007; Lohman et al. 2008; Ortega et al. 2008; Hands et al. 2009; Schofield et al. 2009; 2012; Dencker et al. 2010; Kristensen et al. 2010; Martinez-Gomez et al. 2010*a*; Moliner-Urdiales et al. 2010; Ottevaere et al. 2011; Hay et al. 2012; Machado-Rodrigues et al. 2012; Hjorth et al. 2013; Jimenez-Pavon et al. 2013*c*; Lambourne et al. 2013; Silva et al. 2013; Larouche et al. 2014; Hansen et al. 2014; Santos et al. 2014; Saavedra et al. 2014; Aggio et al. 2015) from **17 unique samples**. **Five studies** reported data from the EYHS (Andersen et al. 2006, Ruiz et al. 2006; Ortega et al. 2008; Rizzo et al. 2008; Kristensen et al. 2010); **6 studies** reported data from HELENA (Martinez-Gomez et al. 2010*a*; Moliner-Urdiales et al. 2010; Ottevaere et al. 2011; Ruiz et al. 2011; Martinez-Gomez et al. 2012; Jimenez-Pavon et al. 2013*c*); **2 studies** reported data from the CoSCIS study (Eiberg et al. 2005; Dencker et al. 2010). Data are reported separately and participants are only counted once.

[o]Positive associations between Total PA and aerobic fitness were found in the total sample (Eiberg et al. 2005; Andersen et al. 2006; Ruiz et al. 2006, 2011; Rizzo et al. 2007; Martinez-Gomez et al. 2012), in boys but not girls (Dencker et al. 2010; Jimenez-Pavon et al. 2013*c*), and in 9-year olds but not 15-year olds (Kristensen et al. 2010).

[p]Dencker et al. (2010) reported a positive association between VPA and aerobic fitness for boys but not girls.

[q]Positive associations were reported between MVPA and aerobic fitness in the total sample (Eiberg et al. 2005; Martinez-Gomez et al. 2010*a*, 2012; Ottevaere et al. 2011; Ruiz et al. 2011) and in boys but not girls in subdivided samples (Dencker et al. 2010; Jimenez-Pavon et al. 2013*b*).

[r]From the HELENA cohort, Martinez-Gomez et al. (2010*a*) and Ottevaere et al. (2011) reported positive associations for MPA and aerobic fitness in total sample, Martinez-Gomez et al. (2012) reported a null association, and Jimenez-Pavon et al. (2013*c*) reported a positive association for boys, not girls. From the Viva la Familia study, Butte et al. (2007*b*) reported positive associations when controlling for BMI z-score but not %FM.

[s]Total PA was positively associated with standing broad jump and not associated with upper body and other lower body strength and endurance in boys, and not associated with any muscular fitness outcome in girls (Moliner-Urdiales et al. 2010). No correlation with abdominal muscle endurance (curl-ups) or upper body strength, but high tertiles of total PA had better upper body strength (grip strength) (Hands et al. 2009).

[t]MVPA was positively associated with lower body strength but not upper body strength in 1 study (Aggio et al. 2015), and not associated with upper and lower body strength in boys and girls, with the exception of a positive association for standing broad jump for boys (Moliner-Urdiales et al. 2010).

[u]The quality of evidence from randomized studies remained as "low" as there were no serious concerns about the quality of included cross-sectional studies or reasons to increase the rating.

Table 4. The relationship between physical activity and behavioural conduct/prosocial behaviour.

No. of participants (no. of studies)	Design	Quality assessment				Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
652 (1)	Cross-sectional[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	There was no association between *total PA* and **prosocial behaviour, peer problems, social acceptance** or **conduct problems** for boys or girls (Sebire et al. 2011). *MVPA* was favourably correlated with **peer problems** and **social acceptance** (in boys, not girls). *MVPA* was favourably associated with **prosocial behaviour** (in girls, not boys). *MVPA* was not associated with **conduct problems** in boys or girls	VERY LOW[c]

Note: Mean age was 10.92 years; data were collected cross-sectionally. Prosocial behaviour, conduct problems, and peer problems were assessed via the Strengths and Difficulties Questionnaire. Social acceptance was assessed via Harter's Self-perception Profile for Children. MVPA, moderate- to vigorous-intensity physical activity; PA, physical activity.

[a]Includes **1 cross-sectional study** (Sebire et al. 2011).

[b]Serious risk of bias. Complete data for only 66% of participants; no indication that data were missing at random. Internal consistency of the scales was questionable ($\alpha = 0.60$ to 0.66).

[c]The quality of evidence from this 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 5. The relationship between physical activity and cognition/academic achievement.

No of participants (no. of studies)	Design	Quality assessment				Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
92 (1)	NRT[a]	Serious risk of bias[b]	No serious inconsistency	Serious indirectness[c]	No serious imprecision	***Academic achievement:*** **GPA** increased in both groups, but there were no between-group differences (Shore et al. 2014)[d]	VERY LOW[e]
5440 (3)	Longitudinal[f]	Serious risk of bias[g]	No serious inconsistency	No serious indirectness	No serious imprecision	***Academic achievement:*** **School grades:** *%MVPA* at age 11 y was favourably associated with **English** (but not **Math** or **Science**), and with academic attainment at age 13 and 16 y in boys and girls (association also significant for **Science** in girls at age 16 y) (Booth et al. 2014) **Standardized tests:** **1 study** found *PA index* was favourably associated with **writing** score, but not **reading** or **numeracy** (Telford et al. 2012*b*) ***Cognition:*** **Executive function tests (CDR):** **1 study** found no association between *total PA* or *% time in MVPA* at age 11 y and test speed or accuracy at age 13 y. In boys, *%MVPA* (adjusted for total PA) was favourably associated with accuracy, but not speed. In girls, no association with speed or accuracy (Booth et al. 2013)	VERY LOW[h]
11 996 (6)	Cross-sectional[i]	Serious risk of bias[j]	Serious inconsistency[k]	No serious indirectness	No serious imprecision	***Academic achievement:*** **Standardized tests:** *Total PA:* **2/2 studies** reported no association between *total PA* and WIAT-III (Lambourne et al. 2013; Hansen et al. 2014). *MPA, MVPA, VPA:* **1/3 studies** reported mixed unfavourable and null associations between *MVPA* and **state Math test** performance with inconsistencies occurring across samples (Young et al. 2014) **1/3 studies** reported mixed favourable and null associations, with *%MVPA* favourably associated with **English** (but not **Math** or **Science**) scores in boys, and **English** and **Science** (but not **Math**) scores in girls (Booth et al. 2014) **School grades:** **1/3 studies** found *MPA, MVPA,* and *VPA* were unfavourably associated with **Math** and **Language scores,** and **GPA** (Esteban-Cornejo et al. 2014) ***Cognition:*** *Total PA and MVPA:* **Executive function tests (TEA-Ch, CDR):** **1/1 studies** reported mixed null and favourable associations between *total PA* or *%MVPA* and **test speed and accuracy** (Booth et al. 2013)	VERY LOW[l]

Note: The range of mean ages was 7.8 to 16.9 years. Data were collected by nonrandomized intervention trial, cross-sectionally, and up to 5 years of follow-up. Cognitive development/academic achievement was assessed by WIAT-III, TEA-Ch, CDR, computerized cognitive assessment system, school records, and GPA, and state or national level standardized tests. All outcomes were measured objectively. ALSPAC, Avon Longitudinal Study of Parents and Children; CDR, Cognitive Drug Research; GPA, grade point average; MPA, moderate-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; NRT, nonrandomized trial; PA, physical activity; TEA-Ch, Test of Everyday Attention for Children; VPA, vigorous-intensity physical activity; WIAT-III, Weschsler Individual Achievement Test of oral language, written language and mathematics-Third Edition.

[a]Includes **1 nonrandomized trial** (Shore et al. 2014).

Table 5 (*concluded*).

[b]Serious risk of bias. No inclusion/exclusion criteria established; inadequate reporting of recruitment, allocation concealment, and blinding; large unexplained loss to follow-up (36.5% retention) and unknown if follow-up differed by group allocation (Shore et al. 2014).

[c]Serious indirectness. Differences in intervention: studies examined physical education class content and provided indirect evidence bearing on the potential effectiveness of different intensities and durations of PA. Indirect comparisons: different durations and intensities of PA were not compared within individual studies.

[d]The intervention group increased steps/day (baseline to post-intervention: 9692 to 12 307) more than the control group (9420 to 10 608) (Shore et al. 2014).

[e]The quality of evidence from the nonandomized study was downgraded from "low" to "very low" because of (*i*) a serious risk of bias that diminished the level of confidence in the observed effects, and (*ii*) serious indirectness of the intervention and the comparison being assessed.

[f]Includes **3 longitudinal studies** (Telford et al. 2012*b*; Booth et al. 2013, 2014) from **2 unique samples**. **Two studies** reported data from the ALSPAC sample (Booth et al. 2013, 2014); results are reported separately and participants are only counted once.

[g]Serious risk of bias. Validity and reliability of outcomes unknown (Telford et al. 2012*b*; Booth et al. 2013, 2014).

[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 **6 cross-sectional studies** (Booth et al. 2013, 2014; Lambourne et al. 2013; Esteban-Cornejo et al. 2014; Hansen et al. 2014; Young et al. 2014) from **5 unique samples**. **Two studies** reported data from the ALSPAC sample (Booth et al. 2013, 2014); results are reported separately and participants are only counted once.

[j]Serious risk of bias. Valid PA data missing for 41.5% of the sample (Hansen et al. 2014). Validity and reliability of outcomes unknown (Booth et al. 2013, 2014; Esteban-Cornejo et al. 2014; Young et al. 2014).

[k]Serious inconsistency. **Two studies** found unfavourable associations (between PA (MPA, MVPA, VPA) and GPA (Esteban-Cornejo et al. 2014), and between MVPA and state Math test performance (Young et al. 2014)), **2 studies** found no associations (between total PA and WIAT-III (Lambourne et al. 2013; Hansen et al. 2014)), and **2 studies** found no or favourable associations (between PA (total, %MVPA) and executive function tests (Booth et al. 2013); and between %MVPA and national English, Math, and Science test scores (Booth et al. 2014)).

[l]The quality of evidence from cross-sectional studies was downgraded from "low" to "very low" because of (*i*) a serious risk of bias in five studies that diminished the level of confidence in the observed effects, and (*ii*) large unexplained inconsistency among the findings.

however, findings were null for BP (pre-high BP, high-BP (de Moraes et al. 2015), diastolic BP, systolic BP (Knowles et al. 2013), mean arterial pressure (Hjorth et al. 2014*a*)); triglycerides; HOMA-IR; and cardiometabolic disease risk score (Hjorth et al. 2014*a*). VPA, MPA, and LPA were not prospectively associated with systolic BP (1/1 studies; Carson et al. 2014).

Forty-seven studies examined relationships between PA and cardiometabolic biomarkers cross-sectionally. Fifteen studies specifically examined a composite cardiometabolic disease risk score. Total PA was favourably associated with cardiometabolic disease risk score in 3/7 studies (Brage et al. 2004*b*; Ekelund et al. 2009; Jimenez-Pavon et al. 2013*b*), and not associated in 4/7 studies (Rizzo et al. 2007; Schofield et al. 2009; Moreira et al. 2011; Hjorth et al. 2014*a*). Longer durations of VPA (1/2 studies), MVPA (7/8 studies), and MPA (2/2 studies) were associated with lower cardiometabolic disease risk score (Table 2). One study measured LPA and found no association with cardiometabolic disease risk score (Stabelini Neto et al. 2014). No studies reported unfavourable associations between PA and cardiometabolic disease risk score.

Regarding individual cardiometabolic biomarkers, total PA was favourably associated with diastolic BP (7/8 studies), systolic BP (4/8 studies), triglycerides (5/7 studies), total cholesterol (2/2 studies), insulin resistance (5/7 studies), fasting insulin (10/11 studies), fasting glucose (4/7 studies), and carotid-femoral pulse-wave velocity (1/1 studies) (Table 2). Associations between total PA and the remaining cardiometabolic biomarkers were mixed (favourable and null; hypertension, HDL cholesterol) or nonsignificant (mean arterial pressure, glycosylated hemoglobin (HbA1c), inflammatory markers (C-reactive protein, interleukin-6 (IL-6), tumor necrosis factor alpha (TNF-α), complement factors 3 and 4 (C3, C4)), alanine amino transferase status, rate pressure product, homocysteine, carotid intima-media thickness) (Table 2).

VPA was favourably associated with fasting insulin (2/4 studies; Rizzo et al. 2008; Jimenez-Pavon et al. 2012), but did not have consistent associations with any other cardiometabolic biomarkers (Table 2).

MVPA was favourably associated with hypertension (1/1 studies), BP *z* score (1/1 studies), systolic BP (5/9 studies), HOMA-IR (4/7 studies), fasting insulin (7/9 studies), non-HDL cholesterol (1/1 studies), and high-risk cholesterol (1/1 studies) (Table 2). Associations between MVPA and the remaining cardiometabolic biomarkers were mixed (favourable or null; diastolic BP, triglycerides, HDL cholesterol, total cholesterol, fasting glucose, C-reactive protein, cardiac sympathetic/parasympathetic modulation) or nonsignificant (mean arterial BP, low-density lipoprotein cholesterol, other measures of insulin resistance (aside from HOMA-IR; i.e., Matsuda IR score, QUICKI, oral glucose tolerance test results, 2-h plasma glucose), HbA1c, inflammatory markers (IL-6, TNF-α, C3, C4), homocysteine, artery properties) (Table 2).

MPA was favourably associated with BP *z* score (1/1 studies; Stabelini Neto et al. 2014), HOMA-IR (1/2 studies; Rizzo et al. 2008), and fasting insulin (2/3 studies; Butte et al. 2007*b*; Rizzo et al. 2008) but was not associated with any other cardiometabolic biomarkers (Table 2).

There were favourable associations between LPA and diastolic BP (1/1 studies; Carson et al. 2013) and BP *z* score (1/1 studies; Stabelini Neto et al. 2014), and mixed (favourable or null; HDL cholesterol, fasting insulin) or nonsignificant (triglycerides, systolic BP, insulin resistance, fasting glucose, C-reactive protein, alanine amino transferase status) associations with the remaining cardiometabolic biomarkers (Table 2).

Physical fitness

Thirty-eight studies examined the relationship between PA and fitness (see Table 3 and Supplementary Table S3 (Supplementary Material B[2])). Six studies used a randomized design, 3 intervention studies used a nonrandomized design, 1 study used a longitudinal design, and 28 studies used a cross-sectional design or also reported

Table 6. The relationship between physical activity and quality of life/well-being.

No. of participants (no. of studies)	Design	Quality assessment				Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
687 (3)	Randomized trial[a]	Serious risk of bias[b]	No serious inconsistency	Serious indirectness[c]	No serious imprecision	**2 studies** reported no difference between intervention and control groups in physical and psychological quality of life post-intervention (Kriemler et al. 2010) or at 3-y follow-up (Meyer et al. 2014).[d] **1 study** reported no differences between groups in PedsQL scores (physical, psychosocial health, aggregate) (Finkelstein et al. 2013)[e]	LOW[f]
1021 (2)	Cross-sectional[g]	Serious risk of bias[h]	No serious inconsistency	No serious indirectness	No serious imprecision	***Meeting/not meeting guidelines:*** **1/1 studies** reported that boys (but not girls) *not meeting PA guidelines* had higher odds of having less-than-excellent self-rated health compared with those *meeting PA guidelines* (Herman et al. 2014) ***Total PA:*** **1/1 studies** reported that *total PA* (steps/day) was positively correlated with quality of life (Standage et al. 2012) ***MVPA:*** **1/1 studies** reported that boys (but not girls) in the lowest tertile of *MVPA* had higher odds of having less-than-excellent self-rated health compared to those in the highest tertile of *MVPA* (Herman et al. 2014)	VERY LOW[i]

Note: The range of mean ages was 6.9 to 12.6 years. Data were collected by randomized trial and cross-sectionally. Quality of life was assessed by self-report with the Child Health Questionnaire, PedsQL 4.0 (Scores: physical health, psychosocial health, and aggregate; health-related quality of life composite score), and the question "In general, is your health excellent, mostly good, or not very good?" KISS, Kinder-Sportstudie; MVPA, moderate- to vigorous-intensity physical activity; PA, physical activity; PedsQL, Pediatric Quality of Life Questionnaire; RCT, randomized controlled trial.

[a]Includes **3 RCT studies** (Kriemler et al. 2010; Finkelstein et al. 2013; Meyer et al. 2014) from **2 unique samples**. Kriemler et al. 2010 and Meyer et al. 2014 report data from the KISS study; results are reported separately and participants are only counted once.

[b]Serious risk of bias. Unclear method of randomization for sibling pairs; allocation concealment unlikely; missing pedometer data disproportionately high in controls relative to intervention group (18.1% vs 6.1%), likely because of incentives for wear time offered to the intervention group only; control group wore sealed pedometers while intervention group wore unsealed pedometers; 6-min walk test assessors were not blinded to group assignment (Finkelstein et al. 2013).

[c]Serious indirectness. Indirect comparisons: different durations and intensities of physical activity were not compared.

[d]MVPA (but not total PA) was significantly greater in the intervention vs control group at post-intervention (post 9-month intervention group difference of ~11 min/day) (Kriemler et al. 2010); there was a trend toward higher levels of total PA (but not MVPA) in the intervention vs control group at 3-y follow-up (Cohen's $d = 0.35$, $p = 0.06$; not significant) (Meyer et al. 2014).

[e]The intervention group had greater total PA (steps/day) vs the control group at the end of the 9-month intervention (Finkelstein et al. 2013).

[f]The quality of evidence from randomized studies was downgraded from "high" to "low" because of (*i*) a serious risk of bias in one study that diminished the level of confidence in the observed effects, and (*ii*) serious indirectness of comparisons.

[g]Includes **2 cross-sectional studies** (Standage et al. 2012; Herman et al. 2014).

[h]Serious risk of bias. One of the measures of quality of life was not a validated tool, was only 1 question, and was dichotomized arbitrarily (excellent vs. not excellent) instead of using a supported (i.e. clinical) cut-point (Herman et al. 2014). Possible attrition bias: the final sample was only 58% of original sample (Standage et al. 2012).

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

Table 7. The relationship between physical activity and bone health.

No. of participants (no of studies)	Design	Quality assessment				Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
73 (1)	Randomized trials[a]	No serious risk of bias	No serious inconsistency	Serious indirectness[b]	No serious imprecision	In both groups, **BMD** increased more during periods of physical training than during periods of no physical training (Gutin et al. 1999)	MODERATE[c]
948 (7)	Longitudinal[d]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	**Total PA:** **1 study** reported that baseline *total PA* predicted follow-up **BMC** at the **hip, trochanter, spine,** and **whole body** in *boys* and at the **trochanter** and **whole body** in *girls* (data not shown). **Total PA** explained 1%–2% of the variability in **BMC** (Janz et al. 2006) Children who maintained **high levels of PA** over the 3-y period (≥50th percentile) accrued, on average, 14% more **trochanteric BMC** and 5% more **whole-body BMC** relative to peers maintaining **low levels of PA** (<50th percentile) (Janz et al. 2006) **1 study** found that spending a higher proportion of total PA in MPA-VPA relative to LPA was favourably associated with **BMC, BMD,** and **bone area** (Heidemann et al. 2013) **VPA:** **Hip** and **spine BMC:** mixed (favourable and null) associations (**2/2 studies;** Francis et al. 2014; Janz et al. 2014*a*) **MVPA:** **Whole-body, spine,** and **hip BMC:** mixed (favourable and null) associations (**3/3 studies;** Janz et al. 2010, 2014*b*; Francis et al. 2014); **Hip BMD:** mixed (favourable and null) associations (**1/1 studies;** Janz et al. 2014b) **Femoral neck cross-sectional area** and **section modulus:** mixed (favourable and null) associations (**2/2 studies;** Janz et al. 2007, 2014*b*); **Measures of bone strength** (**bone stress index** and **polar moment of inertia**): mixed (favourable and null) associations (**1/1 studies;** Janz et al. 2014*b*)	LOW[e]
6520 (14)	Cross-sectional[f]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	***Meeting/not meeting guidelines (≥60 min/day MVPA):*** **1 study** reported that meeting guidelines had no association with **BMC** (whole body, hip, lumbar spine, trochanter, intertrochanter, femoral) (Gracia-Marco et al. 2011*a*) **1 study** reported that meeting guidelines had mixed favourable, null, and unfavourable associations with **BMC** of at least 1 anatomical region (**whole body, upper limb, lower limb)** (Gracia-Marco et al. 2011*b*) **1 study** reported that meeting guidelines had mixed favourable (girls) and null (boys) associations (**lumbar spine**) or null associations (**whole body, hip, trochanter, intertrochanter** or **femoral neck**) with **BMD** (Gracia-Marco et al. 2011*a*)	LOW[g]

Table 7 (*continued*).

No. of participants (no of studies)	Design	Quality assessment				Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
						Total PA: **Total PA and BMC:** *Whole-body BMC:* associations were favourable (**1/2 studies;** Gracia-Marco et al. 2012), or mixed (favourable in boys, null in girls; **1/2 studies**; Janz et al. 2001); *Hip BMC:* favourable associations (**2/2 studies;** Janz et al. 2001; Gracia-Marco et al. 2012); *Spine BMC:* favourable association (**1/1 studies;** Janz et al. 2001) **Total PA and BMD:** *Whole-body BMD:* null associations (**1/1 studies;** Janz et al. 2001); *Hip BMD:* favourable associations (**1/1 studies;** Janz et al. 2001); *Spine BMD:* mixed (null in boys, favourable in girls) associations (**1/1 studies;** Janz et al. 2001); *Calcaneal and distal forearm BMD:* favourable associations (**1/1 studies;** Hasselstrøm et al. 2007) **Total PA and Area and strength:** *Total skeletal area:* favourable associations (**1/1 studies;** Janz et al. 2001) **Femur** and **tibia strength index/strength-strain index:** mixed (favourable and null) associations (**1/1 studies;** Farr et al. 2011) ***VPA:*** **VPA and BMC:** *Whole-body BMC:* associations were favourable (**1/1 studies;** Tobias et al. 2007) or mixed (favourable in boys, null in girls; **1/1 studies;** Janz et al. 2001); *Whole-body BMC adjusted for bone area:* null associations (**1/1 studies;** Tobias et al. 2007); *Hip BMC:* favourable associations (**2/2 studies;** Janz et al. 2001, 2014*a*); *Spine BMC:* associations were favourable (**2/3 studies;** Janz et al. 2001 and 2014*a*) or null (**1/3 studies;** Francis et al. 2014) *Upper limb* absolute *BMC:* favourable associations (**1/1 studies;** Tobias et al. 2007); *Lower limb* absolute *BMC:* null associations (**1/1 studies;** Tobias et al. 2007); *Upper and lower limb* areal *BMC:* null associations (**1/1 studies;** Tobias et al. 2007); *Cortical BMC:* favourable associations (**1/1 studies**; Sayers et al. 2011) **VPA and BMD:** *Whole-body BMD:* associations were favourable (**1/2 studies;** Tobias et al. 2007) or null (**1/2 studies**; Janz et al. 2001); *Whole-body* areal *BMD:* favourable associations (**1/1 studies;** Tobias et al. 2007); *Hip BMD:* favourable associations (**1/1 studies;** Janz et al. 2001);	

Table 7 (*continued*).

No. of participants (no of studies)	Design	Quality assessment				Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
						Spine BMD: mixed (null in boys, favourable in girls) associations (**1/1 studies;** Janz et al. 2001); *Calcaneal and distal forearm:* favourable associations (**1/1 studies;** Hasselstrøm et al. 2007); *Upper limb* absolute *or* areal *BMD:* favourable associations (**1/1 studies;** Tobias et al. 2007); *Lower limb* absolute *or* areal *BMD:* null associations (**1/1 studies;** Tobias et al. 2007); *Femoral neck, trochanter and intertrochanter BMD:* favourable associations (**1/1 studies;** Cardadeiro et al. 2012); *Cortical BMD:* unfavourable associations (**1/1 studies;** Sayers et al. 2011); BMD ratios: null (femoral neck to intertrochanter, trochanter to intertrochanter) or mixed (null in boys, negative in girls; femoral neck to intertrochanter) associations (**1/1 studies;** Cardadeiro et al. 2012) **VPA and area and strength:** *Total skeletal area:* favourable association (**1/1 studies;** Janz et al. 2001); *Cortical bone area:* favourable association (**1/1 studies;** Sayers et al. 2011); *Periosteal circumference of the tibia:* positive association (**1/1 studies;** Sayers et al. 2011); *Endosteal circumference of the tibia:* negative association (**1/1 studies;** Sayers et al. 2011); *Cross-sectional area and section modulus of narrow neck, intertrochantic and shaft regions of femur:* favourable associations (**1/1 studies;** Janz et al. 2004) ***MVPA:*** **MVPA and BMC:** *Whole-body BMC:* mixed (favourable and null) associations (**1/1 studies;** Janz et al. 2008); *Hip BMC:* favourable associations (**2/2 studies;** Janz et al. 2008, 2014*a*); *Spine BMC:* mixed (favourable in boys, null in girls) associations (**2/3 studies;** Janz et al. 2008, 2014*a*), or null associations (**1/3 study;** Francis et al. 2014) **MVPA and BMD:** *Femoral neck, trochanter, and intertrochanter BMD:* null associations (**1/1 studies;** Cardadeiro et al. 2012); *BMD ratios:* null (femoral neck to trochanter, trochanter to intertrochanter) or mixed (null in boys, positive in girls; femoral neck to intertrochanter) associations (**1/1 studies;** Cardadeiro et al. 2012)	

Table 7 (*continued*).

No. of participants (no of studies)	Design	Quality assessment				Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
						MPA: **MPA and BMC:** *Whole-body* absolute *or* areal *BMC:* favourable associations (**1/1 studies;** Tobias et al. 2007); *Upper limb* absolute *or* areal *BMC:* null associations (**1/1 studies;** Tobias et al. 2007); *Lower limb* absolute *or* areal *BMC:* favourable associations (**1/1 studies;** Tobias et al. 2007); *Cortical BMC:* null associations (**1/1 studies**; Sayers et al. 2011) **MPA and BMD:** *Whole-body* absolute *or* areal *BMD:* favourable associations (**1/1 studies;** Tobias et al. 2007); *Upper limb absolute or areal BMD:* null associations (**1/1 studies;** Tobias et al. 2007); *Lower limb* absolute *or* areal *BMD:* favourable associations (**1/1 studies;** Tobias et al. 2007); *Femoral neck, trochanter, intertrochanter BMD:* null associations (**1/1 studies;** Cardadeiro et al. 2012); *Cortical BMD:* null associations (**1/1 studies;** Sayers et al. 2011); *BMD ratios:* null (femoral neck to trochanter, femoral neck to intertrochanter, trochanter to intertrochanter; **1/1 studies;** Cardadeiro et al. 2012) **MPA and area and strength:** *Cortical bone area:* favourable association (**1/1 studies;** Sayers et al. 2011); *Periosteal and endosteal circumference of the tibia:* null associations (**1/1 studies;** Sayers et al. 2011); *Cross-sectional area of femoral shaft:* favourable associations (**1/1 studies;** Janz et al. 2004); *Section modulus of femoral shaft:* mixed (null in boys, favourable in girls) associations (**1/1 studies;** Janz et al. 2004); *Cross-sectional area and section modulus of narrow neck and intertrochantic regions of femur:* mixed (null in boys, favourable in girls) associations (**1/1 studies;** Janz et al. 2004) ***LPA:*** **LPA and BMC:** *Whole-body* absolute *or* areal *BMC:* null associations (**1/1 studies**; Tobias et al. 2007); *Upper or lower limb* absolute *BMC:* favourable associations (**1/1 studies;** Tobias et al. 2007); *Upper or lower limb* areal *BMC:* null associations (**1/1 studies;** Tobias et al. 2007); *Cortical BMC:* null associations (**1/1 studies**; Sayers et al. 2011)	

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Table 7 (*concluded*).

No. of participants (no of studies)	Design	Quality assessment				Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
						LPA and BMD: *Whole-body BMD:* favourable associations (**1/1 studies;** Tobias et al. 2007); *Whole-body* areal *BMD:* null associations (**1/1 studies;** Tobias et al. 2007); *Upper and lower limb* absolute *or* areal *BMD:* favourable associations (**1/1 studies;** Tobias et al. 2007); *Cortical BMD:* unfavourable association (**1/1 studies;** Sayers et al. 2011) **LPA and area and strength:** *Cortical bone area:* null association (**1/1 studies**; Sayers et al. 2011); *Periosteal circumference of the tibia:* positive association (**1/1 studies;** Sayers et al. 2011); *Endosteal circumference of the tibia:* null association (**1/1 studies;** Sayers et al. 2011) ***Other (impact measured by g-band):*** **1/1 studies** (Deere et al. 2012) found both favourable (higher impacts) and null (lower impacts) associations between impact and **BMD** (femoral neck, hip), **hip structure** (femoral neck width, cross-sectional area, cortical thickness), and **predicted strength** (cross-sectional moment of inertia). A dose–response gradient was found for higher impact activity and **BMD** (femoral neck, total hip)	

Note: The range of mean ages was 5.2 to 17.7 years. Data were collected by randomized trial, cross-sectionally, and up to 12 years of follow-up. Measures included: BMD, BMC, scanned area, cross-sectional area, total skeletal area, section modulus, bone stress index, femur and tibia bone strength index, strength-strain index, polar moment of inertia, cross-sectional moment of inertia, periosteal and endosteal circumference, cortical thickness, cortical BMC, cortical bone area, and BMD ratios (femoral neck to trochanter, femoral neck to intertrochanter, trochanter to intertrochanter). All outcomes were measured objectively by DXA or peripheral quantitative CT. ALSPAC, Avon Longitudinal Study of Parents and Children; BMC, bone mineral content; BMD, bone mineral density; CHAMPS, Childhood Health, Activity, and Motor Performance School Study; CoSCIS, Prospective Copenhagen School Child Interventions Study; CT, computer tomography; DXA, dual-energy x-ray absorptiometry; EYHS, European Youth Heart Study; HELENA, Healthy Lifestyle in Europe by Nutrition in Adolescence Cross-Sectional Study; LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; PA, physical activity; VPA, vigorous-intensity physical activity.

[a]Includes **1 randomized controlled trial** (Gutin et al. 1999).

[b]Serious indirectness. Differences in intervention: the randomized controlled trial examined a training program that provided indirect evidence bearing on the potential effectiveness of different intensities and durations of PA. Indirect comparisons: different durations and intensities of PA were not compared.

[c]The quality of the evidence from the randomized study was downgraded from "high" to "moderate" because of serious indirectness of the intervention being assessed.

[d]Includes **7 longitudinal studies** (Janz et al. 2006, 2007, 2010, 2014*a*, 2014*b*; Heidemann et al. 2013; Francis et al. 2014) from **2 unique samples**. **Six studies** reported data from the Iowa Bone Development Study (Janz et al. 2006, 2007, 2010, 2014*a*, 2014*b*; Francis et al. 2014) and **1 study** reported data from the CHAMPS study sample (Heidemann et al. 2013). Results are reported separately and participants are only counted once.

[e]The quality of evidence from longitudinal studies remained rated as "low" as there were no serious limitations across studies or reasons to upgrade.

[f]Includes **14 cross-sectional studies** (Janz et al. 2001, 2004, 2008, 2014*a*; Hasselstrøm et al. 2007; Tobias et al. 2007; Farr et al. 2011; Gracia-Marco et al. 2011*a*, 2011*b*, 2012; Sayers et al. 2011; Cardadeiro et al. 2012; Deere et al. 2012; Francis et al. 2014), from **6 unique samples**. **Five** studies reported data from the Iowa Bone Development Study (Janz et al. 2001, 2004, 2008, 2014*a*; Francis et al. 2014), **3 studies** from the ALSPAC (Tobias et al. 2007; Sayers et al. 2011; Deere et al. 2012), **3 studies** from HELENA (Gracia-Marco et al. 2011*a*, 2011*b*, 2012), and **1 study** from each of CoSCIS (Hasselstrøm et al. 2007), EYHS (Cardadeiro et al. 2012), and Jump-In: Building Better Bones (Farr et al. 2011). Results are reported separately and participants are only counted once.

[g]The quality of the evidence from cross-sectional studies remained rated as "low" as there were no serious limitations across studies or reasons to upgrade.

Table 8. The relationship between physical activity and motor skill development.

No. of participants (no. of studies)	Design	Quality assessment				Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
111 (1)	Randomized trials[a]	Serious risk of bias[b]	No serious inconsistency	Serious indirectness[c]	No serious imprecision	**1/1 studies** found no between-group differences in motor skill development after a PA intervention (Verstraete et al. 2007)	LOW[d]
92 (1)	NRT[e]	Serious risk of bias[f]	No serious inconsistency	Serious indirectness[g]	No serious imprecision	**1/1 studies** found no between-group differences in motor skill development after a PA intervention, but there were significant decreases within both the INT and CTRL groups (Shore et al. 2014)	LOW[h]
790 (1)	Longitudinal[i]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	***Total PA:*** null associations (**1/1 studies;** Telford et al. 2013)	LOW[j]
4389 (5)	Cross-sectional[k]	Serious risk of bias[l]	No serious inconsistency	No serious indirectness	No serious imprecision	***Total PA:*** associations were favourable (**3/5 studies;** Martinez-Gomez et al. 2012; Morrison et al. 2012; Larouche et al. 2014) or null (**2/5 studies;** Hands et al. 2009; Telford et al. 2013) ***VPA:*** favourable associations (**1/1 studies;** Martinez-Gomez et al. 2012) ***MVPA:*** favourable associations (**1/1 studies;** Martinez-Gomez et al. 2012) ***MPA:*** null associations (**1/1 studies;** Martinez-Gomez et al. 2012)	VERY LOW[m]

Note: The range of mean ages was 6.7 to 14.8 years. Data were collected by randomized trial, cross-sectionally, and up to 2 years of follow-up. Motor skill development was assessed by: flamingo balance test, plate tapping test, CAPL obstacle course, KTK test battery, AST throwing accuracy test, eye–hand coordination throw and wall-rebound catch test, a neuromuscular development index, and a 4×10-m and a 30 feet shuttle-run test of speed-of movement, agility, and coordination. All outcomes were measured objectively. AST, Allgemeiner sportmotorischer Test für Kinder; CAPL, Canadian Assessment of Physical Literacy; CTRL, control group; INT, intervention group; KTK, Koordinations Test für Kinder; MPA, moderate-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; NRT, nonrandomized trial; PA, physical activity; total PA, total physical activity; VPA, vigorous-intensity physical activity.

[a]Includes **1 clustered randomized controlled trial** (Verstraete et al. 2007).

[b]Serious risk of bias. Participants are a subset (with objective PA measurement) from a larger sample; only ~35% of those randomly selected to be in the subsample had parental consent and it is unclear whether they differed systematically from the rest of the participants. There was no mention of blinding, and it is possible that this could have influenced the outcome measurements (Verstraete et al. 2007).

[c]Serious indirectness. Differences in intervention: randomized trials examined various types of PA programs and provided indirect evidence bearing on the potential effectiveness of different intensities and durations of PA. Indirect comparisons: different durations and intensities of PA were not compared.

[d]The quality of evidence from randomized studies was downgraded from "high" to "low" because of (*i*) a serious risk of bias that diminished the level of confidence in the observed effects, and (*ii*) serious indirectness of comparisons.

[e]Includes **1 nonrandomized intervention trial** (Shore et al. 2014).

[f]Serious risk of bias. No inclusion/exclusion criteria established; inadequate reporting of recruitment, allocation concealment, and blinding; large unexplained loss to follow-up (36.5% retention); and unknown if follow-up differed by group allocation (Shore et al. 2014).

[g]Serious indirectness. Indirect comparisons: different durations and intensities of PA were not compared.

[h]The quality of evidence from nonrandomized intervention studies was downgraded from "high" to "low" because of (*i*) a serious risk of bias that diminished the level of confidence in the observed effects, and (*ii*) serious indirectness of comparisons.

[i]Includes **1 longitudinal study** (Telford et al. 2013).

[j]The quality of evidence remained rated as "low" as there were no concerns regarding study quality and no reasons to increase the rating.

[k]Includes and **5 cross-sectional studies** (Hands et al. 2009; Martinez-Gomez et al. 2012; Morrison et al. 2012; Larouche et al. 2014) or cross-sectional analysis (Telford et al. 2013).

[l]Serious risk of bias. Participants were asked to report their step counts in a diary, which may have introduced a social desirability bias (Larouche et al. 2014). Participants who did not provide acceptable pedometer data performed more poorly on the obstacle course (Larouche et al. 2014). Validity and reliability of the AST throwing task is unknown (Morrison et al. 2012). No reported reliability/validity of neuromuscular development index (Hands et al. 2009). Insufficient information to permit judgment of attrition bias (Hands et al. 2009; Martinez-Gomez et al. 2012).

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

Table 9. The relationship between physical activity and psychological distress.

No. of participants (no. of studies)	Design	Quality assessment				Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
736 (1)	Longitudinal[a]	No serious risk of bias	No serious inconsistency	No serious indirectness	No serious imprecision	No association between baseline **MVPA** or **PAEE** and **depressed mood** or **MDD** at follow-up (Toseeb et al. 2014)	LOW[b]
10 641 (4)	Cross-sectional[c]	No serious risk of bias	Serious inconsistency[d]	No serious indirectness	No serious imprecision	***Total PA:*** associations were null (**2/3 studies;** Johnson et al. 2008; Toseeb et al. 2014), or mixed (null and favourable) depending on if assignment to tertiles adjusted for total PA or adjusted for %time in MVPA (**1/3 studies;** Wiles et al. 2012) ***VPA:*** null associations (**1/1 studies;** Johnson et al. 2008) ***MVPA:*** associations were favourable (**1/4 studies;** Wiles et al. 2012), null (**2/4 studies;** Johnson et al. 2008; Toseeb et al. 2014), or mixed (null and unfavourable; **1/4 studies;** Young et al. 2014) ***LPA:*** null associations (**1/1 studies;** Johnson et al. 2008)	VERY LOW[e]

Note: The range of mean ages was 12.0 to 16.9 years. Data were collected cross-sectionally and with 3-year follow-up. Psychological distress was assessed as depressed mood by self-reported MFQ, depressive symptoms by self-reported short-MFQ and CES-D and MDD by face-to-face interview using sections of the Schedule for Affective Disorders and Schizophrenia for School Age Children-Present and Lifetime Version. CES-D, Center for Epidemiological Studies-Depression Scale; LPA, light-intensity physical activity; MDD, Major Depressive Disorder; MFQ, Mood and Feelings Questionnaire; MVPA, moderate- to vigorous-intensity physical activity; PA, physical activity; PAEE, physical activity energy expenditure; TAAG, Trial of Activity for Adolescent Girls.

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

[b]The overall quality of evidence remained rated as "low" for the longitudinal study since there were no serious limitations and no reasons to upgrade.

[c]Includes **4 cross-sectional studies** (Johnson et al. 2008; Wiles et al. 2012; Toseeb et al. 2014; Young et al. 2014) from **3 unique samples**. **Two studies** (Johnson et al. 2008; Young et al. 2014) reported data from the TAAG study. Results are reported separately and participants are only counted once.

[d]Serious inconsistency. Inconsistency is related to the associations between MVPA and depressive symptoms/depressed mood; favourable, null, and unfavourable associations were reported in 4 studies, with no clear reason for differences (Johnson et al. 2008; Wiles et al. 2012; Toseeb et al. 2014; Young et al. 2014).

[e]The quality of evidence from cross-sectional studies was downgraded from "low" to "very low" because of unexplained inconsistency among the findings.

Table 10. The relationship between physical activity and self-esteem.

No. of participants (no. of studies)	Design	Quality assessment				Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision		
589 (1)	Cross-sectional[a]	No serious risk of bias	No serious inconsistency	No serious indirectness	Serious imprecision[b]	***MVPA:*** null associations (**1/1 studies;** Young et al. 2014)	VERY LOW[c]

Note: Mean age was 16.9 years; data were collected cross-sectionally. Self-esteem was assessed by self-report "global esteem" scale from the Physical Self-Description Questionnaire. MVPA, moderate- to vigorous-intensity physical activity.

[a]Includes **1 cross-sectional study** (Young et al. 2014).

[b]Serious imprecision. The standard error (SE) and parameter were of similar magnitude (parameter = 0.16, SE = 0.11, $p = 0.14$).

[c]The overall quality of evidence was downgraded from "low" to "very low" because of imprecision.

cross-sectional findings. Various measures of fitness (e.g., cardiorespiratory fitness, muscular strength) were assessed directly and indirectly (e.g., progressive continuous cycling exercise to exhaustion or estimated from "shuttle run" protocol, push-up test; see Table 3 for summary of measures). The quality of evidence ranged from very low to low across study designs (Table 3).

In randomized trials, there was a favourable intervention effect for aerobic fitness in 1/1 studies at post-test (Kriemler et al. 2010), and in 2/2 studies at 6-month and 2-year follow-up (Eather et al. 2013; Meyer et al. 2014). There was a favourable effect on at least 1 measure of muscular strength and endurance in 2/3 studies at post-test (Eather et al. 2013; Meinhardt et al. 2013), but not at 3-month follow-up (Meinhardt et al. 2013). One study found no intervention effect on flexibility at post-test (Verstraete et al. 2007), but another found a favourable effect at 6-month follow-up (Eather et al. 2013). There were no negative intervention effects.

Three nonrandomized intervention studies with physical fitness outcomes were included. One study found no effect of a PA intervention on aerobic fitness (Rowland et al. 1996). Another study found that increasing PA was associated with greater improvements in aerobic fitness, muscular strength and endurance, and flexibility for the intervention group compared with the control group (Dimitriou et al. 2011). The final study found no between-group differences; however, within the intervention group there were unfavourable changes from baseline to post-test for aerobic fitness and muscular strength and endurance, and favourable changes for flexibility (Shore et al. 2014).

One longitudinal study reported a favourable dose–response gradient between baseline VPA and aerobic fitness at 2-year follow-up, but no associations for LPA or MPA (Carson et al. 2014).

Among cross-sectional studies, total PA was favourably associated with at least 1 aerobic fitness indicator in 18/18 studies and with muscular strength and endurance in 3/4 studies (Table 3). There was no correlation between total PA and flexibility overall (Hands et al. 2009; Larouche et al. 2014). However, when examined by tertile, children in the highest tertile for total PA had better hip flexibility than children in the lowest tertile (Hands et al. 2009).

VPA was favourably associated with aerobic fitness in 12/12 studies and with upper and lower body muscular strength and endurance in 2/2 studies for at least 1 fitness indicator (Table 3). There were consistently favourable associations between MVPA and at least 1 measure of aerobic fitness (16/16 studies; Table 3), muscular strength and endurance (3/3 studies; Moliner-Urdiales et al. 2010; Martinez-Gomez et al. 2012; Aggio et al. 2015), and flexibility (1/1 studies; Aggio et al. 2015) across all studies.

MPA was favourably associated with aerobic fitness in 7/9 studies (Table 3), but was not cross-sectionally associated with muscular fitness (0/2 studies; Moliner-Urdiales et al. 2010; Martinez-Gomez et al. 2012). In contrast, LPA was only associated with at least 1 measure of aerobic fitness in 2/6 studies (Butte et al. 2007*b*; Martinez-Gomez et al. 2010*a*), had null (1/2 studies; Moliner-Urdiales et al. 2010) or mixed null and unfavourable (1/2 studies; Aggio et al. 2015) associations with at least 1 measure of muscular strength and endurance, and was not associated with trunk flexibility (0/1 studies; Aggio et al. 2015). When associations were not uniformly favourable, mixed findings were limited to sub-analyses based on sex, PA quantile, body segment (e.g., torso, upper body, lower body), and/or outcome measurement tool. There were no other unfavourable cross-sectional associations.

Behavioural conduct/pro-social behaviour

One cross-sectional study examined the relationships between PA and behavioural conduct/pro-social behaviour (see Table 4 and Supplementary Table S4 (Supplementary Material B[2])). Measures of behavioural conduct and pro-social behaviour (e.g., conduct problems or peer problems) were self-reported using questionnaires (see Table 4 for summary of measures). The quality of evidence was rated as very low (Table 4).

Total PA was not correlated with indicators of pro-social behaviour or behavioural conduct (Sebire et al. 2011). MVPA was not associated with conduct problems and had mixed (favourable and null) associations with pro-social behaviour and behavioural conduct, with results differing by sex and outcome measure in no particular pattern (Sebire et al. 2011).

Cognition/academic achievement

Eight studies examined the relationships between PA and cognition/academic achievement (see Table 5 and Supplementary Table S5 (Supplementary Material B[2])). One intervention study used a nonrandomized design, 3 studies used a longitudinal design, and 6 studies used a cross-sectional design or also reported cross-sectional findings. Cognition and academic achievement were assessed using various objective measures (e.g., executive function test batteries, school grades, or standardized tests; see Table 5 for summary of measures). The quality of evidence was very low across study designs (Table 5).

In the nonrandomized intervention, academic achievement improved in both the intervention and control groups, with no between-group differences (Shore et al. 2014).

Among longitudinal studies, associations were mixed (favourable and null) between total PA (1/1 study; Telford et al. 2012*b*) or MVPA (1/1 study; Booth et al. 2014) and academic achievement. Inconsistent findings were limited to sub-analyses by sex, outcome measure, and/or school subject. One longitudinal study reported null and favourable associations between MVPA and cognition (1/1 study), with differences limited to sub-analyses by sex and executive function task (Booth et al. 2013).

Five cross-sectional studies examined academic achievement. Among studies that examined total PA, 2/2 studies reported null associations with academic achievement (Lambourne et al. 2013; Hansen et al. 2014). VPA was unfavourably associated with school grades and grade point average (GPA) in 1/1 studies (Esteban-Cornejo et al. 2014). Regarding MVPA, 2/3 studies reported at least 1 unfavourable association (Esteban-Cornejo et al. 2014; Young et al. 2014) and 1/3 studies reported at least 1 favourable association (Booth et al. 2013) with academic achievement. One study examined MPA and reported unfavourable associations with school grades across subjects and with GPA (Esteban-Cornejo et al. 2014). Where associations were not uniform, findings varied by school subject, sex, and/or sample. One cross-sectional study reported favourable associations between total PA or MVPA and at least 1 indicator of cognition (Booth et al. 2013). Inconsistent findings were limited to sub-analyses by sex or cognition measure.

Quality of life/well-being

Five studies examined the relationships between PA and quality of life/well-being (see Table 6 and Supplementary Table S6 (Supplementary Material B[2])). Three studies used a randomized controlled design and 2 studies used a cross-sectional design. Quality of life was assessed by self-report (see Table 6 for summary of measures). The quality of evidence ranged from very low to low across study designs (Table 6).

As summarized in Table 6, increasing PA did not improve quality of life compared with a control condition in 3/3 studies (Kriemler et al. 2010; Finkelstein et al. 2013; Meyer et al. 2014). One cross-sectional study reported a favourable association between total PA and quality of life (Standage et al. 2012). One cross-sectional study reported a favourable association between MVPA and self-rated health in boys, but not in girls (Herman et al. 2014).

Harms (i.e., injuries)

No studies were found that examined harms associated with objectively measured total PA or any PA intensity.

Important (secondary) health indicators

Bone health

Twenty studies examined the relationships between PA and indicators of bone health (see Table 7 and Supplementary Table S7 (Supplementary Material B[2])). One study used a randomized crossover design, 7 studies used a longitudinal design, and 14 studies used a cross-sectional design or also reported cross-sectional findings. Measures of bone health (e.g., bone mineral content or density) were assessed objectively (e.g., dual-energy X-ray absorptiometry or peripheral quantitative computed tomography; see Table 7 for summary of measures). The quality of evidence ranged from low to moderate across study designs (Table 7).

As summarized in Table 7, participation in an aerobic training program in a randomized crossover trial resulted in larger increases in bone density during the training period compared with the control period in both groups (Gutin et al. 1999).

Among the longitudinal studies, 1 study found that baseline total PA predicted 3-year follow-up bone mineral content (BMC) in at least 1 anatomical location in boys and girls and that children who maintained high levels of PA over the 3-year period (≥50th percentile) had greater BMC than their less active peers (Janz et al. 2006). One longitudinal study found that spending a higher proportion of total PA engaged in MPA and VPA relative to LPA was prospectively associated with higher BMC, bone mineral density (BMD), and bone area (Heidemann et al. 2013). There were mixed (favourable and null) associations between VPA and spine or hip BMC (2/2 studies; Francis et al. 2014; Janz et al. 2014*a*). Mixed (favourable and null) prospective associations were observed between MVPA and whole-body, hip and spine BMC (3/3 studies; Janz et al. 2010, 2014*a*; Francis et al. 2014), hip BMD (1/1 studies; Janz et al. 2014*b*), femoral neck cross-sectional area and section modulus (2/2 studies; Janz et al. 2007, 2014*b*), and measures of bone strength (bone stress index and polar moment of inertia; 1/1 studies; Janz et al. 2014*b*). Inconsistency in the findings was limited to sub-analyses by sex and differences in consideration of concurrent PA levels at follow-up. There were no unfavourable associations reported.

Fourteen cross-sectional studies examined relationships between PA and indicators of bone health; 4 studies examined total PA. Total PA had favourable (2/2 studies; Janz et al. 2001; Gracia-Marco et al. 2012) or null (1/2 studies; Janz et al. 2001) associations with whole-body BMC, and favourable associations with BMC of the hip (2/2 studies; Janz et al. 2001; Gracia-Marco et al. 2012) and spine (1/1 studies; Janz et al. 2001). Total PA was not associated with whole-body BMD (0/1 studies; Janz et al. 2001), but was favourably associated with BMD of the hip (1/1 studies; Janz et al. 2001), calcaneus and distal forearm (1/1 studies; Hasselstrøm et al. 2007), and had mixed (favourable in girls, null in boys) associations with spine BMD (1/1 studies; Janz et al. 2001). Total PA was favourably associated with total skeletal area (1/1 studies; Janz et al. 2001) and had mixed (favourable and null) associations with femur and tibia strength index/strength-strain index (1/1 studies; Farr et al. 2011).

Seven cross-sectional studies examined associations between VPA and indicators of bone health. VPA was favourably associated with whole-body BMC (2/2 studies; Janz et al. 2001; Tobias et al. 2007), but in 1 study the associations were significant only in boys (null in girls; Janz et al. 2001). VPA was favourably associated with cortical BMC (1/1 studies; Sayers et al. 2011), BMC of the hip (2/2 studies; Janz et al. 2001, 2014*a*) and spine (2/3 studies; Janz et al. 2001, 2014*a*), and with upper (1/1 studies; Tobias et al. 2007) but not lower (0/1 studies) limb BMC. VPA was not associated with whole-body, upper, or lower limb BMC after adjusting for bone area (1/1 studies; Tobias et al. 2007). Associations between VPA and whole-body BMD were favourable (both absolute and areal; 1/2 studies; Tobias et al. 2007) or null (absolute, 1/2 studies; Janz et al. 2001). Regarding specific anatomical regions, VPA was favourably associated with BMD in the hip (1/1 studies; Janz et al. 2001), calcaneous and distal forearm (1/1 studies; Hasselstrøm et al. 2007), femoral neck, trochanter and inter-trochanter (1/1 studies; Cardadeiro et al. 2012), and upper limb absolute and areal BMD (1/1 studies; Tobias et al. 2007), but associations were mixed for spine BMD (null in boys, favourable in girls; 1/1 studies; Janz et al. 2001), null for lower limb absolute and areal BMD (1/1 studies; Tobias et al. 2007), and unfavourable for cortical BMD (1/1 studies; Sayers et al. 2011). In the single study that examined VPA in relation to BMD ratios (Cardadeiro et al. 2012), VPA was negatively associated with the ratio of femoral neck-to-intertrochanter BMD in girls (but not boys), and all other associations were null (see Table 7 for details). Regarding bone area, VPA was favourably associated with total skeletal area (1/1 studies; Janz et al. 2001), cortical bone area (1/1 studies; Sayers et al. 2011), and cross-sectional area of the femur (narrow neck, intertrochantic and shaft regions; 1/1 studies; Janz et al. 2004). VPA was positively and negatively associated with periosteal and endosteal circumference of the tibia, respectively (1/1 studies; Sayers et al. 2011). VPA was favourably associated with bone strength characteristics (section modulus of narrow neck, intertrochantic and shaft regions of femur; 1/1 studies; Janz et al. 2004).

Four cross-sectional studies examined associations between MVPA and indicators of bone health. There were mixed (favourable and null) associations between MVPA and whole-body BMC (1/1 studies; Janz et al. 2008). MVPA was favourably associated with hip BMC (2/2 studies; Janz et al. 2008, 2014*a*) and there were mixed (favourable in boys, null in girls; 2/3 studies; Janz et al. 2008, 2014*a*) or null (1/3 studies; Francis et al. 2014) associations with spine BMC. MVPA was not associated with BMD of the femoral neck, trochanter, or intertrochanter (0/1 studies; Cardadeiro et al. 2012). One study examined MVPA in relation to BMD ratios (Cardadeiro et al. 2012); MVPA was positively associated with the ratio of femoral neck-to-intertrochanter BMD in girls (but not boys) and all other associations were null (Table 7).

Four cross-sectional studies examined associations between MPA and indicators of bone health. Associations between MPA and BMC were favourable (whole-body or lower limb absolute and areal BMC; 1/1 studies; Tobias et al. 2007) and null (upper limb absolute or areal BMC (0/1 studies; Tobias et al. 2007), cortical BMC (0/1 studies; Sayers et al. 2011)). Similarly, MPA was favourably associated with absolute or areal BMD of the whole-body or lower limb (1/1 studies) but not upper limb (0/1 studies) (Tobias et al. 2007). MPA was not associated with cortical BMD (0/1 studies; Sayers et al. 2011) or with some regional measures of lower limb BMD (femoral neck, trochanter, intertrochanter; 0/1 studies; Cardadeiro et al. 2012). One study examined MPA in relation to 3 BMD ratios and all were null associations (Cardadeiro et al. 2012; see Table 7 for details). Regarding bone area, MPA was favourably associated with cortical bone area (1/1 studies; Sayers et al. 2011), cross-sectional area of the femoral shaft (1/1 studies; Janz et al. 2004), and narrow neck and intertrochantic regions (in girls but not in boys; 1/1 studies; Janz et al. 2004), but was not associated with periosteal or endosteal circumference of the tibia (0/1 studies) (Sayers et al. 2011). MPA was favourably associated with strength characteristics of the femoral region in girls (1/1 studies) but not in boys (0/1 studies) (Janz et al. 2004; Table 7).

Two cross-sectional studies examined associations between LPA and indicators of bone health. LPA was not associated with absolute or areal whole-body BMC and was favourably associated with absolute (but not areal) upper and lower limb BMC (1/1 studies Tobias et al. 2007). LPA was not associated with cortical BMC (0/1 studies; Sayers et al. 2011). LPA was favourably associated with whole-body BMD (absolute but not areal) and with absolute and areal BMD of the upper and lower limb (1/1 studies; Tobias et al. 2007), but was unfavourably associated with cortical BMD (1/1 studies; Sayers et al. 2011). LPA was not associated with cortical bone area (0/1 studies; Sayers et al. 2011) or with endosteal circum-

ference but was positively associated with periosteal circumference of the tibia (1/1 studies; Sayers et al. 2011).

One cross-sectional study examined PA across 6 "impact" intensities; favourable associations were found between high-impact PA and femoral bone health (BMD, neck width, cross sectional area and cortical thickness, predicted strength) (Deere et al. 2012). A graded association was observed between impact level and BMD (femoral neck, total hip).

Motor skill development

Seven studies examined the relationships between PA and motor skill development (see Table 8 and Supplementary Table S8 (Supplementary Material B[2])). One study used a cluster-randomized design, 1 intervention study used a nonrandomized design, 1 study used a longitudinal design, and 5 studies used a cross-sectional design or also reported cross-sectional findings. Measures of motor skill development (e.g., balance, accuracy, coordination, agility, and speed) were assessed using physical test batteries (e.g., Canadian Assessment of Physical Literacy; see Table 8 for summary of measures). The quality of evidence ranged from very low to low across study designs (Table 8).

One randomized study found no between-group differences in motor skill development following a PA intervention (Verstraete et al. 2007). One nonrandomized study found no between-group differences in motor skill development, but both the intervention and control groups had a reduction in motor skills from baseline to post-test (Shore et al. 2014).

One longitudinal study found no association between total PA and motor skill development over a 2-year follow-up (Telford et al. 2013). Among cross-sectional studies, a favourable association between total PA and motor skill development was reported in 3/5 studies (Martinez-Gomez et al. 2012; Morrison et al. 2012; Larouche et al. 2014). MVPA and VPA were favourably associated with motor skill development, but MPA was not (1/1 studies; Martinez-Gomez et al. 2012).

Psychological distress

Four observational studies examined the relationships between PA and psychological distress (see Table 9 and Supplementary Table S9 (Supplementary Material B[2])). One study used a longitudinal design and 4 studies used a cross-sectional design or also reported cross-sectional findings. All 4 studies measured depression (e.g., mood, symptoms) by questionnaire or interview (see Table 9 for summary of measures). The quality of evidence ranged from very low to low across study designs (Table 9).

As summarized in Table 9, total PA and MVPA were not prospectively associated with depressed mood or Major Depressive Disorder in the single longitudinal study (Toseeb et al. 2014).

Four studies examined total PA cross-sectionally. In 1 study, higher tertiles of total PA were associated with lower depressive symptoms if tertiles were adjusted for total PA, but not if they were adjusted for the percentage of time spent in MVPA (Wiles et al. 2012). There were no other significant associations between total PA and depressive symptoms or Major Depressive Disorder (Johnson et al. 2008; Toseeb et al. 2014). VPA was not associated with depressive symptoms (0/1 studies; Johnson et al. 2008). There were mixed associations between MVPA and at least 1 psychological distress outcome (favourable (1/4 studies; Wiles et al. 2012), null (3/4 studies; Johnson et al. 2008; Toseeb et al. 2014; Young et al. 2014), and unfavourable (1/4 studies; Young et al. 2014)). LPA was not associated with depressive symptoms (0/1 studies; Johnson et al. 2008).

Self-esteem

One cross-sectional study examined the relationship between MVPA and self-reported self-esteem (see Table 10 and Supplementary Table S10 (Supplementary Material B[2])). There was no association between MVPA and self-esteem among adolescent girls (Young et al. 2014). The quality of evidence was very low (Table 10).

Patterns of physical activity in relation to health indicators

Sporadic PA and bouts of PA

Only 2 cross-sectional studies examined the relationships between sporadic MVPA (i.e., <5 consecutive minutes at a time) and health indicators (Mark and Janssen 2009; Holman et al. 2011). With respect to adiposity, the odds of a high waist circumference decreased in a graded manner across quartiles of sporadic MVPA (Holman et al. 2011), and sporadic MVPA was associated with lower odds of overweight/obesity (Mark and Janssen 2009). Similarly, the odds of a high-composite cardiometabolic disease risk-factor score (and its individual components: non-HDL cholesterol, C-reactive protein, systolic BP, and waist circumference) decreased in a graded manner across quartiles of sporadic MVPA (Holman et al. 2011). Sporadic PA of other intensities was not examined, and sporadic MVPA was not examined in relation to other health indicators.

Seven studies examined the relationships between bouts of MVPA and health indicators (Eiberg et al. 2005; Janz et al. 2005; Butte et al. 2007*b*; Mark and Janssen 2009; Holman et al. 2011; Loprinzi et al. 2013; da Silva et al. 2014), 1 study used a longitudinal design (Janz et al. 2005), and all others used a cross-sectional design. Janz et al. (2005) found that children in the lowest quartile of percent body fat at 2-year follow-up had higher VPA in 5-min bouts (but no difference in MPA in 5-min bouts) at baseline compared with the 3 higher percent body fat quartiles.

Cross-sectionally, 2/3 studies reported favourable (Holman et al. 2011; da Silva et al. 2014) and 1/3 studies reported mixed (favourable and null; Mark and Janssen 2009) associations between bouts of MVPA and adiposity. With respect to cardiometabolic biomarkers, 1 study reported that the odds of a high-cardiometabolic disease risk-factor score decreased in a graded dose–response manner when moving from the lowest to highest quartile of bout MVPA measures, with similar associations for some individual cardiometabolic disease risk factors (non-HDL cholesterol, C-reactive protein, and systolic BP) (Holman et al. 2011). However, another study examined bouts of MVPA in relation to C-reactive protein and found no association (Loprinzi et al. 2013). One study found that 5- but not 10-min bouts of MVPA were favourably associated with fasting serum insulin (Butte et al. 2007*b*). Bouts of MVPA were favourably associated with aerobic fitness in 2/2 studies (Eiberg et al. 2005; Butte et al. 2007*b*). Bouts of PA at other intensities were not examined cross-sectionally, and bouts of MVPA were not examined in relation to other health indicators.

Adherence to current guidelines

Twelve studies examined the relationships between meeting/not meeting PA guidelines (≥60 min MVPA per day; Tremblay et al. 2011) and health indicators (Ortega et al. 2008; Steele et al. 2009; Martinez-Gomez et al. 2010*a*, 2010*b*; Gracia-Marco et al. 2011*a*, 2011*b*; Mendoza et al. 2012; Janssen et al. 2013; Loprinzi et al. 2013; Silva et al. 2013; Herman et al. 2014; de Moraes et al. 2015). One study used a longitudinal design and reported both longitudinal and cross-sectional analyses (de Moraes et al. 2015); all other studies used a cross-sectional design.

Meeting PA guidelines was favourably associated with adiposity in 2/3 studies (Steele et al. 2009; Martinez-Gomez et al. 2010*b*) and not associated with adiposity in 1/3 studies (Mendoza et al. 2012). With respect to cardiometabolic biomarkers, meeting PA guidelines was favourably associated with cardiometabolic disease risk score (2/2 studies; Mendoza et al. 2012; Janssen et al. 2013) but not with C-reactive protein (Loprinzi et al. 2013); 1 study found mixed (favourable and null) associations between meeting PA guidelines and risk of pre–high-BP or high-BP (prospectively and cross-sectionally) (de Moraes et al. 2015); and 1 study found mixed (favourable or null) associations between meeting PA guidelines and

systolic BP, diastolic BP, HDL, and HOMA-IR with more favourable associations in those who were frequently versus infrequently active (5–7 vs 1–4 days per week) (Janssen et al. 2013). All studies (3/3 studies) found that meeting PA guidelines was favourably associated with fitness (Ortega et al. 2008; Martinez-Gomez et al. 2010*a*; Silva et al. 2013). One study reported that meeting PA guidelines was favourably associated with self-rated health (an indicator of quality of life/well-being) in boys but not girls (Herman et al. 2014). All studies (2/2 studies) reported mixed (favourable, unfavourable, null) associations between meeting PA guidelines and bone health (Gracia-Marco et al. 2011*a*, 2011*b*). Meeting PA guidelines was not examined in relation to behavioural conduct/pro-social behaviour, cognition/academic achievement, motor skill development, psychological distress, or self-esteem.

Discussion

A commitment to regularly updating the evidence that informs the Canadian Physical Activity Guidelines for Children and Youth prompted this systematic review (Tremblay et al. 2010*b*). We synthesized peer-reviewed evidence from 162 studies (70 unique samples) that examined the relationships between objectively measured PA (total, and by intensity (i.e., LPA, MPA, MVPA, VPA) and patterns (i.e., sporadic, bouts, or adherence to current guidelines)) and indicators of physical (body composition, cardiometabolic biomarkers, physical fitness, injuries, bone health, motor skill development), psychological/social (behavioural conduct/pro-social behaviour, quality of life/well-being, psychological distress, self-esteem) and cognitive (cognition/academic achievement) health in school-aged children and youth. A summary of the findings is presented in Table 11.

Overall, the findings indicate favourable associations between PA and health indicators. There was strong, consistent evidence of favourable relationships between total PA and adiposity, several cardiometabolic biomarkers (cholesterol, BP, triglycerides, insulin resistance and fasting insulin, and fasting glucose), physical fitness (aerobic fitness, muscular strength, and endurance), and bone health. There was some support for favourable relationships between total PA and quality of life/well-being, motor skill development, and psychological distress, but evidence in relation to other health indicators (fat free mass, behavioural conduct/pro-social behaviour, cognition/academic achievement, and self-esteem) was limited. Similar favourable relationships between PA of specific intensities (i.e., LPA, MPA, MVPA, and VPA) and health indicators were observed, but in general, higher intensities of PA (i.e., MVPA and VPA) were more frequently examined and had both more consistent associations and larger effect sizes than lower intensity PA (i.e., LPA and MPA). Importantly, no studies reported harms (i.e., injuries) associated with objectively measured PA of any intensity. Almost all studies reported on PA of an aerobic nature across a variety of environments (e.g., home, school, community; indoor, outdoor) and contexts (e.g., play, recreation, sport, active transportation).

To our knowledge, this is the first time relationships between LPA and health indicators in children and youth have been systematically reviewed. Unfortunately, very few studies examined LPA, but those that did offered some insight into the contribution of LPA to the health of children and youth. Primarily, evidence identified favourable or null relationships between LPA and health indicators. For example, favourable associations between LPA and diastolic BP, BP *z* score, insulin resistance, and HDL cholesterol were observed. Relationships with other cardiometabolic biomarkers, psychological distress (depression), fitness, and bone health were mixed or null (with 1 study for each of bone health and fitness indicators also reporting at least 1 unfavourable association). In contrast, there were an equal proportion of favourable, unfavourable, and null relationships observed with adiposity indicators. It is unlikely, however, that these weak and mixed associations represent the true effects; rather, it is probable that they are an artefact of how LPA is captured with accelerometry. For instance, Kwon et al. (2011) quantified the relationships between LPA and fat mass in boys and girls at ages 5, 8, and 11 years, using 2 separate cut-points for LPA; across all comparisons, associations were stronger using the higher cut-point (1100–2999 vs 100–2999 counts/min). Similarly, dichotomizing LPA into high and low categories, Carson and colleagues (2013) showed favourable associations between "high LPA" (defined as 800 counts/min to <4 METs) and cardiometabolic biomarkers, and no relationships for "low LPA" (100–799 counts/min). Thus existing cut-points for LPA may not effectively differentiate LPA from sedentary time, and other calculations or combined use of other measures (e.g., inclinometers) may better distinguish these behaviours (Ridgers et al. 2012). In addition to issues with measurement, it should be recognized that for the volume of LPA to increase, time spent in other pursuits must be replaced. An increase in LPA at the expense of MVPA may indeed have a negative impact on health outcomes, while a displacement of sedentary time to increase LPA is likely beneficial. This distinction is difficult to capture empirically, but is supported by recent compositional analyses in adults that identified that replacing sedentary time with LPA had some health benefits (Chastin et al. 2015). This reinforces the assertion that some activity is better than no activity, but that "more is better" (Tremblay et al. 2011). Thus it is worth considering that LPA may be an effective substitute for sedentary activities, and that broadening the focus beyond MVPA as a health promotion strategy deserves further exploration.

Data regarding PA accumulated sporadically or in bouts remains limited, but the available evidence suggests that both sporadic activity and bouts of activity are valuable for promoting health in children and youth. The relationships between sporadic MVPA (i.e., <5 consecutive minutes) or MVPA accumulated in bouts (i.e., sum of all MVPA accumulated in 5, 10, or more consecutive minutes) and health indicators were examined in only 2 and 7 studies, respectively. In general, findings indicated favourable relationships between sporadic MVPA or MVPA bouts and adiposity, fitness, and cardiometabolic disease risk factors. Equivalent volumes of sporadic and bouts of MVPA had a similar impact on adiposity and cardiometabolic disease risk, and there was a clear dose–response gradient (Mark and Janssen 2009; Holman et al. 2011). Thus the available evidence suggests that all activity is important for children and youth (i.e., there is no minimum consecutive duration that must be reached to achieve benefits) and can be accrued in small doses throughout the day.

Twelve studies examined the relationships between meeting/not meeting current PA guidelines (≥60 min MVPA per day; Tremblay et al. 2011) and health indicators. Overall, findings indicated favourable effects of meeting the guidelines on adiposity and quality of life. Findings were less clear for cardiometabolic biomarkers, with both favourable and null results (possibly associated with the different biomarkers assessed; e.g., BP vs C-reactive protein), and for bone density with a mix of favourable, unfavourable, and null results (possibly because bone density is more strongly associated with vigorous-intensity or high-impact activity vs MVPA per se (Deere et al. 2012)). The impact of meeting current PA guidelines was not examined in relation to any other health indicators. These findings provide support for the current recommendation that children and youth should achieve at least 60 min of MVPA each day. Importantly, although only 12 studies examined the 60-min cut-point directly, the overall body of evidence was in agreement and there was an absence of contradictory evidence.

Strengths, limitations, and future directions

Strengths of the present systematic review include the use of a comprehensive search strategy that was developed and peer-reviewed by librarians with expertise in systematic reviews, the

Table 11. High-level summary of findings by health indicator.

Health indicator	No. of studies	Quality of evidence	Summary of findings: Number of studies reporting favourable/null/unfavourable associations with at least 1 health indicator measure by PA intensity*
Critical			
Body composition	72	Very low to low	***Adiposity:*** **Total PA:** favourable (26), null (30), unfavourable (2) **VPA:** favourable (16), null (6), unfavourable (1) **MVPA:** favourable (29), null (16), unfavourable (1) **MPA:** favourable (4), null (10), unfavourable (1) **LPA:** favourable (3), null (9), unfavourable (4) ***Fat free mass:*** **Total PA:** favourable (3), null (2) **VPA:** favourable (2), null (2), unfavourable (2) **MVPA:** null (4), unfavourable (3) **MPA:** null (2) **LPA:** favourable (1), null (1), unfavourable (1)
Cardiometabolic biomarkers	54	Very low to moderate	**Total PA:** favourable (22), null (24) **VPA:** favourable (4), null (9) **MVPA:** favourable (25), null (25) **MPA:** favourable (4), null (9) **LPA:** favourable (3), null (8)
Physical fitness	38	Very low to low	***Aerobic fitness:*** **Total PA:** favourable (22), null (8) **VPA:** favourable (13), null (1) **MVPA:** favourable (16), null (2) **MPA:** favourable (7), null (5) **LPA:** favourable (2), null (6) ***Muscular strength and endurance:*** **Total PA:** favourable (6), null (6) **VPA:** favourable (2), null (1) **MVPA:** favourable (3), null (2) **MPA:** null (2) **LPA:** null (2), unfavourable (1) ***Flexibility:*** **Total PA:** favourable (3), null (4) **MVPA:** favourable (1) **LPA:** null (1)
Behavioural conduct/prosocial behaviour	1	Very low	**Total PA:** null (1) **MVPA:** favourable (1), null (1)
Cognition/academic achievement	8	Very low	***Academic achievement:*** **Total PA:** favourable (1), null (4) **VPA:** unfavourable (1) **MVPA:** favourable (1), null (2), unfavourable (2) **MPA:** unfavourable (1) ***Cognition:*** **Total PA:** favourable (1), null (1) **MVPA:** favourable (1), null (1)
Quality of life/well-being	5	Very low to low	**Total PA:** favourable (1), null (3) **MVPA:** favourable (1), null (1)
Harms (i.e., injuries)	0	na	na
Important			
Bone health	20	Low to moderate	**Total PA:** favourable (6), null (3) **VPA:** favourable (8), null (5), unfavourable (1) **MVPA:** favourable (9), null (9), unfavourable (1) **MPA:** favourable (3), null (4) **LPA:** favourable (2), null (2), unfavourable (1)
Motor skill development	7	Very low to low	**Total PA:** favourable (3), null (4) **VPA:** favourable (1) **MVPA:** favourable (1) **MPA:** null (1)
Psychological distress	4	Very low to low	**Total PA:** favourable (1), null (3) **VPA:** null (1) **MVPA:** favourable (1), null (3), unfavourable (1) **LPA:** null (1)
Self-esteem	1	Very low	**MVPA:** null (1)

Note: LPA, light-intensity physical activity; MPA, moderate-intensity physical activity; MVPA, moderate- to vigorous-intensity physical activity; na, not applicable; PA, physical activity; VPA, vigorous-intensity physical activity.

*The number of studies reporting favourable/null/unfavourable associations does not sum to the total number of studies for a given indicator since some studies reported mixed associations.

inclusion of only objectively-measured PA, as well as the inclusion of a wide range of health indicators encompassing physical, psychological/social, and cognitive health. This systematic review is the first to synthesize the evidence regarding the relationships between all intensities of PA, including LPA, and health indicators in children and youth.

The primary limitation of this review is that the evidence synthesized herein is of "very low" to "moderate" quality; no evidence was rated as "high quality", mainly because of concerns with risk of bias, indirectness of the interventions and the comparisons being assessed, and unexplained inconsistency in the findings (Tables 1–10). However, the relative uniformity of findings and observation of very few unfavourable relationships despite the flaws inherent to many studies indicates that additional research with high-quality evidence would likely serve to increase the confidence in the favourable direction of these findings. In other words, it is likely that inclusion of additional high-quality studies would have strengthened the observed effects, and the quality of evidence in the present review does not preclude drawing confident conclusions about the nature of the relationships observed.

Because of the small number of randomized trials, cause-and-effect relationships cannot be ascertained. No interventions directly compared the effects of various amounts and intensities of PA (in relation to one another or to the absence of PA) on health indicators. Rather, intervention studies tended to be school-, home-, or community-based programs that created the opportunity for additional PA compared with a usual care control condition (e.g., existing physical education curriculum). As a result, it is not possible to precisely differentiate the contribution of various durations and intensities of PA to health indicators. Challenges inherent to conducting this type of research in children, such as achieving adherence to the intervention and testing protocol, as well as controlling for behaviour outside of intervention programs, are important considerations for future high-quality studies in this area. Furthermore, because of heterogeneity in the measurement of PA and health indicators, meta-analyses were not possible and all studies were weighted equally in the resulting narrative. Future work with standardized measures will help to address this limitation.

With respect to the PA exposure in particular, differences and limitations in its measurement may have contributed to variability in the associations between PA and health indicators in the present study. For instance, heterogeneity in the application of cut-points to define PA intensities may have contributed to inconsistency in results, as described earlier in relation to LPA (Kwon et al. 2011; Carson et al. 2013). Similarly, the use of different sampling intervals ("epochs") has historically been dictated by accelerometer capability; however, the use of longer epochs (e.g., 60 s) in some studies is likely to have underestimated the volume of higher intensity PA, particularly in this population where the majority of MVPA occurs in bouts of ≤5 s in duration (Sanders et al. 2014). Finally, objective measures of PA cannot accurately quantify some fitness activities (e.g., weight training), and until recently could not measure water-based activities; this may have resulted in an underestimation or overestimation of true effects in the present study. To begin to address these limitations, future work should adhere to standardized accelerometry cut-points (Trost et al. 2011) or adopt new analytic techniques such as pattern recognition (Freedson et al. 2012; Trost et al. 2014), and use shorter sampling intervals (Sanders et al. 2014).

In general, there was a paucity of data regarding the relationships between objectively measured PA and 6 relevant health indicators (8 or fewer studies for each of behavioural conduct/pro-social behaviour, cognition/academic achievement, quality of life/well-being, motor skill development, psychological distress, and self-esteem); this is an important research gap, and further research using high-quality study designs will be required to inform the relationships between PA and these indicators in children and youth. Additionally, future work is required to identify how to accurately capture LPA and to isolate the intensity that best differentiates sedentary behaviour from LPA in relation to health outcomes. In general, more well-controlled studies are required to identify the optimal dose of PA to achieve health benefits in children and youth, while examining potential age and sex differences.

Conclusions

In summary, this systematic review identified favourable relationships between PA and a wide range of indicators encompassing physical, psychological/social, and cognitive health in children and youth. Overall, there was strong, consistent evidence that total PA was favourably associated with adiposity, cardiometabolic biomarkers, physical fitness, and bone health, with some support for favourable relationships between total PA and quality of life/well-being, motor skill development, and psychological distress. In general, higher intensity PA (i.e., MVPA and VPA) had more consistent and robust relationships with health indicators than lower intensity PA (i.e., LPA and MPA), and all patterns of activity (sporadic, bouts, continuous) provided benefit. These findings continue to support the importance of at least 60 min/day of MVPA for disease prevention and health promotion in children and youth (Janssen and LeBlanc 2010; Tremblay et al. 2010*b*, 2011), but also highlight the potential benefits of LPA and total PA. Similar to the earlier review (Janssen and LeBlanc 2010), the most consistent and compelling evidence was that more PA (duration, intensity, frequency) is better than less PA for health promotion. Additional research using objective PA measures is needed to more definitively establish the relationships between PA and psychological/social and cognitive health indicators. All intensities of PA should be considered in future work aimed at better elucidating the health benefits of PA in children and youth.

Conflict of interest statement

Michelle E. Kho received an honorarium for methodological input to guideline development.

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