# Systematic review of physical activity and health in the early years (aged 0–4 years)

**Brian W. Timmons, Allana G. LeBlanc, Valerie Carson, Sarah Connor Gorber, Carrie Dillman, Ian Janssen, Michelle E. Kho, John C. Spence, Jodie A. Stearns, and Mark S. Tremblay**



**Abstract:** The early years represent a critical period for promoting physical activity. However, the amount of physical activity needed for healthy growth and development is not clear. Using the Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework, we aimed to present the best available evidence to determine the relationship between physical activity and measures of adiposity, bone and skeletal health, motor skill development, psychosocial health, cognitive development, and cardiometabolic health indicators in infants (1 month – 1 year), toddlers (1.1–3.0 years), and preschoolers (3.1–4.9 years). Online databases, personal libraries, and government documents were searched for relevant studies. Twenty-two articles, representing 18 unique studies and 12 742 enrolled participants, met inclusion criteria. The health indicators of interest were adiposity ($n = 11$), bone and skeletal health ($n = 2$), motor development ($n = 4$), psychosocial health ($n = 3$), cognitive development ($n = 1$), and cardiometabolic health indicators ($n = 3$); these indicators were pre-specified by an expert panel. Five unique studies involved infants, 2 involved toddlers, and 11 involved preschoolers. In infants, there was low- to moderate-quality evidence to suggest that increased or higher physical activity was positively associated with improved measures of adiposity, motor skill development, and cognitive development. In toddlers, there was moderate-quality evidence to suggest that increased or higher physical activity was positively associated with bone and skeletal health. In preschoolers, there was low- to high-quality evidence on the relationship between increased or higher physical activity and improved measures of adiposity, motor skill development, psychosocial health, and cardiometabolic health indicators. There was no serious inconsistency in any of the studies reviewed. This evidence can help to inform public health guidelines. (PROSPERO registration: CRD42011001243)

*Key words:* physical activity, play, exercise, adiposity, psychosocial health, cognitive development, motor skill development, pro-social behaviour, preschoolers, toddlers, infants.

**Résumé :** Dans la promotion de l'activité physique, la petite enfance représente une période critique. Pourtant, on ne connait pas vraiment la quantité d'activité physique requise pour une croissance et un développement en santé. Au moyen de la méthodologie GRADE (« Grading of Recommendations Assessment, Development, and Evaluation »), cette étude se propose de présenter les meilleures données probantes pour définir la relation entre l'activité physique et les mesures de l'adiposité, de la santé des os et du squelette, du développement des habiletés motrices, de la santé psychosociale, du développement cognitif et des indicateurs de la santé cardiométabolique chez les nourrissons (1 mois – 1 an), les tout-petits (1,1–3 ans) et les enfants d'âge préscolaire (3,1–4,9 ans). On a fouillé dans les bases de données en ligne, les bibliothèques personnelles et les documents gouvernementaux afin d'en ressortir les études pertinentes. Vingt-deux articles couvrant 18 études distinctes et comptant 12 742 participants inscrits répondent aux critères d'inclusion. Les indicateurs de santé présentant un intérêt sont l'adiposité ($n = 11$), la santé des os et du squelette ($n = 2$), le développement moteur ($n = 4$), la santé psychosociale ($n = 3$), le développement cognitif ($n = 1$) et les indicateurs de santé cardiométabolique ($n = 3$); un groupe d'ex-

Received 21 February 2012. Accepted 17 April 2012. Published at www.nrcresearchpress.com/apnm on 5 July 2012.

**B.W. Timmons and C. Dillman.** Child Health and Exercise Medicine Program, Department of Pediatrics, McMaster University, 1280 Main Street West, Hamilton, ON L8S 4K1, Canada.
**A.G. LeBlanc.** Healthy Active Living and Obesity Research Group, CHEO Research Institute 401 Smyth Road, Ottawa, ON K1H 8L1, Canada.
**V. Carson.** School of Kinesiology and Health Studies, Queen's University, Kingston, ON K7L 3N6, Canada.
**S. Connor Gorber.** Public Health Agency of Canada, Ottawa, ON K1A 0K9, Canada.
**I. Janssen.** School of Kinesiology and Health Studies and Department of Community Health and Epidemiology, Queen's University, Kingston, ON K7L 3N6, Canada.
**M.E. Kho.** Department of Physical Medicine and Rehabilitation, Johns Hopkins University, Baltimore, MD 21287, USA.
**J.C. Spence.** Faculty of Physical Education and Recreation, University of Alberta, W1-16h Van Vliet Centre, Edmonton, AB T6G 2H9, Canada.
**J.A. Stearns.** Faculty of Physical Education and Recreation, University of Alberta, 488 Van Vliet Centre, Edmonton, AB T6G 2H9, Canada.
**M.S. Tremblay.** Healthy Active Living and Obesity Research Group, CHEO Research Institute Department of Pediatrics, University of Ottawa, 401 Smyth Road, Ottawa, ON K1H 8L1, Canada.

**Corresponding author:** Brian W. Timmons (e-mail: timmonbw@mcmaster.ca).

perts avaient déterminé ces indicateurs au préalable. Cinq études distinctes s'adressent à des nourrissons, 2 concernent des tout-petits et 11 portent sur des enfants d'âge préscolaire. Chez les nourrissons, la qualité des données probantes est de faible à modérée pour suggérer que l'augmentation (quantité, intensité) de la pratique de l'activité physique est positivement associée à des mesures améliorées de l'adiposité, du développement des habiletés motrices et du développement cognitif. Chez les tout-petits, la qualité des données probantes est modérée pour suggérer que l'augmentation (quantité, intensité) de la pratique de l'activité physique est positivement associée à la santé des os et du squelette. Chez les enfants d'âge préscolaire, la qualité des données probantes est de faible à élevée pour suggérer que l'augmentation (quantité, intensité) de la pratique de l'activité physique est positivement associée à des mesures améliorées de l'adiposité, du développement des habiletés motrices, de la santé psychosociale et des indicateurs de la santé cardiométabolique. Dans toutes les études analysées, on n'observe pas d'incohérence grave. Cette analyse peut servir de base à l'élaboration de directives en matière de santé publique. (PROSPERO numéro d'enregistrement : CRD42011001243.)

*Mots-clés :* activité physique, jeu, exercice physique, adiposité, santé psychosociale, développement cognitif, développement des habiletés motrices, comportement prosocial, nourrissons, tout-petits, enfants d'âge préscolaire.

[Traduit par la Rédaction]



## Introduction

Although the early years are a critical period for the development of active living behaviours, it is the period of growth for which we know the least about the health impact of physical activity (Timmons et al. 2007). In contrast, the health benefits of physical activity for school-aged children and youth are well established (Strong et al. 2005; Janssen and LeBlanc 2010). It may be that questions regarding the health benefits of physical activity for the early years (i.e., aged 0–4 years) have not been addressed because society has traditionally thought of this as being a time of life when children are habitually "active enough" and, therefore, quite healthy. However, there is evidence that adult-onset chronic diseases have their origins in the early years (Berenson et al. 1998; Napoli et al. 1999) and that other chronic disease risk factors are present at very young ages. For instance, the World Health Organization has estimated that more than 42 million children under the age of 5 years are overweight worldwide (World Health Organization 2011). Thus, the health implications of physical activity during the early years cannot be overlooked.

Studies that assess physical activity among preschoolers using objective measures (e.g., accelerometers) typically report low levels of physical activity of a moderate to vigorous intensity and very high levels of sedentary time (Pate et al. 2004; Timmons et al. 2007; Oliver et al. 2007; Hinkley et al. 2008). A systematic review (Tucker 2008) of physical activity levels of any intensity among children aged 2 to 6 years concluded that only 54% of studies reported children of these ages were meeting the National Association of Sport and Physical Education's physical activity recommendation of at least 60 min of structured and 60 min of unstructured physical activity every day. If we accept that contemporary children have low levels of physical activity and that physical activity is needed for optimal health, then it could be assumed that inactivity during the early years increases the risk for health "deficits". However, in a previous narrative review, very little evidence linking physical activity with health outcomes in children aged 2 to 5 years was found (Timmons et al. 2007). At that time, it was concluded that the scientific evidence was too weak to determine how much physical activity that age group needs.

Until recently, only 1 set of physical activity guidelines had been available for children under the age of 5 years (National Association for Sport and Physical Education 2009). Though these guidelines seem inherently reasonable and offer a common sense approach for those charged with the health of children during the early years, they are not based on a rigorous evaluation of the best available scientific evidence. This limitation reduces the transparency of findings (reproducibility for scientific scrutiny), the ability to objectively identify strengths and weakness of the research, and the ability to identify areas for future research. Examples of evidence-based guideline development include the recently released Australian and United Kingdom guidelines, which recommend that preschoolers be physically active for at least 180 min per day (Australian Government Department of Health and Ageing 2011; Start Active Stay Active 2011). Unfortunately, the scientific reviews of the literature that were used to inform those guidelines have not been published, so the nature of the relationship between physical activity and health during the early years remains uncertain.

In Canada, the demand for guidance on physical activity for the early years is clearly evident from an earlier paper (Timmons et al. 2007); based on journal access records, this paper was downloaded 2–5 times more frequently (nearly 6000 downloads) than other foundation papers used to inform updated guidelines for school-aged children, youth, adults, and older adults. Moreover, a consultation process for these updated guidelines completed by the Canadian Society for Exercise Physiology (Canadian Society for Exercise Physiology 2011) and the Public Health Agency of Canada revealed a strong demand for physical activity guidelines for the early years. Therefore, we embarked on a rigorous and transparent process of guideline development following the framework explained in detail by Tremblay and Haskell (2012), including a systematic review. Thus, the purpose of this paper is to systematically evaluate the available evidence examining the relationship between physical activity and health indicators during the early years (aged 0–4 years). Specifically, this systematic review aims to identify, synthesize, and interpret the best available evidence for minimal and optimal amounts of physical activity needed to promote healthy growth and development (i.e., adiposity, bone and skeletal health, motor skill development, psychosocial health, cognitive develop-

**Table 1.** Priority of health indicators by age group determined by consensus panel a priori.

| | Infant | Toddler | Preschooler |
|---|---|---|---|
| Adiposity (e.g., BMI, bioelectrical impedance analysis) | Critical | Critical | Critical |
| Bone and skeletal health (e.g., bone mineral content) | Unimportant | Important | Critical |
| Motor skill development (e.g., motor proficiency, gross motor skills, and (or) locomotor and object control) | Critical | Critical | Critical |
| Psychosocial health (e.g., self-concept, self-esteem,) | Unimportant | Critical | Critical |
| Cognitive development (e.g., language development, attention) | Important | Important | Critical |
| Cardiometabolic health Indicators (e.g., blood pressure, insulin resistance, blood lipids) | Unimportant | Unimportant | Important |
| Risks (injury) | NA | NA | NA |

**Note:** BMI, body mass index; NA, not applicable.



ment, and cardiometabolic health indicators) in infants (1 month – 1 year), toddlers (1.1–3.0 years), and preschoolers (3.1–4.9 years). Another aim of this review was to help inform the development of evidence-based physical activity guidelines for this age group.

## Methods

This review is registered with the international prospective register of systematic reviews PROSPERO network (registration no. CRD42011001243). More information on PROSPERO is available at http://www.crd.york.ac.uk/prospero/.

### Evidence synthesis and quality assessment

The Grading of Recommendations Assessment, Development, and Evaluation (GRADE) framework was used to guide our evaluation of the evidence from this systematic review, including a priori ranking of health indicators and risks of harm for increasing physical activity, and quality assessment of the evidence. In brief, GRADE is an internationally endorsed framework that provides systematic and transparent methods for clarifying research questions, determining outcomes of interest, summarizing relevant evidence, and presenting recommendations based on the quality of available evidence. For this review, included studies were divided by age group and then by health indicator. Quality of evidence for each health indicator was assessed based on study design, risk of bias, consistency of results, directness of the intervention, precision of results, and possible dose–response gradient. Details on data extraction are presented in the following sections. Details on GRADE methodology can be found elsewhere (Balshem et al. 2011; Guyatt et al. 2011*a*, 2011*b*, 2011*c*, 2011*d*, 2011*e*, 2011*f*, 2011*g*, 2011*h*).

### Study inclusion criteria

The review sought to identify studies that examined the relationship between physical activity and one or more specified health indicators in the early years (infants: 1 month – 1.0 year; toddlers: 1.1–3.0 years; preschoolers: 3.1–4.9 years). Studies were included only if there was a measure of physical activity. For the purpose of this review, we defined physical activity as any bodily movement generated by skeletal muscles that results in energy expenditure above resting levels (Caspersen et al. 1985). Priority of the specified health indicators can be seen in Table 1 and were a priori identified by an expert panel that convened in March 2011 as part of the Canadian physical activity guidelines for the early years development process (Tremblay et al. 2012). The 6 eligible health indicators were as follows:

1. Adiposity (e.g., overweight–obesity measured by body mass index (BMI), waist circumference skinfolds, bio-impedance analysis (BIA), dual-energy X-ray absorptiometry (DXA or DEXA));
2. Bone and skeletal health (e.g., determined with measurements such as bone mineral density or bone mineral content or related measure);
3. Motor skill development (e.g., motor proficiency, gross motor skills, or locomotor and object control);
4. Psychosocial health (e.g., self-concept, self-esteem, emotions, happiness, social–peer interaction and acceptance, aggression, and temperament);
5. Cognitive development (e.g., language development and attention);
6. Cardiometabolic health indicators (e.g., blood pressure; plasma lipid concentrations, such as high-density lipoprotein (HDL)-cholesterol and triglycerides; fasting glucose; insulin resistance; and inflammatory markers, such as C-reactive protein).

Study design was an aspect of the inclusion criteria so that only the highest quality evidence was included, risk of bias was minimized, and to ensure our search identified a manageable number of possible studies. Studies were included if they were published and peer reviewed, and employed one of the following designs: randomized controlled trial, quasi-experimental, prospective cohort, or any study that has either a comparison group or a follow-up period (Haynes et al. 1990; Dishman et al. 2004). Longitudinal studies were included if the data presented in the article were consistent with established age limits (i.e., the study was required to have at least 1 measurement from the 0- to 4.9-year-old period). Cross-sectional studies were not included because this design does not include a follow-up period. No language or date limits were imposed in the search; however, because of issues of feasibility, potential papers published in languages other than English or French ($n$ = 9) were excluded. Details on included study designs and relevant definitions can be found in Appendix A.

### Search strategy

The following electronic bibliographic databases were searched using a comprehensive search strategy to identify relevant studies: Ovid MEDLINE(R) (1948 to 11 May 2011), Ovid EMBASE (1947 to 11 May 2011), and Ovid psycINFO (1806 to week 2 of May 2011), EBSCO SPORTDiscus (1985 to 11 May 2011), and Cochrane Central Database (until May 2011). The search strategy (see Appendix B) was created and run by A.G.L. with the help of an expert in library and information science. Database searches were limited to studies involving "infant", "toddler", or "preschool" children (exact age limitations varied by database). References were extracted as text files from the OVID, EBSCO, and Cochrane interfaces and imported into Reference Manager Software (version 11; Thompson Reuters, San Francisco, Calif., USA). Duplicate articles were first removed using Reference Manager Software; remaining duplicates were removed manually. All articles were assigned a unique reference identification number in the database.

The title and abstract of all potentially relevant articles were screened by 2 reviewers (C.D. and J.A.S.) and a full text copy of each article that met initial screening criteria was obtained. The same reviewers independently examined all full-text articles for inclusion in the review. Any discrepancies were resolved with a discussion and consensus between the 2 reviewers. If they were unable to reach consensus, a third reviewer was asked to examine the article, and in some cases, the questionable articles were presented to the entire guideline development panel and consensus on inclusion was achieved.

In addition to our search, 6 key content experts were contacted and asked to identify the most influential papers from their personal libraries examining physical activity and health during the early years. Two of these experts were involved in the development of preschool guidelines in Australia and the United Kingdom. Content experts were also consulted to help identify key health indicators and guide decisions on search terms. To further help identify studies and to guide the review process, government documents from Canada (Canadian Paediatric Society), Australia (Australian Government Department of Health 2011), and the United Kingdom (Start Active Stay Active 2011) were used for reference.

### Data extraction

Standardized data extraction tables were created through consultation with methodological experts and input from the guideline development panel; data extraction was completed by 1 reviewer and checked by another for accuracy (one of C.D. or J.A.S.). Information was extracted regarding study characteristics (year, study design, country, number of participants, age), type of physical activity, measure of physical activity, and health indicator. Within age groups, at least 2 reviewers (S.C.G., M.E.K., B.W.T., and A.G.L.) independently assessed the quality of the evidence for all of the studies (Guyatt et al. 2011*a*, 2011*b*, 2011*c*, 2011*d*, 2011*e*, 2011*f*, 2011*g*, 2011*h*; Balshem et al. 2011). Based on the quality assessments, we examined the impact of the risk of bias assessments on our overall confidence in the estimates of effect across studies, within 1 outcome (e.g., adiposity), and across outcomes, within 1 age group (e.g., infants). Reviewers were not blinded to the authors or journals.

### Risk of bias assessment

Risk of bias assessment was completed for all included studies as part of the GRADE assessment of evidence quality. Briefly, the risk of bias assessment identifies methodological features of each study that impact our confidence in the overall estimate of effect for an outcome (e.g., allocation concealment, blinding, loss to follow-up, intention-to-treat principle (Guyatt et al. 2011*h*)). Because of the nature of physical activity interventions, it is impossible to blind child participants and their caregivers to group allocation. Furthermore, since the majority of observational studies used parental report methods for assessing levels of physical activity, there was likely some inherent self-report bias. However, if it was determined that blinding of treatment allocation or parental report was the only potential source of bias, the quality of evidence was not downgraded.

### Analysis

By age group (i.e., infants, toddlers, or preschoolers), we identified all studies contributing to each health indicator. By health indicator, meta-analysis was planned for data that were sufficiently homogeneous in terms of statistical, clinical, and methodological characteristics using Review Manager Software 5.0 (The Cochrane Collaboration, Copenhagen, Denmark). Otherwise, qualitative synthesis was conducted for remaining studies. A priori comparisons for subgroup analysis were planned as follows: by direct (e.g., accelerometer or direct observation) versus indirect (e.g., self-report; parent, teacher, or caregiver proxy) measurement; by different frequencies, intensities, times, or types of physical activity (i.e., dose of physical activity); finally, by study quality (if sufficient homogeneity existed, through risk of bias assessment).

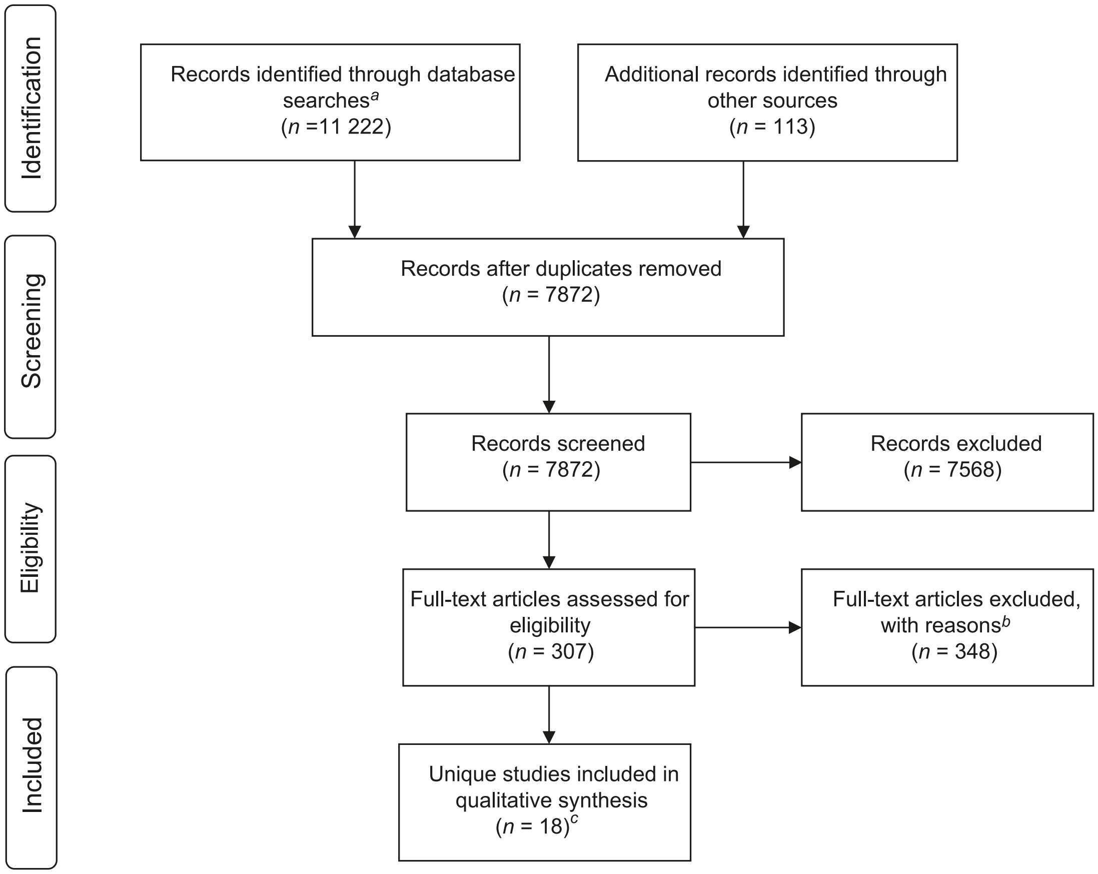
### Harms of increased physical activity

To ensure that both benefits and harms of interventions to increase physical activity were considered, potential harms associated with increased physical activity were discussed a priori and ranked by priority by 4 reviewers (S.C.G., M.E.K., A.G.L., M.S.T.). Similar to discussions regarding importance of health indicators mentioned above, potential harms associated with increased physical activity were ranked as unimportant, important, or critical. Ovid MEDLINE was searched for risks ranked as "important" or "critical". The search strategy was created by A.G.L., M.E.K., S.C.G., and M.S.T. and run by A.G.L. with the help of an expert in library and information science. No risks were ranked as important, and musculoskeletal injury was the only risk ranked as critical. An Ovid MEDLINE search was performed to assess the evidence for musculoskeletal injury. To maximize the search, all study designs were included (see search strategy in Appendix C).

## Results

The preliminary search of electronic databases, reference lists, and documents provided by International consultants identified 11 222 potentially relevant articles (Fig. 1). Of these, 4534 were identified in MEDLINE, 3845 in EMBASE, 828 in psycINFO, 874 through SportDiscus, and 1141 through Cochrane Central Database. An additional 113 articles were identified through key informants, government documents, and bibliographies. After de-duplication, 7872 relevant articles remained. After a preliminary review of titles and abstracts, 307 articles were included for detailed assessment of the full-text article. Of these, 18 unique studies, rep-

**Fig. 1.** Flow diagram for the identification, screening, eligibility, and inclusion of studies. a, Databases included the following: Medline ($n$ = 4534), Embase ($n$ = 3845), PsycINFO ($n$ = 828), SportDiscus ($n$ = 874), Cochrane central database ($n$ = 1141); b, some full-text articles were excluded for multiple reasons; c, data from 18 unique studies are represented in 22 papers included in the review.






resenting 22 papers, met inclusion criteria. Reasons for excluding studies included ineligible age ($n$ = 119), ineligible exposure (e.g., diet) ($n$ = 87), ineligible outcome ($n$ = 54), ineligible analysis (e.g., review article, cross-sectional design or analysis) ($n$ = 87); many studies were excluded for multiple reasons.

Table 2 provides a summary of the characteristics of all studies included in the review. In total, 12 742 enrolled participants from 8 countries were included in this review. Studies ranged from 31 (Li et al. 1995) to 9674 (Sugimori et al. 2004) participants. Articles were published over a 39-year period from 1972 (Porter 1972) to 2011 (Jones et al. 2011), and follow-up duration, where applicable, ranged from 2 months to 8 years.

Quality of evidence by age group and across outcomes can be found in Tables 3–5. Five unique studies examined the relationship between physical activity and health in infants (Table 3); 2 unique studies examined this relationship in toddlers (Table 4); and 11 unique studies examined this relationship in preschoolers (Table 5). The outcomes of interest represented in these unique studies were adiposity ($n$ = 11), bone and skeletal health ($n$ = 2), motor development ($n$ = 4), psychosocial health ($n$ = 3), cognitive development ($n$ = 1), and cardiometabolic health indicators ($n$ = 3). Parent-report was the most common indirect measure used to assess physical activity. Other studies used either accelerometry or a measure of direct observation to quantify time spent participating in physical activity. Some studies included results for more than 1 age category and were presented accordingly. Because of the heterogeneity of measurement tools, interventions, and outcomes, meta-analysis was not possible for any health indicator. Therefore, subgroup (or sensitivity) analysis was not possible or appropriate for measurement type, dose, or study quality.

## Data synthesis

Overall, in infants there was low- to moderate-quality evidence to suggest that increased or higher physical activity is positively associated with improved measures of adiposity, motor skill development, and cognitive development. In toddlers, there was moderate-quality evidence to suggest increased or higher physical activity was positively associated with bone and skeletal health. In preschoolers, there was low- to high-quality evidence on the relationship between increased or higher physical activity and improved measures of adiposity, motor skill development, psychosocial health, and cardiometabolic health indicators.

## Adiposity

Eleven unique studies (reported as 13 papers) examined the relationship between physical activity and adiposity, primarily through measures of BMI. Of the 11 unique studies, 3 studied infants, 1 studied toddlers, and 7 studied preschoolers. Although the study involving toddlers (Sugimori

**Table 2.** Descriptive characteristics of included studies.

| Reference | Country | Study design | Population (*n*) | Age group (mean age or estimate of age) | Exposure | Outcome |
|---|---|---|---|---|---|---|
| Buss et al. 1980 | USA | Prospective cohort | T1 = 129 | Preschoolers (T1 = 3 y, T2 = 4 y); >5 y (T3 = 7 y) | PA (actometer) | Psychosocial health (personality traits) |
| Jones et al. 2011 | Australia | RCT | Baseline: intervention = 52, control = 45; follow-up: intervention = 46, control = 40 | Preschool (4.1 y) | PA = structured activities designed to improve motor skill 3× per wk for 20 wk in a childcare setting; comparison = usual care in a childcare setting | Adiposity (BMI); motor skill development |
| Klesges et al. 1995 | USA | Prospective cohort | T1 = 203; T2 = 168; T3 = 146 | Preschool; mean = 4.0 y; follow-up = 2 y later | Aerobic activity, leisure activity | Adiposity (BMI) |
| Ku et al. 1981 | USA | Prospective cohort | T1, T2 = 90; T3 = 88; T4 = 87; T5 = 87; T6 = 90 | Infant (T1 = 6 mo); toddler (T2 = 1 y, T3 = 2 y); preschooler (T4 = 3 y, T5 = 4 y, T6 = 8 y) | All activity (inactive, light, active) | Adiposity (% body fat) |
| Li et al. 1995 | USA | Prospective cohort | T1 = 31 | Infants (T1 = 6 mo, T2 = 9 mo, T3 = 12 mo) | PA (1st min of every 15 min for 6 h; minimal, light, moderate, vigorous, or maximal activity) | Adiposity (total body fat) |
| Lobo and Winsler 2006 | USA | RCT | Baseline and follow-up: experimental group = 21; control group = 19 | Preschoolers (50 mo) | PA = dance–movement program; comparison = played with other children and the researcher (similar to regular preschool curriculum activities); both = 35 $min \cdot d^{-1}$, 2× per wk, 8 wk | Psychosocial health (social competence, internalizing and externalizing behaviour) |
| Metcalf et al. 2008 | UK | Prospective cohort | T1 = 307; T4 = 212 | Preschoolers (T1 = 4.9 y); >5 y (T2 = 6 y, T3 = 7 y, T4 = 8 y) | PA (measured by accelerometer; active vs. inactive; active = ≥54 $min \cdot d^{-1}$ at ≥2500 $counts \cdot min^{-1}$ for boys; ≥42 $min \cdot d^{-1}$ at ≥2500 $counts \cdot min^{-1}$ for girls) | Adiposity (BMI, BMI SDS, sum of 5 skinfolds, WC), Cardiometabolic health indicators (insulin resistance, triglycerides, cholesterol, mean BP, composite metabolic score) |
| Metcalf et al. 2009 | UK | Prospective cohort | T1 = 307; T4 = 202–213 (depending on the risk factor) | Preschoolers (T1 = 4.9 y); >5 y (T2 = 6 y, T3 = 7 y, T4 = 8 y) | PA (measured through accelerometer; total volume, min of MVPA) | Cardiometabolic health indicators (insulin resistance, adiponectin, leptin, hsCRP) |
| Mo-suwan et al. 1998 | Thailand | RCT | Baseline and follow-up: intervention = 147, control = 145 | Preschoolers (4.5 y) | PA = 15 min walk, 20 min aerobic dance session, 3× per wk, 29–30 wk; comparison = typical kindergarten activities | Adiposity (BMI, weight/height$^3$, triceps skinfold thickness) |
| Moore et al. 1995 | USA | Prospective cohort | T1 = 106; T2 = 97 | Preschoolers (T1 = 4 y); >5 y (T2 = 6.5 y) | PA (low active vs. high active) | Adiposity (BMI, triceps skinfold, subscapular skinfold) |



Published by NRC Research Press

**Table 2** (*continued*).

| Reference | Country | Study design | Population ($n$) | Age group (mean age or estimate of age) | Exposure | Outcome |
|---|---|---|---|---|---|---|
| Moore et al. 2003 | USA | Prospective cohort | T1 = 106; T8 = 103 | Preschoolers (T1 = 3.9–4.2 y); >5 y (T2 = 5 y, T3 = 6 y, T4 = 7 y, T5 = 8 y, T6 = 9 y, T7 = 10 y, T8 = 11 y) | PA (MVPA) | Adiposity (BMI) |
| Porter 1972 | Phillipines | Nonrandomized trial | Baseline and follow-up: intervention = 47, control = 47 | Infants (18.3 wk) | PA = 20 min of passive cycling (alternating 5 min cycling, 5 min rest), 2× per day, 6 d·wk$^{-1}$, 2 mo); comparison = typical child rearing practice | Motor skill development (motor, adaptive); psychosocial health (personal–social); cognitive development (language) |
| Reilly et al. 2006 | UK | RCT | Baseline: intervention = 268, control = 277; 6 mo follow-up: intervention = 231, control = 250; 12 mo follow-up: intervention = 245, control = 259 | Toddlers (intervention = 4.2 y; control = 4.1 y) | PA = program in nursery (three 30-min sessions per wk over 24 wk); comparison = usual preschool curriculum | Adiposity (BMI); motor skill development |
| Sääkslahti et al. 2004 | Finland | Prospective cohort | T1 = 155; T2 = 143; T3 = 128 | Preschoolers (T1 = 4.9 y); >5 y (T2 = 5.7 y; T3 = 6.7 y) | Play (low activity vs. high activity) | Adiposity (BMI), cardiometabolic health indicators (SBP, DBP, total cholesterol, HDL cholesterol, HDL/total cholesterol, triglycerides) |
| Shapiro et al. 1984 | USA | Prospective cohort | T1 = 450; T2 = 386; T3 = 312; T4 = 270; T5 = 242; T6 = 186; T7 = 170 | Infant (T1 = 6 mo); toddler (T2 = 1 y, T3 = 2 y); preschooler (T4 = 3 y, T5 = 4 y, T6 = 6 y, T7 = 9 y) | PA (parent reported, 1 d) | Adiposity (sum of skinfolds) |
| Specker and Binkley 2003 | USA | RCT | Total = 239; intervention (gross motor + placebo) = 62; control (fine motor + placebo) = 57 | Preschooler (gross motor = 4 y; fine motor = 3.8 y) | PA (gross motor vs. fine motor intervention 30 min·d$^{-1}$, 5 d·wk$^{-1}$ + placebo, 1 year) | Adiposity (total body fat, total body lean); bone and skeletal health (arm BMC, leg BMC, total body BA, arm BA, leg BA, periosteal circumference, endosteal circumference, cortical area, cortical thickness) |
| Specker et al. 1999 | USA | RCT | T1 = 72, T2 = 69, T3 = 66, T4 = 60, T5 = 58; gross motor = 34; fine motor = 35 | Infants (T1 = 6 mo, T2 = 9 mo, T3 = 12 mo); toddlers (T4 = 15 mo, T5 = 18 mo) | PA (gross vs. fine motor intervention 15–20 min·d$^{-1}$, 5 d·wk$^{-1}$, 1 y long) | Bone and skeletal health (BMC, bone circumference) |

**Table 2** (*concluded*).

| Reference | Country | Study design | Population ($n$) | Age group (mean age or estimate of age) | Exposure | Outcome |
|---|---|---|---|---|---|---|
| Specker et al. 2004 | USA | RCT | Baseline: gross motor = 89, fine motor = 89; follow-up: intervention = 80, control = 81 | Preschoolers (gross motor = 6.0 y; fine motor = 5.9 y) | PA (gross motor vs. fine motor intervention both, 30 min·d$^{-1}$, 5 d·wk$^{-1}$, 12 mo) | Bone and skeletal health (total body, arm, and leg BMC) |
| Sugimori et al. 2004 | Japan | Prospective cohort | T1 = 9674; T2 = 8170 | Toddlers (T1 = 3 y); >5 y (T2 = 6 y) | PA (physical club frequency and duration) | Adiposity (normal weight vs. obese) |
| Venetsanou and Kambas 2004 | Greece | Nonrandomized trial (no mention of randomization) | Baseline: intervention = 28; control = 38 | Preschoolers (59.8 mo) | PA = dance program, 45 min·d$^{-1}$, 2× per wk, 20 wk; comparison = performed regular kindergarten curricular activities | Motor skill development (motor proficiency) |
| Wells and Ritz 2001 | UK | Prospective cohort | T1 = 38; T2 = 23 | Infants (T1 = 0.87 y); toddlers (T2 = 1.99 y) | PA (awake and active) | Adiposity (skinfolds, fat mass index) |
| Wilson et al. 1992 | USA | Prospective cohort | T1 = 204; T2 = 167; T3 = 158 | Preschoolers(4.5 y) (yearly follow-up for 3 y) | Parent reported (Energy Balance Questionnaire; structured, leisure, and aerobic activity) | Cardiometabolic health indicators (SBP, DBP) |

**Note:** Specker et al. 2004 and Specker and Binkley 2003 both reported data from the same randomized controlled study; Ku and Shapiro both reported data from the same longitudinal study; Metcalfe et al. 2008 and 2009 both reported data from the EarlyBird study; Moore et al. 1995 and 2003 both reported data from the Framingham Children's Study. Studies by Sugimori and Wilson met inclusion criteria but data was presented cross-sectionally and therefore excluded from analysis. Sample sizes provided as T1 indicate no. of participants enrolled. RCT, randomized controlled trial; PA, physical activity; BMI, body mass index; T1, time 1; T2, time 2; T3, time 3, etc.; SDS, standard deviation scores; WC, waist circumference; BP, blood pressure; MVPA, moderate- to vigorous-intensity physical activity; hsCRP, high sensitivity C-reactive protein; SBP, systolic blood pressure; DPB, diastolic blood pressure; HDL, high-density lipoprotein; BMC, bone mineral content; BA, bone area.

**Table 3.** Is physical activity associated with better health outcomes in infants (1 month – 1.1 years)?

| Quality assessment | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of unique studies | Design | Risk of bias | Inconsistency | Indirectness | Imprecision | Other considerations | Increased physical activity | Absolute effect (confidence interval, SE) | Quality | Importance |
| **Adiposity (infants; observational; follow-up 6 to 84 mo; intervention is activity levels at 6–12 mo, energy expenditure over 8 d at 9–12 mo; outcomes are % body fat; skinfolds, fat-free mass, and dual-energy X-ray absorptiometry** | | | | | | | | | | |
| 3 | Observational studies[a,b,c] | No serious risk of bias | No serious inconsistency | No serious indirectness | No serious imprecision | None | 571[d] | B = –0.6 ($p$ = 0.028)[e]; no effect[f] | ⊕⊕○○ LOW | CRITICAL |
| **Bone (infants; follow-up 12 mo; intervention is gross motor activity program for 15–20 daily, 5 d per week for 1 y; outcome is bone mineral content)** | | | | | | | | | | |
| 1 | RCT[g] | Serious[h,i] | No serious inconsistency | No serious indirectness | No serious imprecision | None | Intervention = 34; control = 35 | No effect[j] | ⊕⊕⊕○ MODERATE | NOT IMPORTANT |
| **Motor development (infants; follow-up 2 mo; intervention is passive cycling at 4 to 40 mo; outcome is motor development score on Gesell Development Schedule, higher scores are better)** | | | | | | | | | | |
| 1 | RCT[k] | Serious[l] | No serious inconsistency | No serious indirectness | No serious imprecision | None | Intervention = 62; control = 68 | MD 17.0 units higher[m] | ⊕⊕⊕○ MODERATE | CRITICAL |
| **Psychosocial health (infants; follow-up 2 mo; intervention is passive cycling at 4 to 40 mo; outcome is personal and social development score on Gesell Development Schedule, higher scores are better)** | | | | | | | | | | |
| 1 | RCT[k] | Serious[l] | No serious inconsistency | No serious indirectness | No serious imprecision | None | Intervention = 62; control = 68 | MD 23.7 units higher[n] | ⊕⊕⊕○ MODERATE | NOT IMPORTANT |
| **Cognitive development (infants; follow-up 2 mo; intervention is passive cycling at 4 to 40 mo; outcome is cognitive development score on Gesell Development Schedule, higher scores are better)** | | | | | | | | | | |
| 1 | RCT[k] | Serious[l] | No serious inconsistency | No serious indirectness | No serious imprecision | None | Intervention = 62; control = 68 | MD 16.3 units higher[o] | ⊕⊕⊕○ MODERATE | IMPORTANT |

**Note:** Bibliography: Adiposity, Ku et al. 1981, Li et al. 1995, Shapiro et al. 1984, Wells and Ritz 2001; bone and skeletal health, Specker et al. 1999; motor development, Porter 1972; psychosocial health, Porter 1972; cognitive development, Porter 1972. RCT, randomized controlled trial; MD, mean difference.

[a]Includes 4 prospective cohort studies (Ku et al. 1981; Li et al. 1995; Shapiro 1984; Wells and Ritz 2001).

[b]Shapiro et al. (1984) and Ku et al. (1981) are both reports of the same longitudinal cohort of 450 infants. Shapiro reports obesity defined by sum of skinfolds measures, and Ku reports sum of skinfolds and underwater weighing measures.

[c]Did not present longitudinal analysis of physical activity and skinfolds and therefore excluded from further analysis (Shapiro et al. 1984).

[d]Ku $n$ = 170; Li $n$ = 31; Wells $n$ = 38.

[e]For each 15-min interval child spent active, skinfolds decreased by 0.6 mm; no effect on fat-free mass (Wells and Ritz 2001).

[f]No effect of physical activity levels at 6 months and 1 year on percent body fat at 8 years (Ku et al. 1981); no effect of activity at 6 months and fat mass at 12 months (Li et al. 1995).

[g]Includes 1 randomized control trial (Specker et al. 1999).

[h]Authors reported 72 infants randomized; however, they did not report number of infants initially randomized to each group, only number analyzed at 9 months of age.

[i]Randomization method not reported; allocation concealment not reported; randomization stratified according to childcare center and gender. Not reported if parents or childcare providers were blinded to physical activity intervention (gross vs. fine motor). Unlikely that infants' knowledge of assignment would affect intervention.

[j]No beneficial effect of physical activity levels at 6, 9, and 12 months on BMC at 18 months (Specker et al. 1999).

[k]Includes 1 randomized controlled trial (Porter 1972).

[l]Parents and caregivers were not blinded to treatment allocation; unsure if outcomes assessors were blinded to treatment allocation; no intention-to-treat analysis; excluded those who did not carry out the management plan for the group and those who became sick during the study and had exercise interrupted.

[m]Intervention group had mean motor development quotient scores on the Gesell Development Schedule that were 17 units higher than the control group ($p < 0.01$) (Porter 1972).

[n]Intervention group had mean personal social development quotient scores on the Gesell Development Schedule that were 24 units higher than the control group ($p < 0.01$) (Porter 1972).

[o]Intervention group had mean language quotient scores on the Gesell Development Schedule that were 16 units higher than the control group ($p < 0.01$) (Porter 1972).

Published by NRC Research Press

**Table 4.** Is physical activity associated with better health outcomes in toddlers (1.1–3.0 years)?

| Quality assessment | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of unique studies | Design | Risk of bias | Inconsistency | Indirectness | Imprecision | Other considerations | Increased physical activity | Absolute estimate (confidence intervals, SE) | Quality | Importance |
| **Adiposity: (RCT, follow-up mean 1 y; intervention is physical activity program at age 4–5 y, 3×30-min sessions over 24 wk; outcome is BMI** | | | | | | | | | | |
| **Adiposity: (prospective cohort) follow-up mean 3 y; measured with BMI** | | | | | | | | | | |
| 1 | Observational study[a] | No serious risk of bias | No serious inconsistency | No serious indirectness | No serious imprecision | None | 8170 | NA | ⊕○○○ VERY LOW | CRITICAL |
| **Bone: follow-up mean 3 mo; measured with BMC** | | | | | | | | | | |
| 1 | RCT[b,c] | Serious[d] | No serious inconsistency | No serious indirectness | No serious imprecision | None | Intervention = 34; control = 35 | No numeric data[e] | ⊕⊕⊕○ MODERATE | NOT IMPORTANT |

**Note:** Bibliography: Adiposity, Sugimori et al. 2004; bone and skeletal health, Specker et al. 1999 (RCT). RCT, randomized controlled trial; BMI, body mass index; BMC, bone mineral content.

[a]Includes 1 prospective cohort study (Sugimori et al. 2004); although measurements of physical activity were collected at more age 3 and age 6, data were only presented for level of physical activity at age 6 and therefore this study was excluded from further analysis. Quality of evidence has been downgraded accordingly.

[b]Includes 1 randomized trial (Specker et al. 1999).

[c]Toddlers were randomized to a gross motor or fine motor program. The gross motor program included activities that focused on loading the skeleton and were performed for 15–20 $min \cdot day^{-1}$, 5 $days \cdot week^{-1}$, and supervised by study personnel. The fine motor program included a similar number of activities but focused on fine motor and cognitive skills.

[d]Randomization method not reported; allocation concealment not reported; randomization stratified according to childcare center and gender. Not reported if parents or childcare providers were blinded to physical activity intervention (gross vs. fine motor). Unlikely that infants' knowledge of assignment would affect intervention.

[e]At no age was total body BMC correlated with average 48-h sensor readings, activity scores, or percentage of time bearing weight on the legs. Specific results not reported (Specker et al. 1999).

et al. 2004) met our inclusion criteria, because the physical activity data were only presented at 6 years of age the study was excluded from further analysis. Details of these 11 unique studies can be found in Table 2.

In infants, higher activity levels were associated with lower skinfold thickness (Wells and Ritz 2001); infant time spent active was negatively related to triceps skinfold thickness, after adjusting for total fatness, suggesting that the impact of physical activity was most pronounced on peripheral adiposity rather than whole-body adiposity. In contrast, 2 other studies did not find a relationship between infant activity level and measures of adiposity later in life (Ku et al. 1981; Li et al. 1995). The studies had low-quality evidence and no serious risk of bias, inconsistency, indirectness, or imprecision (Table 3).

In preschoolers, 4 randomized trials and 3 prospective cohort studies (represented in 4 papers) were found. Of the 4 randomized controlled trials (RCTs) included, 3 found no effect of an exercise program on BMI (Reilly et al. 2006; Jones et al. 2011) or total body fat (Specker and Binkley 2003). Trials by Jones and by Reilly both compared structured activity programming in the childcare setting that aimed to increase physical activity. Specker and Binkley compared a program of gross motor activity to a fine motor activity intervention to improve body fat. The final RCT (Mo-suwan et al. 1998) used a structured dance class. This study found no effect on the prevalence of obesity, but found that girls in the exercise group were 68% less likely to increase their BMI; an effect that was not observed in boys. In other words, exercise protected the girls against gains in BMI. One prospective study found no effect (Metcalf et al. 2008). Three other observational studies involving preschoolers were included. Two unique studies (Klesges et al. 1995; Moore et al. 2003, 1995) found that higher activity at baseline was associated with smaller gains in BMI, with evidence of a dose–response relationship between physical activity and BMI and skinfold thickness (Moore et al. 2003); higher physical activity during the preschool years was associated with better measures of adiposity up to 7 years later (Moore et al. 2003). Ku found that activity at 3 years of age was associated with less percent body fat, as measured using hydrostatic weighing, at 8 years of age in boys only (Ku et al. 1981).

Across both RCT and observational study designs, we identified no serious risk of bias, inconsistency, indirectness, or imprecision. For RCTs, the overall quality of evidence was high, and for observational studies, we upgraded the quality of evidence from low to moderate because of the dose–response relationship (as the level of physical activity increased, the risk of unfavourable measures of adiposity decreased; Table 5).

## Bone and skeletal health

Two unique studies, both RCTs, examined the relationship between physical activity and skeletal health (represented in 3 papers). One paper reported this relationship in infants and toddlers (Specker et al. 1999) and 2 papers reported results in preschoolers (Specker and Binkley 2003; Binkley and Specker 2004). Details of these 2 unique studies can be found in Table 2.

In preschoolers, we identified 2 reports from the same RCT that delivered a program of gross motor activity. Increased activity was associated with increases in tibia circumference at post-intervention (Specker and Binkley 2003) and this effect was present up to 12 months later (Binkley and Specker 2004). In contrast, there was no effect on total body bone mineral content, arm bone mineral content, leg bone mineral content, total body bone area, arm bone area, or leg bone area (Specker and Binkley 2003; Binkley and Specker 2004). The overall quality of evidence was moderate, with no serious inconsistency, indirectness, or imprecision; however, because of many small issues with study design, quality was downgraded because of possible risk of bias (Table 5).

### Motor skill development

Four studies examined the relationship between physical activity and motor skill development. One RCT studied this relationship in infants (Porter 1972) and 3 (2 RCTs and 1 nonrandomized study) in preschoolers (Jones et al. 2011; Reilly et al. 2006; Venetsanou and Kambas 2004). Details of these 4 unique studies can be found in Table 2.

In infants, an RCT reported that passive cycling for 2 months during the first year of life resulted in motor (body control balance, grasping) and adaptive (hand–eye coordination) development that was greater than the control group, according to the Gesell Development Schedule (Porter 1972). The study had moderate-quality evidence and no serious inconsistency, indirectness, or imprecision; however, because of many small issues with study design, quality was downgraded on account of possible risk of bias (Table 3).

In preschoolers, a randomized controlled trial found a movement skill development physical activity program improved scores on the Test of Gross Motor Development (2nd edition) (Jones et al. 2011), and a nonrandomized trial (Venetsanou and Kambas 2004) reported significant improvements in motor development scores for preschoolers enrolled in bi-weekly dance classes. Reilly et al. (2006) found that an enhanced physical activity program delivered in a nursery setting significantly increased fundamental movement skills compared with those in the control group, although there was no increase in habitual physical activity levels. The RCTs had no serious risk of bias, inconsistency, indirectness, or imprecision, representing high quality evidence. We identified no reason to upgrade the nonrandomized study and therefore it was left as low quality, with no serious risk of bias, inconsistency, indirectness, or imprecision (Table 5).

### Psychosocial health

Three studies examined the relationship between physical activity and psychosocial health. One RCT studied infants and 2 (1 RCT, 1 observational study) studied preschoolers. No studies examined the relationship between physical activity and psychosocial health in toddlers. Details of these 3 unique studies can be found in Table 2.

In preschoolers, children randomized to a dance program made greater gains in their social competence and externalizing behaviour (as measured by the Social Competence Behavior Evaluation: Preschool Edition) relative to a control group (Lobo and Winsler 2006). In a prospective cohort study, more active preschoolers were rated by their teachers as being more outgoing and less socially withdrawn, using the California Child Q set (Buss et al. 1980). The quality of evidence was high (randomized control trial) and low (prospective cohort study), and had no serious risk of bias, inconsistency, indirectness, or imprecision (Table 5).

### Cognitive development

One study examined the relationship between physical activity and cognitive development in infants. No studies examined the relationship between physical activity and cognitive development in toddlers or preschoolers.

In infants, passive cycling for 2 months during the first year of life increased language development, defined by the authors as forms of communications by facial expression, sounds, vocalizations, and babble and measured using the Gesell Development Schedule (Porter 1972). The quality of evidence was moderate with no serious inconsistency, indirectness, or imprecision; however, because of many small issues with study design, quality was downgraded on account of possible risk of bias (Table 3).

### Cardiometabolic health indicators

Three unique studies (reported in 4 papers) examined the relationship between physical activity and indicators of cardiometabolic health. All studies were in preschoolers. Although the study met our inclusion criteria, physical activity data from Wilson et al. (1992) were analyzed cross-sectionally, and were therefore excluded from analysis. Details of these 3 unique studies can be found in Table 2.

The relationships between physical activity and cardiometabolic health indicators were often different between boys and girls. Using parent report of physical activity, girls who retained high levels of physical activity had greater reductions in total cholesterol and HDL/total cholesterol ratio (Saakslahti et al. 2004). Similarly, boys who retained high levels of physical activity had greater reductions in triglycerides (Saakslahti et al. 2004). Using accelerometry as an objective measure of physical activity, Metcalf et al. (2008, 2009) reported on the relationship between physical activity and cardiometabolic health. In 1 study, no relationship was found (Metcalf et al. 2009). In another study, male preschoolers participating in more than 56 min (median of the boys) of moderate intensity physical activity (i.e., >3 METs) per day had better metabolic status as assessed from a composite score of various cardiovascular disease risk factors (Metcalf et al. 2008). There was a trend ($p = 0.06$) for a similar effect in female preschoolers participating in 42 min (median of the girls) of moderate to vigorous physical activity (Metcalf et al. 2008). The overall quality of evidence was low, with no serious risk of bias, inconsistency, indirectness, or imprecision (Table 5).

### Risk of increased physical activity

A total of 115 articles were found but none specifically examined the risks associated with increased physical activity in this age group.

## Discussion

As part of a rigorous and transparent process to develop Canada's first physical activity guidelines for the early years (aged 0–4 years), we conducted this systematic review to evaluate the available evidence examining the relationship between physical activity and health indicators during the

**Table 5.** Is physical activity associated with better health outcomes in preschoolers (3.1–4.9 years)?

| Quality assessment | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| No. of unique studies | Design | Risk of bias | Inconsistency | Indirectness | Imprecision | Other considerations | No. of participants | Absolute estimate (confidence intervals, SE) | Quality | Importance |
| **Adiposity: (RCT) measured with BMI, total body fat (kg); adiposity: (prospective cohorts) follow-up 3–8 y; measured with: BMI, BMI *z* score, BMI percentile, skinfold, sum of skinfold** | | | | | | | | | | |
| 4 | RCT[a] | No serious risk of bias | No serious inconsistency | No serious indirectness | No serious imprecision | None | Intervention = 591; control = 571[c] | –0.8(–0.33, 0.17)[d], no effect[e] | ⊕⊕⊕⊕ HIGH | CRITICAL |
| 3 | Observational studies[f] | No serious risk of bias | No serious inconsistency | No serious indirectness | No serious imprecision | Dose–response gradient[g] | 252[h] | –0.316, $p = 0.03$[i], OR: 2.6 (1.0–6.4)[j], 18.6±0.6, $p = 0.05$; 15.1±1.1, $p = 0.03$; 74.1±7.0, $p = 0.05$[k] | ⊕⊕⊕○ MODERATE | CRITICAL |
| **Bone: (RCT) follow-up 12 mo, measured with total body BMC** | | | | | | | | | | |
| 1 | RCT[l] | Serious[m] | No serious inconsistency | No serious indirectness | No serious imprecision | None | Intervention = 142; control = 138[n] | 49.9±0.7, $p = 0.03$[o]; 41.7±0.9, $p = 0.05$[p] | ⊕⊕⊕○ MODERATE | CRITICAL |
| **Motor development: (RCT) follow-up mean 20 wks to 1 year; measured with: Test of Gross Motor Development (2nd edition); range of scores: 0–40, better indicated by higher values (Jones et al. 2011); fundamental movement skills score; range of scores: 0–15 (Reilly et al. 2006). Motor development: (nonrandomized trial) measured with Test of Motor Proficiency for children 4–6 y of age; range of scores: 0–34, better indicated by higher values** | | | | | | | | | | |
| 2 | RCT[q] | No serious risk of bias | No serious inconsistency | No serious indirectness | No serious imprecision | None | Intervention = 320; control = 322[r] | 2.08 (0.76, 3.40) $p = 0.00$[s], MD = 0.7 (0.3, 1.1)[t] | ⊕⊕⊕⊕ HIGH | CRITICAL |
| 1 | Observational studies[u] | No serious risk of bias | No serious inconsistency | No serious indirectness | No serious imprecision | None | Intervention = 28; control = 38 | Mean difference = 3.74 $p<0.001$[v] | ⊕⊕○○ LOW | CRITICAL |
| **Psychosocial health: (RCT) follow-up mean 1–4 y; measured with California Child Q set** | | | | | | | | | | |
| 1 | RCT[w] | No serious risk of bias | No serious inconsistency | No serious indirectness | No serious imprecision | None | Intervention = 21; control = 19 | $F_{[1,38]} = 16.25$, $p<0.001$ $F_{[1,38]} = 11.28$, $p<0.001$ $F_{[1,38]} = 14.75$, $p<0.001$[x] | ⊕⊕⊕⊕ HIGH | CRITICAL |
| 1 | Observational studies[y] | No serious risk of bias | No serious inconsistency | No serious indirectness | No serious imprecision | None | 129 | $p<0.05$–$<0.001$[z] | ⊕⊕○○ LOW | CRITICAL |
| **Cardiometabolic health indicators: (prospective cohorts) follow-up 1–3 y; measured with: blood pressure, insulin resistance, blood lipids; better indicated by lower values** | | | | | | | | | | |
| 3 | Observational studies* | No serious risk of bias | No serious inconsistency | No serious indirectness | No serious imprecision | None | 543[†,‡] | $r = –0.33$, $p<0.01$; $r = –0.13$, $p = 0.21$[§]; –0.10, $p = 0.02$[‖]; –0.17, $p = 0.06$[¶]; no numeric data** | ⊕⊕○○ LOW | IMPORTANT |

**Note:** Bibliography: Adiposity, Jones et al. 2011 (RCT), Reilly et al. 2006 (RCT), Specker and Binkley 2003) (RCT), Klesges et al. 1995, Moore et al. 1995 and 2003, Saakslahti et al. 2004; bone health, Specker and Binkley 2003; Binkley and Specker 2004; motor development, Jones et al. 2011 (RCT), Venetsanou and Kambas 2004; psychosocial health, Lobo and Winsler 2006 (RCT), Buss et al. 1980; cardiometabolic health indicators, Metcalf et al. 2008, 2009, Saakslahti et al. 2004, Wilson et al. 1992. RCT, randomized control trial; BMI, body mass index; BMC, bone mineral content.

[a]Includes 4 randomized control trials (Jones et al. 2011; Mo-suwan et al. 1998; Reilly et al. 2006; Specker and Binkley 2003).

[b]There was no difference in physical activity levels between the intervention and control group; therefore, it is difficult to draw inferences on the effectiveness of the intervention. Authors conclude dose of intervention was not strong enough to have an overall impact on physical activity levels (Reilly et al. 2006). This was not enough evidence to warrant downgrading the overall study quality.

[c]Intervention: $n = 52$, control: $n = 45$ (Jones et al. 2011); intervention: $n = 147$, control: $n = 145$ (Mo-suwan et al. 1998); intervention: $n = 268$, control: $n = 277$ (Reilly et al. 2006); intervention (gross motors): $n = 88$ analyzed, $n = 124$ enrolled; control (fine motor) $n = 90$ analyzed, $n = 114$ enrolled (Specker and Binkley 2003).

[d]Adjusted mean difference between BMI of experimental and control group from baseline to follow-up (Jones et al. 2011).

[e]Exercise intervention did not significantly reduce weight (Mo-suwan et al. 1998); gross motor physical activity intervention had no effect on total body lean or fat mass (Specker and Binkley 2003); no effect of intervention of BMI (Reilly et al. 2006).

[f]Includes 3 prospective cohort studies (Klesges et al. 1995; Moore et al. 1995, 2003; Saakslahti et al. 2004). Moore et al. 1995 and 2003 report follow-ups of the same study — 1 at 1st grade (Moore et al. 1995) and 1 at 11 years of age (Moore et al. 2003). Saakslahti reported on BMI cross-sectionally (although did control for it during longitudinal analysis) and was excluded from further analysis.

[g]Higher baseline aerobic activity and increased leisure activity from year 2 to 3 were associated with smaller gains in BMI (Klesges et al. 1995; Moore et al. 2003); those in the highest tertile of physical activity had lower BMI, triceps skinfolds, and sum of 5 skinfolds at each year of follow-up.

[h]Klesges $n = 146$; Moore (Framingham children's study) $n = 106$; $n = 97$ analyzed at first grade (1995); $n = 103$ analyzed at 8-year follow-up (2009).

[i]Regression coefficients of baseline activity as a predictor of BMI 2 years later; higher baseline activity was associated with smaller gains in BMI (Klesges et al. 1995).

[j]Odds ratio for skinfold measurement in active vs. inactive participants (as measured by Caltrac counts per day); differences in subscapular skinfolds and BMI were not significant between groups (Moore et al. 1995).

[k]Mean BMI, triceps skinfolds, and sum of skinfolds in most active tertile; *p* value is for trend compared with the low and moderately active groups of average daily activity from ages 4 to 11 years (Moore et al. 2003).

[l]Includes 1 unique prospective cohort study with results presented in 2 papers (Specker and Binkley 2003; Binkley and Specker 2004). Specker is main study and outcomes. Binkley reports BMC at 12 months post-intervention.

[m]Randomization methods not reported; allocation concealment not reported; randomization stratified according to childcare centre and gender. Not reported if children, parents, or childcare providers were blinded to physical activity intervention (gross vs. fine motor). No intention-to-treat analysis; excluded those who completed less than 38 weeks of the 1-year intervention.

[n]Intervention: $n = 80$, control: $n = 81$ (Binkley and Specker 2004); intervention: $n = 62$, control: $n = 57$ (Specker and Binkley 2003).

[o]Tibia periosteal circumference (mm) post-intervention was significantly larger than fine motor group.

[p]Tibia endosteal circumference (mm) post-intervention was significantly larger than fine motor group (Specker and Binkley 2003). Gross motor physical activity intervention had no effect on total body BMC, arm BMC, leg BMC, total body bone area, arm bone area, or leg bone area (Specker and Binkley 2003; Binkley and Specker 2004).

[q]Includes 2 randomized control trial (Jones et al. 2011; Reilly et al. 2006).

[r]Intervention $n = 52$, control $n = 45$ (Jones et al. 2011); intervention $n = 268$, control $n = 277$ (Reilly et al. 2006).

[s]Adjusted mean difference between score on movement skill development test of experimental and control group from baseline to follow-up (Jones et al. 2011).

[t]Mean differences in fundamental movement skills score, interpret with caution as the intervention was not able to significantly increase physical activity levels (Reilly et al. 2006).

[u]Includes 1 nonrandomized controlled study (Venetsanou and Kambas 2004). The children of the experimental group ($n = 28$) attended the intervention program for 20 weeks, participating in 2 sessions a week, while the children of the control group ($n = 38$) did not participate regularly in any organized physical activity program.

[v]Mean difference on motor development score (The *Motoriktest für vier-bis sechsjährige Kinder* (MOT 4–6)) between intervention and control group at follow up.

[w]Includes 1 randomized control trial (Lobo and Winsler 2006).

[x]Children who participated in the dance program made significantly greater gains from pre-test to post-test on parent and teacher reports of social competence; internalizingand externalizing behaviour (Lobo and Winsler 2006).

[y]Includes 1 prospective cohort (Buss et al. 1980).

[z]Correlations between physical activity and teacher ratings on the California Child Q set (measure of personality characteristics) were significant.

*Includes 3 unique prospective studies (Metcalf et al. 2008, 2009; Saakslahti et al. 2004; Wilson et al. 1992). Metcalf et al. (2008, 2009) report follow-ups of the same study. Wilson et al. (1992) measured physical activity at yearly intervals for 3 years but presented cross-sectional analysis and was excluded from further analysis.

[†]Metcalf $n = 213$; Saakslahti $n = 155$; Wilson $n = 175$.

[‡]Metcalf et al. (2009): between 202–213 analyzed of 307 originally enrolled; Metcalf et al. (2008) — 212 analyzed of 307 originally enrolled.

[§]Association between moderate to vigorous physical activity and adiponectin for girls but not for boys, although in the opposite direction as expected by the authors (Metcalf et al. 2009).

[‖]Change in composite metabolic status score for boys above the median for moderate to vigorous physical activity.

[¶]Change in composite metabolic status score for girls above the median (Metcalf et al. 2008).

**No numeric data provided, but constantly active girls reported to have decreased cholesterol ($p = 0.004$) and increased high-density lipoprotein/total cholesterol ratio ($p < 0.001$); constantly active boys reported to have decreased triglyceride concentration ($p = 0.011$) (Saakslahti et al. 2004).





Published by NRC Research Press

early years. We found evidence to support a positive relationship between increased or higher physical activity and favourable measures of adiposity, bone and skeletal health, motor skill development, psychosocial health, cognitive development, and aspects of cardiometabolic health. However, because of the dearth of information we could not determine the specific amount, intensity, frequency, or type of physical activity needed to promote healthy growth and development.

In recent years, a number of surveillance studies have used objective measures to assess physical activity during the early years, particularly within toddlers and preschoolers. These studies measured daily physical activity of at least a light intensity, and reported values that ranged between 118 (Reilly et al. 2004) to 144 min per day (Obeid et al. 2011), with an average value of ~130 min (Reilly et al. 2004; Obeid et al. 2011; Gabel et al. 2011; Pate et al. 2004). If one assumes that 130 $\text{min}\cdot\text{day}^{-1}$ reflects the "background" physical activity level of these children, the question remains as to how much additional physical activity is necessary for health benefits. In this review, we were not able to answer that question. Another important question relates to the intensity at which the physical activity should be performed. Though the results of this review cannot provide specific information to answer this question, more intense physical activity may be important as children approach the school years (Janssen and LeBlanc 2010).

This review was able to investigate how physical activity during the early years might be related to health later in life. Some adult diseases are believed to have their origins in childhood (Berenson et al. 1998; Napoli et al. 1999) and we know that the initial signs of atherosclerosis, for example, are already detectable during the early years (Newman et al. 1991). The idea of a physical activity "investment" is an important public health message at a time when childhood obesity (World Health Organization 2011) and physical inactivity (Colley et al. 2011) are at unprecedented levels. The results of this systematic review suggest that investing in physical activity during the early years has health benefits later in life, particularly with respect to adiposity.

An important consideration in this review was the definition of physical activity, because the age limits of the included studies ranged from 1 month to 4.9 years. While we recognize that the form and context of physical activity are different from infants to toddlers to preschoolers, we believe the concept of physical activity can be consistently defined across these ages as any bodily movement generated by skeletal muscles that results in energy expenditure above resting levels (Caspersen et al. 1985). Of the studies included in this review, we also faced the challenge that measures of physical activity differed markedly and were reported both as indirect and direct measures. Though we had planned a priori to conduct subgroup analysis of direct (e.g., accelerometer or direct observation) versus indirect (e.g., self-report; parent, teacher, or caregiver proxy) measures of physical activity, this was not possible because of heterogeneity of measurement tools and interventions. Future research should try to harmonize the approach to measuring physical activity so that the health benefits of physical activity can be further elucidated across the early years.

In addition to the health benefits of physical activity, effort was made to determine possible risks associated with increasing physical activity during the early years. However, no studies that specifically examined the association between increased physical activity and increased health risk (musculoskeletal risks) could be identified. The lack of evidence may be indicative of the fact that children aged 0–4 years do not usually participate in the kinds of activity that increase the risk of injuries requiring medical treatment (e.g., contact sports). For the most part, infants, toddlers, and preschoolers engage in relatively safe physical activities, such as play, that likely contribute to minor bumps and bruises rather than significant injuries (Chang et al. 1989). These activities are typically supervised by parents or caregivers, thus reducing the likelihood of dangerous situations.

This review sought to compile the best available evidence that linked physical activity and health during the early years by following the rigorous methodological standards that have been established for systematic reviews. We used the GRADE framework to guide the review process and assess the evidence. In accordance with GRADE, as many decisions as possible were made a priori, which helps limit potential bias throughout the review. Furthermore, all steps of the review (i.e., inclusion criteria, exclusion criteria, data extraction, GRADE tables) were done in duplicate to minimize error. In all of the studies included in this review, we found no serious risk of bias, inconsistency, indirectness, or imprecision. However, using such a rigorous methodology also creates limitations. For example, this review may have benefited from including studies that used a lower quality design (i.e., cross-sectional). It is important to note that other scientific reviews of the literature that were used to inform recent physical activity recommendations for the early years for Australia and the United Kingdom, where cross-sectional evidence was included, obtained similar conclusions regarding the relationship between physical activity and specific health indicators. Another limitation of this review is that most of the included observational studies used parent-reported measures of physical activity. This increases the likelihood that estimates of physical activity levels were over-reported because of social desirability bias, and that the relationships between physical activity and the health indicators were underestimated because of measurement error. Finally, we cannot discount the possibility of publication bias in this area of research, suggesting that only positive findings between physical activity and health would have been published and, therefore, available to our search strategy.

This systematic review builds on a previous narrative review (Timmons et al. 2007). Over the last 5 years, several studies have been published studying the relationships between physical activity and health during the early years. Nevertheless, there remains a critical need to build research capacity in this area and to enhance understanding of how much physical activity is needed for optimal growth and development. There is a need for more rigorous research designs, including higher quality randomized controlled trials in this age group (e.g., larger and more diverse samples using direct measures and reporting outcomes important for healthy growth and development). Prospective cohort studies using objective and standardized measures of physical activity (e.g., accelerometers) and age-specific health outcomes while accounting for covariates such as age, gender, socioeconomic status, ethnicity, and diet are also needed to understand the trajectories of physical activity and health. We propose that research on physical activity during the early years (aged 0–4 years) is needed to address the following questions:

- What is the frequency, intensity, duration, and type (mode) of physical activity associated with favourable health indicators and improvements in health indicators?
- Are the relationships between physical activity and health the same for children growing up with a chronic disease or disability?
- What are the risks of physical activity during the early years?
- What are the best physical activity methods and measures to use for the early years?
- What are the most appropriate and responsive health indicators (or surrogate indicators) relevant to active healthy living during the early years?

## Conclusion

To our knowledge, this is the first published systematic review aimed specifically at clarifying the relationship between physical activity and a broad spectrum of health indicators in the early years (aged 0–4 years). This review found low- to high-quality evidence to suggest increased or higher physical activity is associated with better measures of adiposity, bone and skeletal health, motor skill development, psychosocial health, cognitive development, and aspects of cardiometabolic health during the early years. Because of the dearth of information we could not determine the specific amount, intensity, frequency, or type of physical activity needed to promote healthy growth and development. More studies, especially with infants and toddlers, are needed to address these gaps. No risks of increased physical activity were found. This work can be used as evidence to inform public health guidelines.

### Competing interests

No competing interests were disclosed by the authors. B.W.T. holds a Canadian Institutes of Health Research (CIHR) New Investigator Award. V.C. is supported by a CIHR – Frederick Banting and Charles Best Doctoral Award. I.J. holds a Tier 2 Canada Research Chair position at Queen's University. M.E.K. is funded by a Fellowship Award and Bisby Prize from the CIHR. J.A.S. is supported by a Social Sciences and Humanities Research Council – Joseph-Armand Bombardier CGS Master's Scholarship.

### Authors contributions

B.W.T., in collaboration with M.S.T., was responsible for the initiation, conceptualization, and design of the systematic review; oversaw the data collection and extraction, analysis, and interpretation of data; and was responsible for revising the manuscript critically for important intellectual content. B.W.T. was the primary author of the manuscript. A.G.L. was responsible for developing and conducting the search and involved with data collection and extraction, completing the GRADE tables, analysis and interpretation of data, and drafting the manuscript. M.E.K. and S.C.G. were responsible for the design and methodology of the review, completing the GRADE tables, and revising the manuscript critically for important intellectual content. C.D. and J.A.S. were responsible for data collection and extraction, risk of bias assessment, and were responsible for revising the manuscript critically for important intellectual content. I.J. and J.C.S. oversaw the data collection and extraction, analysis, and interpretation of data and were responsible for revising the manuscript critically for important intellectual content. All authors have read and approved the final manuscript. B.W.T. is the guarantor of the paper.

## Acknowledgements

The authors are grateful to Dr. Margaret Sampson at the Children's Hospital of Eastern Ontario for her contributions to developing the search strategy for this project. We wish to acknowledge the expert contribution of Drs. Anthony Okely and John Reilly. This systematic review was made possible by a Knowledge Synthesis Grant from the Canadian Institutes of Health Research awarded to M.S.T. and B.W.T. (Award no: PAC-111612.)

## References

Australian Government. Department of Health and Ageing 2011. Move and play every day. National physical activity recommendations for children 0–5 years. Commonwealth of Australia. Departmento of Health and Ageing.

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

Berenson, G.S., Srinivasan, S.R., Bao, W., Newman, W.P., III, Tracy, R.E., and Wattigney, W.A. 1998. Association between multiple cardiovascular risk factors and atherosclerosis in children and young adults. The Bogalusa Heart Study. N. Engl. J. Med. **338**(23): 1650–1656. doi:10.1056/NEJM199806043382302. PMID:9614255.

Buss, D.M., Block, J.H., and Block, J. 1980. Preschool activity level: personality correlates and developmental implications. Child Dev. **51**(2): 401–408. doi:10.2307/1129273.

Canadian Society for Exercise Physiology. 2011. CSEP physical activity guidelines stakeholder survey results and final report. Canadian Society for Exercise Physiology. Ottawa, Ont., Canada.

Caspersen, C.J., Powell, K.E., and Christenson, G.M. 1985. Physical activity, exercise, and physical fitness: definitions and distinctions for health-related research. Public Health Rep. **100**(2): 126–131. PMID:3920711.

Chang, A., Lugg, M.M., and Nebedum, A. 1989. Injuries among preschool children enrolled in day-care centers. Pediatrics, **83**(2): 272–277. PMID:2783627.

Colley, R.C., Garriguet, D., Janssen, I., Craig, C.L., Clarke, J., and Tremblay, M.S. 2011. Physical activity levels of Canadian children and youth. Health Rep. **22**: 1–9.

Dishman, R.K., Washburn, R.A., and Heath, G.W. 2004. Physical Activity Epidemiology. Human Kinetics, Champaign, Ill., USA.

Gabel, L., Obeid, J., Nguyen, T., Proudfoot, N.A., and Timmons, B.W. 2011. Short-term muscle power and speed in preschoolers exhibit stronger tracking than physical activity. Appl. Physiol. Nutr. Metab. **36**(6): 939–945. doi:10.1139/h11-118. PMID:22087797.

Guyatt, G., Oxman, A.D., Akl, E.A., Kunz, R., Vist, G., Brozek, J., et al. 2011*a*. GRADE guidelines: 1. Introduction – GRADE evidence profiles and summary of findings tables. J. Clin. Epidemiol. **64**(4): 383–394. doi:10.1016/j.jclinepi.2010.04.026. PMID:21195583.

Guyatt, G.H., Oxman, A.D., Kunz, R., Atkins, D., Brozek, J., Vist, G., et al. 2011*b*. GRADE guidelines: 2. Framing the question and deciding on important outcomes. J. Clin. Epidemiol. **64**(4): 395–400. doi:10.1016/j.jclinepi.2010.09.012. PMID:21194891.

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

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

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

Guyatt, G.H., Oxman, A.D., Montori, V., Vist, G., Kunz, R., Brozek, J., et al. 2011*f*. GRADE guidelines: 5. Rating the quality of evidence–publication bias. J. Clin. Epidemiol. **64**(12): 1277–1282. doi:10.1016/j.jclinepi.2011.01.011. PMID:21802904.

Guyatt, G.H., Oxman, A.D., Sultan, S., Glasziou, P., Akl, E.A., Alonso-Coello, P., et al.; GRADE Working Group. 2011*g*. GRADE guidelines: 9. Rating up the quality of evidence. J. Clin. Epidemiol. **64**(12): 1311–1316. doi:10.1016/j.jclinepi.2011.06.004. PMID:21802902.

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

Haynes, R.B., Mulrow, C.D., Huth, E.J., Altman, D.G., and Gardner, M.J. 1990. More informative abstracts revisited. Ann. Intern. Med. **113**(1): 69–76. PMID:2190518.

Hinkley, T., Crawford, D., Salmon, J., Okely, A.D., and Hesketh, K. 2008. Preschool children and physical activity: a review of correlates. Am. J. Prev. Med. **34**(5): 435–441.e7. doi:10.1016/j.amepre.2008.02.001. PMID:18407012.

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

Jones, R.A., Riethmuller, A., Hesketh, K., Trezise, J., Batterham, M., and Okely, A.D. 2011. Promoting fundamental movement skill development and physical activity in early childhood settings: a cluster randomized controlled trial. Pediatr. Exerc. Sci. **23**(4): 600–615. PMID:22109783.

Klesges, R.C., Klesges, L.M., Eck, L.H., and Shelton, M.L. 1995. A longitudinal analysis of accelerated weight gain in preschool children. Pediatrics, **95**(1): 126–130. PMID:7770289.

Ku, L.C., Shapiro, L.R., Crawford, P.B., and Huenemann, R.L. 1981. Body composition and physical activity in 8-year-old children. Am. J. Clin. Nutr. **34**(12): 2770–2775. PMID:7315778.

Li, R., O'Connor, L., Buckley, D., and Specker, B. 1995. Relation of activity levels to body fat in infants 6 to 12 months of age. J. Pediatr. **126**(3): 353–357. doi:10.1016/S0022-3476(95)70447-7. PMID:7869191.

Lobo, Y.B., and Winsler, A. 2006. The effects of a creative dance and movement program on the social competence of Head Start preschoolers. Soc. Dev. **15**(3): 501–519. doi:10.1111/j.1467-9507.2006.00353.x.

Metcalf, B.S., Voss, L.D., Hosking, J., Jeffery, A.N., and Wilkin, T.J. 2008. Physical activity at the government-recommended level and obesity-related health outcomes: a longitudinal study (Early Bird 37). Arch. Dis. Child. **93**(9): 772–777. doi:10.1136/adc.2007.135012. PMID:18591181.

Metcalf, B.S., Jeffery, A.N., Hosking, J., Voss, L.D., Sattar, N., and Wilkin, T.J. 2009. Objectively measured physical activity and its association with adiponectin and other novel metabolic markers: a longitudinal study in children (EarlyBird 38). Diabetes Care, **32**(3): 468–473. doi:10.2337/dc08-1329. PMID:19033408.

Mo-suwan, L., Pongprapai, S., Junjana, C., and Puetpaiboon, A. 1998. Effects of a controlled trial of a school-based exercise program on the obesity indexes of preschool children. Am. J. Clin. Nutr. **68**(5): 1006–1011. PMID:9808215.

Moore, L.L., Nguyen, U.D.T., Rothman, K.J., Cupples, L.A., and Ellison, R.C. 1995. Preschool physical activity level and change in body fatness in young children: The Framingham children's study. Am. J. Epidemiol. **142**(9): 982–988. PMID:7572980.

Moore, L.L., Gao, D., Bradlee, M.L., Cupples, L.A., Sundarajan-Ramamurti, A., Proctor, M.H., et al. 2003. Does early physical activity predict body fat change throughout childhood? Prev. Med. **37**(1): 10–17. doi:10.1016/S0091-7435(03)00048-3. PMID:12799124.

Napoli, C., Glass, C.K., Witztum, J.L., Deutsch, R., D'Armiento, F.P., and Palinski, W. 1999. Influence of maternal hypercholesterolaemia during pregnancy on progression of early atherosclerotic lesions in childhood: Fate of Early Lesions in Children (FELIC) study. Lancet, **354**(9186): 1234–1241. doi:10.1016/S0140-6736(99)02131-5. PMID:10520631.

National Association for Sport and Physical Education. 2009. Active start: A statement of physical activity guidelines for children from birth to age 5. American Alliance for Health, Physical Education, Recreation, and Dance. Sewickley, Pa., USA.

Newman, W.P., III, Wattigney, W., and Berenson, G.S. 1991. Autopsy studies in United States children and adolescents. Relationship of risk factors to atherosclerotic lesions. Ann. N.Y. Acad. Sci. **623**: 16–25. doi:10.1111/j.1749-6632.1991.tb43715.x. PMID:2042824.

Obeid, J., Nguyen, T., Gabel, L., and Timmons, B.W. 2011. Physical activity in Ontario preschoolers: prevalence and measurement issues. Appl. Physiol. Nutr. Metab. **36**(2): 291–297. doi:10.1139/h11-002. PMID:21609292.

Oliver, M., Schofield, G.M., and Kolt, G.S. 2007. Physical activity in preschoolers: understanding prevalence and measurement issues. Sports Med. **37**(12): 1045–1070. doi:10.2165/00007256-200737120-00004. PMID:18027993.

Pate, R.R., Pfeiffer, K.A., Trost, S.G., Ziegler, P., and Dowda, M. 2004. Physical activity among children attending preschools. Pediatrics, **114**(5): 1258–1263. doi:10.1542/peds.2003-1088-L. PMID:15520105.

Porter, L.S. 1972. The impact of physical-physiological activity on infants' growth and development. Nurs. Res. **21**(3): 210–219. PMID:4481916.

Reilly, J.J., Jackson, D.M., Montgomery, C., Kelly, L.A., Slater, C., Grant, S., and Paton, J.Y. 2004. Total energy expenditure and physical activity in young Scottish children: mixed longitudinal study. Lancet, **363**(9404): 211–212. doi:10.1016/S0140-6736(03)15331-7. PMID:14738795.

Reilly, J.J., Kelly, L., Montgomery, C., Williamson, A., Fisher, A., McColl, J.H., et al. 2006. Physical activity to prevent obesity in young children: cluster randomised controlled trial. BMJ, **333**(7577): 1041. doi:10.1136/bmj.38979.623773.55. PMID:17028105.

Sääkslahti, A., Numminen, P., Varstala, V., Helenius, H., Tammi, A., Viikari, J., and Valimaki, I. 2004. Physical activity as a preventive measure for coronary heart disease risk factors in early childhood. Scand. J. Med. Sci. Sports, **14**(3): 143–149. doi:10.1111/j.1600-0838.2004.00347.x. PMID:15144353.

Shapiro, L.R., Crawford, P.B., Clark, M.J., Pearson, D.L., Raz, J., and Huenemann, R.L. 1984. Obesity prognosis: a longitudinal study of children from the age of 6 months to 9 years. Am. J. Public Health, **74**: 968–972.

Specker, B., and Binkley, T. 2003. Randomized trial of physical activity and calcium supplementation on bone mineral content in 3- to 5-year-old children. J. Bone Miner. Res. **18**(5): 885–892. doi:10.1359/jbmr.2003.18.5.885. PMID:12733728.

Specker, B.L., Mulligan, L., and Ho, M. 1999. Longitudinal study of calcium intake, physical activity, and bone mineral content in infants 6–18 months of age. J. Bone Miner. Res. **14**(4): 569–576. doi:10.1359/jbmr.1999.14.4.569. PMID:10234578.

Specker, B., Binkley, T., and Fahrenwald, N. 2004. Increased periosteal circumference remains present 12 months after an exercise intervention in preschool children. Bone, **35**(6): 1383–1388. doi:10.1016/j.bone.2004.08.012. PMID:15589220.

Start Active Stay Active. 2011. A report on physical activity for health from the four home countries' Chief Medical Officers. UK.

Strong, W.B., Malina, R.M., Blimkie, C.J., Daniels, S.R., Dishman, R.K., Gutin, B., et al. 2005. Evidence based physical activity for school-age youth. J. Pediatr. **146**(6): 732–737. doi:10.1016/j.jpeds.2005.01.055. PMID:15973308.

Sugimori, H., Yoshida, K., Izuno, T., Miyakawa, M., Suka, M., Sekine, M., et al. 2004. Analysis of factors that influence body mass index from ages 3 to 6 years: A study based on the Toyama cohort study. Pediatr. Int. **46**(3): 302–310. doi:10.1111/j.1442-200x.2004.01895.x. PMID:15151547.

Timmons, B.W., Naylor, P.J., and Pfeiffer, K.A. 2007. Physical activity for preschool children: How much and how? Can. J. Public Health, **98**(Suppl. 2): S122–S134. PMID:18213943.

Tremblay, M.S., and Haskell, W.L. 2012. From science to physical activity guidelines. *In* Physical Activity and Health. 2nd ed. Human Kinetics Publishers. Champaign, Ill., USA. pp. 359–378.

Tremblay, M.S., LeBlanc, A., Carson, V., Choquette, L., Connor-Gorber, S., Dillman, C., et al. 2012. Canadian physical activity guidelines for the early years (aged 0–4 years). Appl. Physiol. Nutr. Metab. **37**(2): 345–356. doi:10.1139/h2012-018. PMID:22448608.

Tucker, P. 2008. The physical activity levels of preschool-aged children: A systematic review. Early Child. Res. Q. **23**(4): 547–558. doi:10.1016/j.ecresq.2008.08.005.

Venetsanou, F., and Kambas, A. 2004. How can a traditional Greek dances programme affect the motor proficiency of pre-school children? Res. Dance Educ. **5**(2): 127–138. doi:10.1080/14617890500064019.

Wells, J.C., and Ritz, P. 2001. Physical activity at 9–12 months and fatness at 2 years of age. Am. J. Hum. Biol. **13**(3): 384–389. doi:10.1002/ajhb.1062. PMID:11460904.

Wilson, D.K., Klesges, L.M., Klesges, R.C., Eck, L.H., Hackett-Renner, C.A., Alpert, B.S., and Dalton, E.T. 1992. A prospective study of familial aggregation of blood pressure in young children. J. Clin. Epidemiol. **45**(9): 959–969. doi:10.1016/0895-4356(92)90112-Z. PMID:1432025.

World Health Organization 2011. Obesity and Overweight: Fact Sheet No. 3. World Health Organization, Geneva, Switzerland.

## Appendix A: Glossary and relevant study designs

*Sedentarism:* Extended engagement in behaviours characterized by minimal movement, low energy expenditure, and rest.

*Sedentary:* A distinct class of behaviours characterized by low energy expenditure (school work, reading, television, computer, video games) that is characterized by little physical movement and low energy expenditure (≤1.5 METs).

*Physically active:* Meeting established guidelines for physical activity (see Canadian guidelines at www.csep.ca/guidelines).

*Physical inactivity:* The absence of physical activity, usually reflected as the proportion of time not engaged in physical activity of a predetermined intensity.

*Active video gaming:* Video games that are designed to promote movement and interaction from the participant(s). Some examples include Nintendo Wii, Microsoft Kinect, Sony's Playstation Move, and video arcades that require movement.

*Recreational screen time:* Television watching, video game playing, using the computer, or use of other screens during discretionary time (i.e., nonschool- or work-based use) that are practiced while sedentary.

*Frequency:* The number of times an exercise or activity is performed. Frequency is generally expressed in sessions, episodes, or bouts per day or week.

*Interruptions:* Interruptions refer to the number of times sedentary behaviour is interrupted by physical activity, thus decreasing the amount of prolonged sedentary behaviour.

*Time:* The length of time in which a sedentary behaviour is performed. Duration is generally expressed in minutes.

*Type:* The type of activity that the individual is engaging in. As sedentary physiology is a fairly new field and technology is constantly providing new types of sedentary behaviours, this may be in constant flux.

### Experimental studies

*Randomization, random allocation, random sample:* A sample derived by selecting sampling units (such as patients) such that each unit has an independent (and generally equal) chance of being selected. Selection is determined by chance, often with the aid of a table of randomly ordered numbers.

*Randomized trial (randomized control(led) trial, randomized clinical trial, RCT):* Experiment in which individuals are randomly allocated to receive or not receive an experimental preventative, therapeutic, or diagnostic procedure and then followed to determine the effect of the intervention.

*Nonrandomized control trial (or quasi-experimental):* Experiment in which assignment of patients to the intervention groups is at the convenience of the investigator or according to a preset plan that does not conform to the definition of random.

*Before–after trial:* Investigation of therapeutic alternatives in which individuals of 1 period and under 1 treatment are compared with individuals at a subsequent time, and treated in a different fashion. If the disorder is not fatal and the "before" treatment is not curative, the same individuals may be studied in the before and after periods, strengthening the design through increased group comparability for the 2 periods.

*Crossover trial:* A method of comparing 2 or more treatments or interventions in which subjects or patients, on completion of the course of 1 treatment, are switched to another. Typically, allocation to the first treatment is by random performance in 1 period is used to judge their performance in others, usually reducing variability.

*Community-based clinical trial:* Designed to be administered directly through primary health care physicians, community health care centers, and outpatient facilities.

**Observational studies**

*Cohort:* A group of persons with a common characteristic or set of characteristics. Typically, the group is followed for a specified period to determine the incidence of a disorder or complications of an established disorder (that is, prognosis), as in cohort study.

*Cohort analytic study:* Prospective investigation of the factors that might cause a disorder in which a cohort of individuals who do not have evidence of an outcome of interest but who are exposed to the putative cause are compared with a concurrent cohort who are also free of the outcome but not exposed to the putative cause. Both cohorts are then followed to compare the incidence of the outcome of interest.

*Prospective cohort study:* A group of individuals is selected at random from a defined population. After the cohort is selected, baseline information on potential risk factors is collected, and individuals are followed over time to track the incidence of disease between those people subsequently exposed or not exposed to the risk factor of interest.

*Case-control studies:* Study generally used to test possible causes of a disease or disorder, in which individuals who have a designated disorder are compared with individuals who do not have the disorder with respect to previous current exposure to a putative causal factor. For example, persons with cancer (cases) are compared with persons without cancer (controls) and history of hepatitis is determined for the 2 groups. Often referred to as a retrospective study because the logic of the design leads from effect to cause. In essence, this type of study is an attempt to look backward in time to identify the characteristics that may have contributed to the development of the disease.

*Panel study:* Study used prospectively to measure participants at multiple time points in an effort to determine the cause–effect relationship between and exposure and an outcome.

## Appendix B: Search strategy

**Preschool PA_May4_Medline: MEDLINE**

1. Motor activity/ or motor activit*.tw.
2. Locomotor activity/
3. Physical exertion/
4. exercise/ or aerobic exercise.tw.
5. Play/
6. exp obesity/
7. (obesit* or obese).tw.
8. exp overweight/
9. (overweight or over-weight).tw.
10. exp body fat distribution/
11. exp body composition/
12. waist circumference/
13. skinfold thickness/ or (skin fold* or skinfold*).tw.
14. (body composition* or BMI or body mass index).tw.
15. exp “body weights and measures”/
16. (bio-impedance analysis or BIA).tw.
17. absorptiometry, photon/
18. (absorptiometery or densitometry or photodensitometry or DXA or DEXA).tw.
19. exp bone/
20. bone tissue.tw.
21. Bone density/
22. Bone development/
23. Osteogenesis/
24. insulin resistance/
25. (metabolic cardiovascular syndrome or metabolic syndrome or syndrome x).tw.
26. ((cardiovascular or heart or vascular) adj2 risk*).tw.
27. exp hypertension/
28. exp blood pressure determination/ or exp blood pressure monitoring, ambulatory/ or exp blood/
29. exp blood pressure/
30. exp blood glucose/ or exp diabetes mellitus, type 2/
31. exp glucose intolerance/ or glucose tolerance test/
32. Motor activity/
33. Psychomotor performance/
34. Child development/
35. gross motor skill*.tw.
36. cognitive development.tw.
37. “growth and development”/
38. Attention/
39. Self efficacy/
40. Self concept/
41. Child behavior disorder/
42. (pro-social behav* or prosocial behav* or pro social behav*).tw.
43. exp social behavior/
44. Aggression/
45. Temperament/
46. Social adjustment/
47. or/1–5
48. or/6–18
49. or/18–23
50. or/24–31
51. or/32–35
52. or/36–38
53. or/39–46
54. or/48–53
55. 47 and 54
56. Limit 55 to (“infant (1 to 23 months)” or “preschool child (2 to 5 years)”)
57. (infant* or preschool* or child* or pediatric* or paediatric*).tw.
58. 55 and 57
59. 56 or 58
60. Limit 59 to randomized controlled trial
61. Clinical trials as topic.sh.
62. randomly.ab.
63. trial.ti.
64. randomized controlled trial.pt.
65. controlled clinical trial.pt.
66. randomized.ab.
67. or/61–66
68. cohort studies/ or comparative studies/ or follow-up studies/ or prospective studies/ or risk factors/ or cohort.mp. or compared.mp. or groups.mp. or multivariate.mp.

69. 67 or 68
70. 59 and 69
71. 60 or 70

Preschool PA_May4_Embase

**EMBASE**

1. Motor activity/ or motor activit*.tw.
2. Locomotor activity/
3. Physical exertion/
4. exercise/ or aerobic exercise.tw.
5. Play/
6. exp obesity/
7. (obesit* or obese).tw.
8. exp overweight/
9. (overweight or over-weight).tw.
10. exp body fat distribution/
11. exp body composition/
12. waist circumference/
13. skinfold thickness/ or (skin fold* or skinfold*).tw.
14. (body composition* or BMI or body mass index).tw.
15. exp “body weights and measures”/
16. (bio-impedance analysis or BIA).tw.
17. absorptiometry, photon/
18. (absorptiometery or densitometry or photodensitometry or DXA or DEXA).tw.
19. exp bone/
20. bone tissue.tw.
21. Bone density/
22. Bone development/
23. Osteogenesis/
24. insulin resistance/
25. (metabolic cardiovascular syndrome or metabolic syndrome or syndrome x).tw.
26. ((cardiovascular or heart or vascular) adj2 risk*).tw.
27. exp hypertension/
28. exp blood pressure determination/ or exp blood pressure monitoring, ambulatory/ or exp blood/
29. exp blood pressure/
30. exp blood glucose/ or exp diabetes mellitus, type 2/
31. exp glucose intolerance/ or glucose tolerance test/
32. Motor activity/
33. Psychomotor performance/
34. Child development/
35. gross motor skill*.tw.
36. cognitive development.tw.
37. “growth and development”/
38. Attention/
39. Self efficacy/
40. Self concept/
41. Child behavior disorder/
42. (pro-social behav* or prosocial behav* or pro social behav*).tw.
43. exp social behavior/
44. Aggression/
45. Temperament/
46. Social adjustment/
47. or/1–5
48. or/6–18
49. or/18–23
50. or/24–31
51. or/32–35
52. or/36–38
53. or/39–46
54. or/48–53
55. 47 and 54
56. (infant* or preschool* or child* or pediatric* or paediatric*).tw.
57. randomly.ab.
58. trial.ti.
59. randomized.ab.
60. cohort studies/ or comparative studies/ or follow-up studies/ or prospective studies/ or risk factors/ or cohort.mp. or compared.mp. or groups.mp. or multivariate.mp.
61. Limit 55 to (infant or preschool child <1 to 6 years > )
62. 55 and 56
63. 61 or 62
64. Limit 63 to (clinical trial or randomized controlled trial or controlled clinical trial)
65. or/57–59
66. 60 or 64 or 65
67. 63 and 66

**Preschool PA_May4_PsycINFO**

***PsycINFO***

1. exp obesity/
2. (obesit* or obese).tw.
3. exp overweight/
4. (overweight or over-weight).tw.
5. Body Fat/
6. Body Weight/
7. waist circumference.tw.
8. skin fold*.mp. or skinfold*.tw. [mp = title, abstract, heading word, table of contents, key concepts, original title, tests & measures]
9. (body composition* or BMI or body mass index).tw.
10. (bio-impedance analysis or BIA).tw.
11. (absorptiometery or densitometry or photodensitometry or DXA or DEXA).tw.
12. bones/
13. bone tissue.tw.
14. bone disorders/
15. insulin resistance/
16. (metabolic cardiovascular syndrome or metabolic syndrome or syndrome x).tw.
17. ((cardiovascular or heart or vascular) adj3 risk$).tw.
18. exp hypertension/
19. exp blood pressure determination/ or exp blood pressure monitoring, ambulatory/ or exp blood/
20. exp blood pressure/
21. Diabetes Mellitus/ or Glucose/
22. exp motor development/
23. exp motor performance/
24. Motor Skills/ or Gross Motor Skill Learning/
25. exp attention/

26. Self Efficacy/
27. Self Concept/
28. childhood play development/
29. behavior problems/
30. prosocial behavior/
31. Social Behavior/
32. Aggressive Behavior/ or Child Attitudes/
33. Personality/
34. Social Adjustment/
35. Physical Activity/
36. Activity Level/
37. energy expenditure/
38. exp exercise/
39. exp recreation/
40. Language Development/
41. or/1–11
42. or/11–14
43. or/15–21
44. exp cognitive development/
45. Development/ or Early Childhood Development/ or Childhood Development/
46. 22 or 23 or 24
47. 22 or 23 or 24
48. 25 or 40 or 44 or 45
49. 26 or 27 or 28 or 29 or 30 or 31 or 32 or 33 or 34
50. or/35–39
51. 41 or 42 or 43 or 46 or 48 or 49
52. (infant* or preschool* or child* or pediatric* or paediatric*).tw.
53. 50 and 51
54. 52 and 53
55. Limit 53 to (140 infancy or 160 preschool age)
56. 54 or 55
57. cohort studies/ or comparative studies/ or follow-up studies/ or prospective studies/ or risk factors/ or cohort.mp. or compared.mp. or groups.mp. or multivariate.mp.
58. 56 and 57
59. Limit 56 to (“0430 followup study” or “0450 longitudinal study” or “2000 treatment outcome/randomized clinical trial”)
60. 58 or 59



**Table B1.** SPORT DISCUS (EBSCO). Monday, May 09, 2011, 3:22:51 PM.

| No. | Query | Results |
|---|---|---|
| S12 | S8 and S9 and S11 | 874 |
| S11 | S1 and S10 | Display |
| S10 | (S2 or S3 or S4 or S5 or S6 or S7) | Display |
| S9 | case control study or cohort analysis or compared or multivariate or randomized controlled trial or longitudinal or follow up | Display |
| S8 | children or preschool or infant or pediatric or peadiatric | Display |
| S7 | self efficacy or self esteem or self concept or pro social behaviour or aggression or temperament or social adjustment | Display |
| S6 | cognitive development or attention or language development | Display |
| S5 | motor activity or gross motor skill or motor development or object control or child development or (growth and development) | Display |
| S4 | insulin resistance or metabolic syndrome or hypertension or blood pressure or blood glucose or glucose intolerance | Display |
| S3 | bone or bone density or bone development or osteogenesis | Display |
| S2 | obesity or obese or overweight or body fat or waist circumference or skinfold or (DXA or DEXA) | Display |
| S1 | motor activity or physical activity or exercise or play | Display |

**Table B2.** Cochrane Central: Preschool PA_May10: HALO.

| ID no. | Search | Hits |
|---|---|---|
| 1 | (physical activity) | 10 133 |
| 2 | (activity level) | 18 146 |
| 3 | (energy expenditure) | 1 612 |
| 4 | (play) | 9 392 |
| 5 | (motor activity) | 4 176 |
| 6 | (No. 1 OR no. 2 OR no. 3 OR no. 4 OR no. 5) | 35 364 |
| 7 | (obesit* OR obese OR overweight OR over-weight OR body composition OR body fat OR waist circumference OR bio-impedance analysis OR BIA OR absorptiometry OR DXA OR DEXA OR body mass index OR BMI OR skin folds OR skin-folds OR skin-fold OR skin-folds) | 22 737 |
| 8 | ((cardiovascular disease* OR heart disease* OR vascular disease*) ADJ risk*) | 517 |
| 9 | (self-esteem OR self concept OR motor development OR child development) | 12 059 |
| 10 | (cognition development OR behavioural conduct OR behavioral conduct OR pro-social behaviour OR pro-social behavior OR prosocial behaviour OR prosocial behavior) | 4 246 |
| 11 | (no. 7 OR no. 8 OR no. 9 OR no. 10) | 36 688 |
| 12 | (no. 6 AND no. 11) | 7 146 |
| 13 | (child* OR infant* OR preschool* OR pediatric OR paediatric) | 86 523 |
| 14 | (no. 12 AND no. 13) | 2 901 |
| 15 | (no. 14) | 1 141 |

## Appendix C: Search strategy for physical activity and risk of injury

Database: Ovid MEDLINE(R) In-process and other non-indexed citations and Ovid MEDLINE(R) <1946 to present >

Search strategy:

1. "Wounds and Injuries"/ (56 375)
2. Motor activity/ or motor activit*.tw. (71 441)
3. Locomotor activity/ (64 483)
4. Physical exertion/ (50 776)
5. exercise/ or aerobic exercise.tw. (57 397)
6. Play/ (6111)
7. 2 or 3 or 4 or 5 or 6 (180 814)
8. 1 and 7 (402)
9. limit 8 to ("infant (1 to 23 months)" or "preschool child (2 to 5 years)") (115)