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Background

The health benefits of physical activity, in particular moderate- to vigorous-intensity physical activity (MVPA), have been frequently studied in school-aged children and youth (5-17 years) as well as adults (≥18 years) [1–4]. Accordingly, global recommendations on the amount of MVPA recommended for health benefits in these age groups exists [5]. In contrast, less research has focused on the health benefits of physical activity in the early years (0-4 years). Given that the early years are a critical and rapid period of physical, cognitive, social, and emotional development [6], determining the dose (e.g., frequency, intensity, time/duration, type) of physical activity needed for healthy growth and development is of great importance.

To better understand the dose of physical activity needed in the early years, in 2012 Timmons and colscreening) determined Population, Intervention, Comparison, and Outcome (PICO) study criteria [25]. Conference abstracts and grey literature were not eligible because they may not be subject to the same peer-review rigour. However, preliminary results from registered clinical trials were eligible.

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The population was apparently healthy (i.e., general popularge volume of observational studies had already been captured, so it was a priority to focus on studies with designs that have the potential to provide the highest quality of evidence to inform review findings and guideline formation.

All records retrieved from the database searches were imported into Reference Manager Software (Version 11; Thompson Reuters, San Francisco, CA, USA), and duplicate records were removed by employing a two-step strategy. Specifically, duplicates were first identified automatically in Reference Manager; one member of the review team then manually checked and removed additional duplicates where appropriate. After de-duplication, records were imported into Distiller SR Software (Evidence Partners, Ottawa, ON, Canada) for screening. First, titles and abstracts were screened by two independent reviewers; if a record was included by at least one reviewer, the record was obtained for further screening. Second, full-text articles were obtained and screened by two independent reviewers. Agreement between reviewers was required for a study to be included or excluded. Discrepancies that could not be resolved by the two independent reviewers were resolved by discussions with a third reviewer or with the review team if needed.

The reference lists of relevant reviews identified during screening were also checked to see if any additional relevant studies could be identified. To capture registered clinical trials, two trial registries (https://clinicaltrials.gov and http://www.who.int/ictrp/en/) were searched on February 1, 2017, using search terms for physical activity and the early years age group. This final search was to detect any large studies that were in progress and could potentially overturn findings. If found, this pending new evidence would have been included in the discussion.

Data extraction

Descriptive study characteristics as well as information regarding the exposure, outcome, and results were extracted in Microsoft Excel for each included study. For the results, where applicable, information was extracted from both unadjusted models and the most fully adjusted model. Furthermore, a finding was deemed to be statistically significant when $p < 0.05$ was reported, even if statistical significance was defined differently in a study. One reviewer completed data extraction for each study and a second reviewer checked the extracted data. A third reviewer then checked all extracted results.

Quality assessment

The quality of evidence assessment for each included study design within each health indicator was guided by the GRADE framework [30]. Quality of evidence reflects the level of confidence in the estimated effects. Detailed information on GRADE methodology can be found elsewhere [30]. Briefly, five assessment criteria (risk of bias, inconsistency, indirectness, imprecision, other [e.g., dose-response evidence]) were used to rate quality of evidence as “high”, “moderate”, “low”, or “very low”. Quality of evidence ratings started at “high” for RCTs and “low” for all other experimental and observational studies. The quality of evidence could be downgraded for any study design due to limitations associated with the five assessment criteria. The review team decided a priori that if the only identified sources of bias were selection bias due to the use of a convenience sample or performance bias due to lack of intervention/control group blinding, the quality of evidence would not be downgraded because of the risk of bias. If no limitations were identified, the quality of evidence from non-randomized and observational study designs could be upgraded if large effect sizes or evidence of a dose-response gradient were reported. Since dose-response evidence could not be determined for cross-sectional studies, observations of a gradient of higher exposure with higher/lower outcome were considered a reason to upgrade the quality of evidence associated with this study design [29].

Risk of bias was the only criterion out of the five assessment criteria that was first assessed at the individual study level. The Cochrane risk of bias assessment was used for experimental studies [31]. For observational studies, the risk of selection bias, performance bias, selective reporting bias, detection bias, attrition bias, and other biases (e.g., inadequate control for key confounders) was assessed [32]. For all studies, risk of bias was assessed by one reviewer and checked by two other reviewers. Overall quality of evidence was evaluated by one reviewer and verified by the larger review team, including two members with expertise in systematic review methodology.

Data analysis

Two members of the review team with experience in conducting meta-analyses assessed the data for each health indicator to determine if any of the data was sufficiently homogenous with regard to statistical, clinical, and methodological characteristics for meta-analyses. Due to high levels of heterogeneity in study design and measured outcomes, only one meta-analysis was possible for four studies that included adiposity as a health indicator [33–36]. Change (post-intervention minus baseline) values from studies were entered into Review Manager Software 5.3 (The Cochrane Collaboration, Copenhagen,8(t((Tde)-6.v10.1(r30(d)12.m)an)15.12.1(a)0(lk12.87.t)0(i.(T to calculate the weighted mean difference according to the DerSimonian and Laird method [38, 39]. Due to the small number of studies included in the meta-analysis, sensitivity analyses and/or sub-group analyses were not possible.

A narrative synthesis was also conducted for all included studies. Results were first synthesized by health indicator and study design then further synthesized by intensity or type of physical activity. For fitness and cardiometabolic health, results were also synthesized by different dimensions of the indicator (i.e., cardiorespiratory fitness and other fitness measures; blood pressure, cholesterol, and triglycerides). Finally, a sub-group analysis was conducted to examine frequency and duration of physical activity. Since not all studies reported on frequency and duration, data were synthesized across health indicators but examined separately for experimental and observational study designs. For observational study designs, frequency and duration data were also synthesized for intensity and type of physical activity. When multiple associations were examined (e.g., physical activity and BMI and physical activity and waist circumference or sex-stratified analyses between physical activity and BMI), a study was classified in one of four mutually exclusive groups: 1) “favourable” if at least one favourable but no unfavourable associations were observed, 2) “unfavourable” if at least one unfavourable but no favourable associations were observed, 3) “null” if no favourable or unfavourable associations were observed, and 4) “mixed” if both favourable and unfavourable or favourable, unfavourable and null associations were all observed. Within the narrative analysis, all studies were weighted equally. Finally, unless otherwise stated, findings are based on samples classified as preschool-aged children.

Results

Description of studies

After de-duplication, 20,848 titles and abstracts and 915 full-text articles were screened (see Fig. 1). It was deter-

Table 1 The relationship between physical activity and adiposity

# of studies	Design	Quality assessment					# of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			

Table 1

For the three case-control studies, physical activity was favourably associated with adiposity in one study [51] and not associated with adiposity in two studies [52, 53]. One study with null findings had an infant and toddler sample [53]. In terms of the intensity or type of physical activity, at least one favourable association was observed between outdoor physical activity and adiposity (1/2 studies). However, primarily null associations were observed between each of the following physical activity exposures and adiposity: TPA, moderate-intensity physical activity (MPA), and VPA (see Table 1). The quality of evidence was downgraded from “low” to “very low” because of a serious risk of bias (see Table 1).

For the 40 cross-sectional studies, physical activity was favourably associated with adiposity for at least one association in 12 studies [54–65], unfavourably associated with adiposity for at least one association in four studies [66–69], and not associated with adiposity in 20 studies [45, 46, 70–87]; mixed findings were observed in four studies [49, 50, 88, 89]. In two of the studies that observed some favourable associations, primarily null associations were observed [55, 64]. One study with favourable findings [64] and one study with null findings [45] had infant samples. Similarly, one study with null findings had a toddler sample [86]. In regard to intensity or type of physical activity, at least one favourable association was observed between each of the following and adiposity: active play (2/3 studies), leisure physical activity (1/1 study), and structured/organized physical activity (1/1 study); and at least one unfavourable association was observed between organized sport and adiposity (1/1 study). However, primarily null or mixed findings were observed between each of the following physical activity exposures and adiposity: TPA, LPA, LPA bouts, MPA, MVPA, MVPA bouts, VPA, activity energy expenditure, active transportation, indoor physical activity, and outdoor physical activity (see Table 1). The quality of evidence was downgraded from “low” to “very low” because of a serious risk of bias and serious inconsistency (see Table 1).

Motor development

The association between physical activity and motor development was examined in 23 studies (21 unique samples; see Table 2 and Table S2 in Additional file 2). Among the four RCTs, significant increases in motor de-

Table 2 The relationship between physical activity and motor development

# of studies	Design	Quality assessment					# of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			

favourable effects were observed with the different motor development measures [94, 96]. One intervention had an infant sample at baseline [96]. The quality of evidence was downgraded from "low" to "very low" because of a serious risk of bias (see Table 2).

In the longitudinal study, higher duration of prone positioning at 4 months of age was favourably associated with the earlier achievement of several developmental milestones and gross motor development at 6 months but not at 24 months of age [97]. However, no significant differences were observed in fine motor development [97]. In separate analyses, no significant differences in motor development at 6 and 24 months of age were observed between infants who had, versus had not, experienced prone position at 4 months of age [97]. Apart from "crawled on abdomen", significant differences for achievement of developmental milestones were also not observed between groups [97]. In further analyses comparing infants that preferred prone position at 6 months of age to those that did not, no significant differences were observed in gross and fine motor development at 24 months of age; however, the prone-preference group achieved several developmental milestones significantly earlier [97]. The quality of evidence was downgraded from "low" to "very low" because of a serious risk of bias (see Table 2).

Among the 10 cross-sectional studies, physical activity was favourably associated with at least one measure of motor development in seven studies [56, 67, 69, 97–100], unfavourably associated with motor development in one study [101], and not associated with motor development in one study [86]; mixed findings were observed in one study [81]. Three of the studies with favourable associations [97–99] and one study with unfavourable associations had infant samples [101]. One study with null findings had a toddler sample [86]. For the intensity or type of physical activity, at least one favourable association was observed between each of the following physical activity exposures and motor development: MVPA (3/4 studies), VPA (1/1 study), indoor physical activity (1/1 study), and prone position (3/3 studies). However, primarily null or mixed findings were observed between each of the following physical activity exposures and motor development: TPA, LPA, LPA bouts, MVPA bouts, and outdoor physical activity (see Table 1). The quality of evidence was downgraded from "low" to "very low" because of a serious risk of bias (see Table 2).

[illegible]

The association between physical activity and psychosocial health was examined in 11 studies (9 unique samples; see Table 3 and Table S3 in Additional file 2). Among the two RCTs, greater increases in psychosocial health were observed in the intervention groups (planned passive cycling or dance program) compared to the control groups (standard care) [90, 102]. One of the interventions had an infant sample [90]. The quality of evidence was downgraded from "high" to "moderate" because of a serious risk of bias (see Table 3).

In the clustered RCT, no significant differences in quality of life were observed between the intervention (government-led physical activity program) and control (standard care) groups [41]. Physical activity was also not significantly different between groups [41]. The quality of evidence was downgraded from "high" to "very low" because of a serious risk of bias and very serious indirectness (see Table 3).

Among the two longitudinal studies, sport participation was favourably associated with psychosocial health in one study [103], and TPA was favourably associated with psychosocial health in one study [104] but not the other [103]. The quality of evidence was downgraded from "low" to "very low" because of a serious risk of bias (see Table 3).

Among the six cross-sectional studies, physical activity was favourably associated with at least one measure of psychosocial health in one study [105], unfavourably associated with at least one measure of psychosocial health in three studies [101, 106, 107], and not associated with psychosocial health in two studies [108, 109]. However, primarily null associations were observed in all studies. One study with unfavourable associations had an infant sample [101]. In regard to intensity or type of physical activity, at least one favourable association was observed between MVPA and psychosocial health (1/2 studies), and at least one unfavourable association was observed between bike riding and psychosocial health (2/2 studies). However, primarily null or mixed findings were observed between each of the following physical activity exposures and psychosocial health: TPA, exercise play, rough-and-tumble play, and walking (see Table 3). The quality of evidence was downgraded from "low" to "very low" because of a serious risk of bias and serious inconsistency (see Table 3).

[illegible]

The association between physical activity and cognitive development was examined in 13 studies (13 unique samples; see Table 4 and Table S4 in Additional file 2). Among the two RCTs, significant increases in cognitive development were observed in the [illegible]

Table 3 The relationship between physical activity and psychosocial health

# of studies	Design	Quality assessment					# of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
Mean baseline age ranged from 18.3 weeks-57.61 months; where mean age was not reported, baseline age ranged from 12 months-5 years. Data were collected by RCT, clustered RCT longitudinal with up to 8-									

groups (physical activity to enact meaning of words and physical activity unrelated to words) compared to the control groups (no physical activity) [110]. The quality of evidence remained at “high” (Table 4).

Among the four non-randomized interventions, a significant increase in at least one measure of cognitive development was observed in the intervention groups that participated in the intervention (academic lessons, free play, and structured activities) compared to the control groups (standard care) in three studies [93, 111, 112], and significant increases in children’s creativity at follow-up compared to baseline were reported in one study [113]. The quality of evidence was downgraded from “low” to “very low” because of a serious risk of bias (Table 4).

Among the three cross-over trials, at least one measure of cognitive development was significantly higher in the physical activity condition (MVPA breaks, structured/organized physical activity) compared to the control condition (typical instruction, sedentary session) in two studies [114, 115], and attention was significantly higher after 10-, 20-, and 30-min outdoor recess conditions in one study [116]. The quality of evidence was downgraded from “low” to “very low” because of a serious risk of bias (Table 4).

Among the three cross-sectional studies, physical activity was unfavourably associated with cognitive development in one study [101] and not associated with cognitive development in two studies [58, 109]. The study with unfavourable associations had a sample of infants [101]. In regard to intensity or type of physical activity, at least one favourable association was observed between TPA and cognitive development (1/2 studies). However, MVPA and outdoor physical activity were not associated with cognitive development (see Table 4). The quality of evidence was downgraded from “low” to “very low” because of a serious risk of bias (see Table 4).

F

The association between physical activity and fitness was examined in three studies (three unique samples; see Table 5 and Table S5 in Additional file 2). In the longitudinal study, TPA was favourably associated with cardiorespiratory fitness [43]. The quality of evidence was downgraded from “low” to “very low” because of a serious risk of bias (see Table 5).

Among the two cross-sectional studies, physical activity was favourably associated with at least one measure of fitness in both studies [55, 117]. As for physical activ-

Table 6 The relationship between physical activity and bone and skeletal health

Table 8 The relationship between physical activity and risks/harm

# of studies	Design	Quality assessment					# of participants	Absolute effect	Quality
		Risk of bias	Inconsistency	Indirectness	Imprecision	Other			
Mean baseline age ranged from 7.4 weeks-24 months; where mean age was not reported, baseline age ranged from 2 months-4.5 years. Data were collected by case cross-over and longitudinal with 4.5-6.5 years follow-up, case control, and cross-sectional study designs. Risks/harm was assessed as injury risk (proxy-report; Participant Event Monitoring method), injury severity (proxy-report; minor injury severity scale), fracture incidence (proxy-report), and plagiocephaly (objectively measured).									
1	Case cross-over[a]	Serious risk of bias[b]	No serious inconsistency	No serious indirectness	No serious imprecision	None	170	**TPA** was unfavourably associated with injury risk but was not associated with injury severity [128].	LOW[c]
1	Longitudinal[d]	Serious risk of bias[e]	No serious inconsistency	Serious indirectness[f]	No serious imprecision	Dose-response evidence[g]	2692	**Outdoor time** was favourably associated with fracture incidence in the winter but unfavourably associated with fracture incidence in the summer [129].	VERY LOW[h]
1	Case-control[i]	Serious risk of bias[j]	No serious inconsistency	No serious indirectness	No serious imprecision	None	194	**TPA** was favourabW[s91fl280Dfture incidence inEncy	

between leisure physical activity and blood pressure (1/1 study). Structured physical activity was not associated

This review builds on a previous systematic review conducted in 2012 that synthesized the evidence from 22 studies on the association between physical activity and health indicators among infants, toddlers, and pre-

physical activity studies in the present review were not focused on “risky” outdoor play per se. Nevertheless, the favourable associations between a number of different types of physical activity and health indicators suggest that children in the early years should participate in a variety of physical activities for the most health benefits.

It was difficult to draw conclusions about the specific frequency or duration of physical activity that is needed for health benefits because only a small proportion of the included studies examined these dose parameters.

Along with the evidence gaps and limitations associated with age groups studied and physical activity measurement, limited studies were available for a number of the health indicators. For example, there were 10 or fewer included studies for each of the following health indicators: psychosocial health, fitness, bone and skeletal health, cardiometabolic health, and risks/harm. Future high-quality research that increases the evidence base for these health indicators is needed. Additionally, while only three studies were included for fitness, some overlap existed between fitness and motor development categories (e.g., standing long jump versus standing broad jump; 12-m run versus 20-m shuttle run). Consensus is needed on what measures constitute fitness versus motor development in this age group.

One strength of the present systematic review was the use of a comprehensive search strategy that was both developed and peer-reviewed by librarians with expertise in systematic reviews. Another strength was the broad scope of the review through the inclusion of all study designs, both subjective and objective measures of physical activity, multiple health indicators, and multiple age groups (i.e. infants, toddlers, and preschoolers). Furthermore, the conduct of sub-analyses on dose of physical activity was a notable strength of the review, as was the meta-analysis of four adiposity interventions. Finally, the use of the established GRADE framework to guide the review and assess the quality of evidence was an additional strength [28].

The present review also had several limitations, including English and French language limits for feasibility, as well as sample size restrictions for both feasibility and generalizability. It is possible that studies published in other languages or with smaller sample sizes might have provided additional insight, especially for health indicators where evidence was limited. Furthermore, while a meta-analysis was conducted on four included studies, due to the large heterogeneity of the study designs and measured outcomes, the majority of findings were based on a narrative synthesis that weighted all studies equally. For some health indicators, conclusions from the narrative synthesis had to be drawn from a small number of studies. Furthermore, it was not possible to do sensitivity analyses between higher- and lower-quality evidence because the vast majority of evidence was “low” to “very low” quality.

Conclusions

This review synthesized evidence from 96 studies on the health implications of physical activity in the early years. Physical activity was consistently found to be favourably associated with a broad range of health indicators. Several types of physical activity, especially prone position for infants, TPA, and physical activity of at least moderate to vigorous intensity, particularly for preschool-aged children, were consistently found to be favourable with a number of health indicators. Although it was not possible to identify the specific frequency and duration of physical activity needed for health benefits in all age groups, it was consistently observed that more physical activity (in terms of frequency or duration) was better for health. Therefore, it can be concluded that it is important to promote physical activity in the early years. The findings of this review will help to inform evidence-based guidelines to facilitate physical activity promotion aimed at optimizing the overall health of our youngest children. Given that the study of physical activity in the early years is still a relatively new area of inquiry, future research should focus on addressing a number of gaps and limitations mentioned in this review, in order to strengthen the evidence base and accurately inform future health promotion efforts.

Additional files

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