Review

Is device-measured vigorous physical activity associated with health-related outcomes in children and adolescents? A systematic review and meta-analysis

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Abstract

Objective: This study sought to analyze the prospective association between vigorous-intensity physical activity (VPA) and health-related outcomes in children and adolescents.

Methods: Studies reporting associations between device-measured VPA and health-related factors in children and adolescents aged 3−18 years were identified through database searches (MEDLINE, EMBASE, and SPORTDiscus). Correlation coefficients were pooled if outcomes were reported by at least 3 studies, using DerSimonian-Laird random effects models.

Results: Data from 23 studies including 13,674 participants were pooled using random effects models. Significant associations were found between VPA at baseline and overall adiposity ($r = -0.09$, 95% confidence interval (95%CI): -0.15 to -0.03; $p = 0.002$; $I^2 = 89.8\%$), cardiometabolic risk score ($r = -0.13$, 95%CI: -0.24 to -0.02, $p = 0.020$; $I^2 = 69.6\%$), cardiorespiratory fitness ($r = 0.25$, 95%CI: $0.15-0.35$; $p < 0.001$; $I^2 = 57.2\%$), and total body bone mineral density ($r = 0.16$, 95%CI: 0.06 to 0.25; $p = 0.001$; $I^2 = 0\%$).

Conclusion: VPA seems to be negatively related to adiposity and cardiometabolic risk score and positively related to cardiorespiratory fitness and total body bone mineral density among children and adolescents at follow-up. Therefore, our findings support the need to strengthen physical activity recommendations regarding VPA due to its health benefits in children and adolescents.

Keywords: Accelerometry; Adiposity; Fitness; Physical activity

1. Introduction

There is robust evidence that physical activity (PA) in youth, specifically moderate-to-vigorous PA (MVPA; i.e., a combination of moderate and vigorous PA), is strongly associated with several favorable health-related outcomes.[1] Accordingly, many national and international organizations have developed guidelines recommending that children and adolescents accumulate at least 60 min of MVPA daily.[1−3] These guidelines also recommend the inclusion of vigorous-intensity, bone-strengthening, and muscle-strengthening PAs at least 3 times weekly.[1−3]

Most exercise-related research in youth has been focused on MVPA,[4,5] and there is less evidence for a link between vigorous PA (VPA) and health outcomes in this population. In this regard, 2 narrative reviews suggested that VPA may be especially beneficial for youth and may even bring more benefits than moderate-intensity activities.[6,7] However, the findings supporting the favorable associations between VPA and health-related outcomes in youth are typically derived from cross-sectional studies, and it is unclear whether the relationship is temporal in nature.

The sporadic nature of PA in youth is characterized by daily brief intermittent bouts of VPA.[8] Several studies suggest that every minute of VPA favors the same improvements in adiposity as 2 min or 3 min of moderate PA,[9,10] and it therefore seems reasonable to think that this type of PA is more attainable by children and adolescents; that is, VPA may be more attainable simply because a health-improving dose is less time consuming to attain. Because each PA intensity seems to provide different benefits,[11] this type of study could provide important information for those who develop national and international PA guidelines and determine how much daily VPA children and adolescents should be acquiring. To date, however, only a limited number of longitudinal studies have analyzed associations between VPA and health-related outcomes among youth, with inconsistent results.[6,12] Thus, the purpose of the present study was to analyzes the prospective association between VPA and health-related factors in children and adolescents.

2. Methods

The protocol was published in the International Platform of Registered Systematic Review and Meta-analysis Protocols under registration number (INPLASY202060082) and was conducted in accordance with Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines.[13]

2.1. Search strategy

The search was performed independently by 2 authors (AGH and YE) in the electronic databases MEDLINE, EMBASE, and SPORTDiscus, from inception to September 2020. Studies had to be observational prospective reports on the associations between device-measured VPA and health-related outcomes in children and adolescents. We combined variations of terms related to children and adolescents (e.g., pediatrics, child, adolescent, youth*, paediatr* or pediatr* or infant* or child* or teenage* or adolescen* or pre-schooler* or pre-schooler* or schoolchild* or girl* or boy* or teen*), VPA (e.g., vigorous physical activity, vigorous exercise), device-measured VPA (e.g., accelerometer, heart rate monitor), and health-related factors (e.g., body mass index, body fat, fat mass index, waist circumference, bone health, cardiometabolic risk factors, health-related physical fitness) (Supplementary Material 1). Hand-searching of reference lists of potentially eligible studies was undertaken to identify additional articles. Only studies published in peer-reviewed English-language journals were considered.

2.2. Selection criteria

To be included in our systematic review and meta-analysis, each article had to include the following elements: (1) exposure: device-measured VPA (e.g., accelerometers, heart rate monitors, or similars); (2) population: children and adolescents aged 3 years up to 18 years at baseline (mean age); (3) outcomes: health-related factors, including adiposity (e.g., body mass index, body fat, fat mass index, waist circumference),

cardiometabolic outcomes (e.g., cardiometabolic risk score, systolic blood pressure, homeostatic model assessment for insulin resistance), bone outcomes (e.g., total body bone mineral density (BMD) and bone mineral content), and/or health-related physical fitness (e.g., cardiorespiratory fitness, muscular fitness, speed-agility); and (4) study design: observational prospective cohort studies. Disagreements or uncertainties were discussed and resolved by consensus with 2 other authors (RRV and MI), and reasons for exclusions were recorded.

2.3. Data collection process and data items

Two authors (AGH and YE) extracted the following information for each study: study characteristics (e.g., country, follow-up duration), population characteristics (e.g., sex, age), VPA data reduction (e.g., wear time in terms of days, number of valid days, epochs, cut-points), and analysis and study results (e.g., adjusted variables, outcome of interest). Study authors were contacted to retrieve any missing data or to seek clarification if inadequate or insufficient information was detected.

2.4. Risk of bias and quality assessment in individual studies

The risk of bias was assessed by the Quality Assessment Tool for Observational Cohort and Cross-sectional Studies.[14] This methodological tool is composed of 14 items classified as "yes", "no", or "not reported". Two authors (YE and AGH) conducted the risk-of-bias assessment independently. If necessary, a third author (RRV) was consulted. For Item 9—"Were the exposure measures (independent variables) clearly defined, valid, reliable, and implemented consistently across all study participants?", and Item 14—"Were key potential confounding variables measured and adjusted statistically for their impact on the relationship between exposure(s) and outcome(s)?", we have included additional details in order to consider specific and topic-relevant biases. For Item 9, it was considered "yes" if the study used an epoch ≤ 15 s for the reduction of VPA data;[15] for Item 14, it was considered "yes" if the analysis was adjusted at least for baseline values of the outcome (the strongest confounder in prospective analyses) and sedentary time.

2.5. Meta-analysis

All analyses were performed using STATA Version 16.1 (STATA Corp., College Station, TX, USA). We used the correlation coefficient (r) as the main effect size for the present study. We converted other estimations (e.g., standardized regression coefficients, unstandardized regression coefficients, standardized mean differences (Cohen's d), and odds ratios) to correlation coefficients according to their corresponding formulas.[16−18] We selected fully adjusted models, partial models, or unadjusted models according to availability (i.e., in that order). DerSimonian-Laird random effects models[19] were used to pool correlation coefficients if outcomes were reported by at least 3 studies. Separate pooled analyses were conducted on the following parameters based on the available data:

overweight/obesity, body mass index, waist circumference, body fat, fat mass index, cardiometabolic risk score, systolic blood pressure, cardiorespiratory fitness, total body BMD, lumbar spine BMD, and femoral neck BMD. Also, we determined an overall effect on adiposity parameters according to Cliff et al.[20] To avoid duplication, we selected only 1 coefficient from each study using the following hierarchy: (1) body fat measured by dual-energy X-ray absorptiometry; (2) body fat measured by skinfolds thickness; (3) body fat measured by bioelectrical impedance analysis; (4) waist circumference; and (5) body mass index and overweight/obesity.

Random effects models[19] were used to account for anticipated between-study heterogeneity, calculated using the total variance (Q) and the inconsistency index (I^2).[21] Inconsistency was considered insignificant for $I^2 < 25\%$, low for $25\% \leq I^2 < 50\%$, moderate for $50\% \leq I^2 < 75\%$, and high for $I^2 \geq 75\%$.[22]

Publication bias was determined by visual examination of funnel plots (we have only used this visual test for overall adiposity due to the limited number of studies in the rest of the parameters).[23] Also, small-study effects bias was assessed using Egger's test[24] in all of the parameters.

Finally, random-effects meta-regression analyses using method of moments[25] were estimated to independently evaluate whether results were different by length of follow-up (months). Sub-group analyses according to age and sex were not possible because most of the included studies used both sexes and ages (children and adolescents) in their analyses.

3. Results

3.1. Study selection

A total of 3612 potentially relevant articles were identified, and, after screening for duplicates, 601 full-text studies were assessed for inclusion after checking titles and abstracts. Finally, 23 studies met the eligibility criteria and were included in the systematic review[26−48] and 21 in the meta-analysis. The reasons for exclusion based on full texts are reported in Supplementary Material 2. The PRISMA flow diagram illustrating the number of studies excluded at each stage of the systematic review and meta-analysis is shown in Fig. 1.

3.2. Study characteristics

The end points for all 23 prospective cohort studies are listed in Table 1. The studies involved a total sample of 13,674 children and adolescents with mean ages between 4.5 years and 17.5 years at baseline (mean age: 10.0 years). Most studies included boys and girls (49.7% and 50.3%, respectively), with the exception of 5 studies that included only boys[29,33,36,45,47] and two only girls.[39,42] Sample sizes across studies ranged from 88[33] to 4770[44] participants. The mean follow-up time was 38.5 months (between 7 and 120 months).

The correlation coefficient was presented in 4 studies[33,43,45,47]. Other effect sizes were converted from studies reporting β coefficients ($n = 17$), analysis of variance (ANOVA) ($n = 1$), and odds ratio ($n = 1$). Most of the studies analyzed associations between VPA at baseline and the dependent variables at follow-up
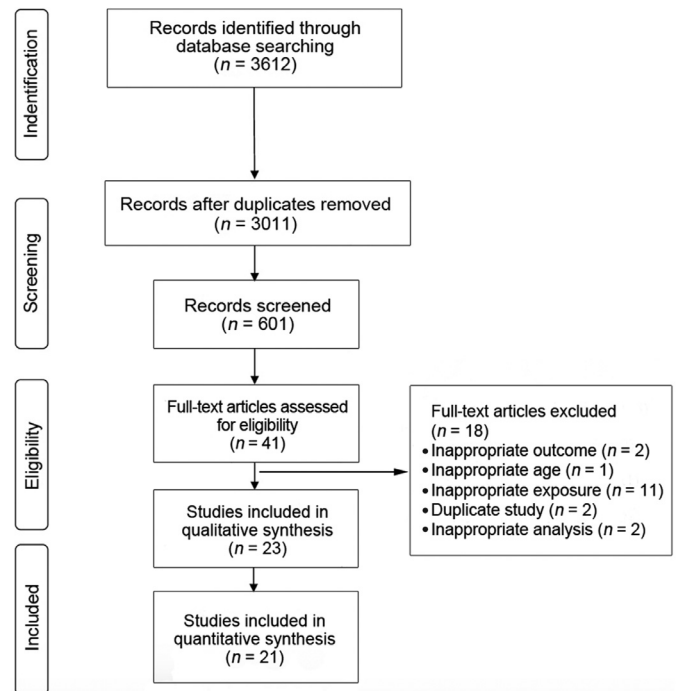

Fig. 1. Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) flow chart.

($n = 19$) (i.e., a determinant model); other studies also analyzed the association between changes in the VPA and changes in the dependent variables during follow-up ($n = 8$) (i.e., a change model). Regarding the covariates used in the statistical models applied, there was much heterogeneity between studies and few of these included baseline values of the outcomes or other important covariables such as maturation or time spent in other intensity domains.

3.3. Measurements

All studies device-measured VPA using accelerometers placed on the hip, waist, or wrist, and 2 studies used an Actigraph chest-worn monitoring device.[35,43] The VPA data reduction across studies was diverse, with different cut-off points characterizing VPA, epochs, total days of use, criteria for non-wear time and minimum wear time per day used for analysis.

Regarding health-related outcomes, most studies reported data on adiposity,[26−28,32,34,35,37,38,41−44,47,48] cardiometabolic risk factors,[26,30,32,35,38] bone outcomes,[29,31,33,36,39,40,45,46] and health-related physical fitness[27,38,41,48] (Table 1).

3.4. Risk of bias and quality assessment within studies

All 23 studies met at least 8 criteria (between 8 and 12 criteria) and were considered to have low-moderate methodological quality. Overall, all studies satisfied Items 1, 2, 6, 7, 8, and 11. In contrast, only 2 studies[34,43] fulfilled Item 12 (regarding assessors blinding), and no studies fulfilled Item 14 (i.e., regarding potential confounding variables and it adjust in the analyses). The average score was 9.6 of 14 (Supplementary Table 1).

Table 1
Study characteristics

Study, country	n	Females	Mean age at baseline (year)	Study length (month)	Outcome	VPA device	VPA data reduction	Covariate
Arvidsson et al. (2018)[26] Sweden	248	109	9.8	24	Adiposity, cardiometabolic risk factors	ActiGraph 7164	VPA: ≥6000 cpm Epoch: 10 s Non-wear: 10 min of 0 count Wear time: 8 h/day Valid days: 3	NR
Bland et al. (2020)[39] USA	131	131	12.9	24	Bone outcomes	Actigraph GT3X	VPA: ≥4012 cpm Epoch: 1 s Non-wear: ≥30 min Wear time: 10 h/day Valid days: 3 Total days: 7	Accelerometer wear time, baseline peripheral quantitative computed tomography measurement, 2-year maturity offset (years), and 2-year height (cm), and 2-year lean body
Bürgi et al. (2011)[27] Switzerland	217	113	5.2	9	Adiposity, health-related physical fitness	ActiGraph GT1M	VPA: ≥842 cpm Epoch: 15 s Non-wear: 10 min of 0 count Wear time: 6 h/day Valid days: 3 Total days: 6	Parental migrant status, educational level, and, for the fitness variables, body fat
Carson et al. (2014)[38] Canada	315	187	12.2	24	Adiposity, health-related physical fitness, and cardiometabolic risk factors	Actical B101270-B101375	VPA: >6500 cpm Epoch: 15 s Non-wear: 60 min of 0 count Wear time: 8 h/day Valid days: 3 Total days: 7	Age, sex, and dietary intake
Cohen et al. (2014)[42] USA	265	265	13.9	24	Adiposity	Accelerometer NR	VPA: ≥2600 counts/30 s Epoch: 15 s Wear time: 8.3 h/day (weekend) and 10.6 h/day (weekday) Valid days: NR Total days: NR	Age, race/ethnicity, mother's education, and neighborhood percent households in poverty
Collings et al. (2016)[43] UK	728	415	17.5	29	Adiposity	Actiheart NR	VPA: ≥7 METs Epoch: 30 s Wear time: >32 h (weekday) and 16 h/day (weekend) Total days: 4	Basline, age, sex, area-level SES, follow-up duration, season of baseline assessment, ST, sleep duration, ethnicity, pubertal status, energy intake, depressive symptoms, birth weight, maternal age at parturition, and FMI
Hamer and Stamatakis (2018)[44] UK	4770	2329	7.0	84	Adiposity	ActiGraph GT1M	VPA: >3841 cpm Epoch: 15 s Non-wear: 60 min of 0 count Wear time ≥8 h /day Valid days: 3 Total days: 7	Total volume of MVPA, BMI at baseline, sex, ethnicity, and social status

Table 1 (Continued)

Study, country	n	Females	Mean age at baseline (year)	Study length (month)	Outcome	VPA device	VPA data reduction	Covariate
Ivuškāns et al. (2015)[45] Estonia	169	0	12.1	12	Bone outcomes	ActiGraph GT1M	VPA: >4012 cpm Epoch: 60 s Non-wear: 10 min of 0 count Wear time: 8 h/day Valid days: 2 weekdays and 1 weekend day Total days: 7	Age, pubertal status, and body mass
Janz et al. (2014)[46] USA	369	197	5.2	120	Bone outcomes	ActiGraph GT1M	VPA: >4012 cpm Epoch: 60 s Non-wear: 60 min of 0 count Wear time: ≥10 h/day Valid days: 2 Total days: 4	Height, weight, linear age, non-linear age, maturity, and MVPA
Lätt et al. (2015)[47] Estonia	136	0	11.9	24	Adiposity	ActiGraph GT1M	VPA: >4000 cpm Epoch: 15 s Non-wear: 10 min of 0 count Wear time: 8 h/day Valid days: 2 weekdays and 1 weekend day Total days: 7	ST
Leppänen et al. (2017)[48] Sweden	138	65	4.5	12	Adiposity and health-related physical fitness	ActiGraph wGT3XBT	VPA: ≥1969 VM Epoch: 10 s Non-wear: blocks of 30 min Wear time: >10 h/day Valid days: 3 weekdays and 1 weekend day Total days: 7	Sex, age, ActiGraph awake wearing time, and ST
Lima et al. (2019)[28] Denmark	2520	1406	9.8	36	Adiposity	Actigraph GT3X	VPA: ≥4012 cpm Epoch: 2 s Non-wear: 30 min of 0 count Wear time: 10 h/day Valid days: ≥4 Total days: NR	School type, age, sex, height, school class, mother's education, pubertal status, season of accelerometer measurements, accelerometer wearing time, learning difficulty, physical disabilities, and cluster structure
Marin-Puyalto et al. (2018)[29] Estonia	140	0	11.9	12	Bone outcomes	ActiGraph GT1M	VPA: ≥4012 cpm Epoch: 15 s Non-wear: 20 min of 0 count Wear time: 10 h/day Valid days: ≥3 Total days: 7	Change in body weight and skeletal age
Metcalf et al. (2020)[40] USA	439	220	11.2	96	Bone and musculoskeletal outcomes	ActiGraph 7164, GT1M, and GT3X+	VPA: >4012 cpm Epoch: 60 s Non-wear: 60 min of 0 count Wear time: ≥10 h/day Valid days: 3−5 Total days: 5	Height and weight

Table 1 (Continued)

Study, country	n	Females	Mean age at baseline (year)	Study length (month)	Outcome	VPA device	VPA data reduction	Covariate
Reisberg et al. (2020)[41] Estonia	200	98	6.6	12	Adiposity and health-related physical fitness	Actigraph GT3X	VPA: ≥4000 cpm Epoch: 15 s Non-wear: >20 min of 0 count Wear time: 600 min/day Valid days: 3 Total days: 7	Sex, age at measurement, total awake wear time, and ST
Ried-Larsen et al. (2014)[30] Denmark	251	145	9.8	72	Cardiometabolic risk factors	Actigraph AM7164, GT3X, and GT1M	VPA: >1733 counts per 20 s Epoch: 20 s Non-wear: >60 min of 0 count Wear time: 576 min/day Valid days: 3 Total days: 5	Sex, body height, and biological development at follow-up
Rønne et al. (2019)[31] Denmark	663	333	9.6	72	Bone outcomes	Actigraph GT3X and GT3X+	VPA: >4012 cpm Epoch: 10 s Non-wear: ≥30 min of 0 count Wear time: 10 h/day Valid days: 3 Total days: 7	Maturity, sex, size (height, TBLH BA), body composition (weight, lean mass), and baseline TBLH BMC
Skrede et al. (2017)[32] Norway	700	356	10.2	7	Adiposity and cardiometabolic risk factors	Actigraph GT3X	VPA: >4012 cpm Epoch: 10 s Non-wear: >20 min of 0 count Wear time: >480 min/day Valid days: ≥4 Total days: 7	Sex, group allocation, pubertal status, SES, monitor wear time, baseline clustered cardiometabolic risk score, Andersen test, and adiposity
Tamme et al. (2019)[33] Estonia	88	0	12.1	72	Bone outcomes	ActiGraph GT1M and GT3X	VPA: >4000 cpm Epoch: NR Non-wear: >10 min of 0 count Wear time: >10 h/day Valid days: 2 weekdays and 1 weekend day Total days: 7	Baseline bone age and mean body mass
Tanaka et al. (2018)[34] UK	356	182	7.5	24	Adiposity	ActiGraph GT1M	VPA: >2050 counts per 15 s Epoch: 15 s Non-wear: wear time diaries and visual inspection Wear time: 6 h/day Valid days: 3 Total days: 7	Sex, ST, and MVPA or moderate PA, and BMI z-score or fat index at baseline
Väistö et al. (2019)[35] Finland	258	140	7.6	24	Adiposity and cardiometabolic risk factors	Actiheart	VPA: >7.0 METs (1 MET was 71.2 J/min/kg) Epoch: 60 s Non-wear: NR Wear time: 48 h/day Valid days: 2 weekdays and 2 weekend days Total days: 7	Age, sex, the explanatory and outcome variables at baseline and puberty

Table 1 (Continued)

Study, country	n	Females	Mean age at baseline (year)	Study length (month)	Outcome	VPA device	VPA data reduction	Covariate
Vaitkeviciute et al. (2014)[36] Estonia	206	0	12.0	24	Bone outcomes	ActiGraph GT1M	VPA: >4000 cpm Epoch: 60 s Non-wear: > 10 min of 0 count Wear time: 8 h/day Valid days: 2 weekdays and 1 weekend day Total days: 7	Biological age, height, lean body mass, and testing for ST and MVPA
van Sluijs et al. (2016)[37] UK	367	192	10.0	48	Adiposity	ActiGraph GT1M	VPA: ≥4000 cpm Epoch: 5 s Non-wear: ≥10 min of 0 count Wear time: NR Valid days: ≥3 Total days: 7	Parental weight status, birth weight, and sleep duration

Abbreviations: BMI = body mass index; cpm = count per minute; FMI = fat mass index; MET = metabolic equivalent task; MVPA = moderate-to-vigorous physical activity; NR = not reported; SES = socioeconomic status; ST = sedentary time; TBLH BA = total body less head bone area; TBLH BMC = total body less head bone mineral content; VM = vector magnitudes; VPA = vigorous-intensity physical activity.

3.5. Synthesis of results

The association between VPA and overall adiposity was statistically significant ($r = -0.09$, 95% confidence interval (95%CI): -0.15 to -0.03; $p = 0.002$; $I^2 = 89.8\%$; $n = 14$) (Fig. 2). For each adiposity outcome separately, VPA was negatively associated with overweight/obesity ($r = -0.20$, 95%CI: -0.38 to -0.03; $p = 0.022$; $I^2 = 82.2\%$; $n = 4$) and waist circumference ($r = -0.06$, 95%CI: -0.10 to -0.01; $p = 0.016$; $I^2 = 25.7\%$; $n = 5$) (Supplementary Fig. 1). Analyzing changes along time, change in VPA was not negatively related to change in overall adiposity ($r = -0.11$, 95%CI: -0.26 to 0.04; $p = 0.139$; $I^2 = 84.7\%$; $n = 4$) (Supplementary Fig. 2).

Regarding cardiometabolic risk factors, there was a negative relationship between VPA and cardiometabolic risk score ($r = -0.13$, 95%CI: -0.24 to -0.02; $p = 0.020$; $I^2 = 69.6\%$; $n = 3$) (Fig. 3). Also, VPA was positively related to cardiorespiratory fitness ($r = 0.25$, 95%CI: $0.15-0.35$; $p < 0.001$; $I^2 = 57.2\%$; $n = 4$) (Fig. 4). Finally, the results indicated a positive association between VPA and total body BMD ($r = 0.16$, 95%CI: $0.06-0.25$; $p = 0.001$; $I^2 = 0\%$; $n = 3$) (Fig. 5).

Based on meta-regression analysis, there was no significant effect of length of follow-up ($\beta = 0.001$, 95%CI: -0.004 to 0.006, $p = 0.663$) on the correlation coefficient estimate for overall adiposity (Supplementary Fig. 3).

Egger's test indicated no small-study effects bias for any outcome (overall adiposity, $p = 0.117$; cardiometabolic risk factors, $p = 0.273$; cardiorespiratory fitness, $p = 0.378$; speed-agility, $p = 0.057$; and bone and musculoskeletal outcomes, $p = 0.756$). The funnel plot for overall adiposity also showed no asymmetry (Supplementary Fig. 4).

4. Discussion

The present systematic review and meta-analysis summarizes the evidence for the prospective association between VPA and health-related factors among children and adolescents. Overall, VPA seems to be negatively related to adiposity and cardiometabolic risk score and positively related to cardiorespiratory fitness and total body BMD later in life.

Our results are consistent with prior reports in the literature given that a number of previous reviews have emphasized that time spent in higher intensities of PA is a significant predictor of levels of adiposity in children and adolescents.[6,11,12] Owens et al.[12] suggested that VPA provided adiposity-related benefits to children and adolescents over and above those obtained from moderate or light PA. Specifically, the authors stated that every minute of VPA favors the same improvements in adiposity as 2 or 3 min of moderate PA, in accordance with cross-sectional studies.[9,10] This is also consistent with a review published by Gralla et al.,[6] which reported favorable associations between VPA and adiposity in children and adolescents, particularly in studies where participants engaged in an average of at least 10 min of VPA. The majority of the studies included in the aforementioned reviews are, however, cross-sectional in nature, and therefore the directionality of the relationship between
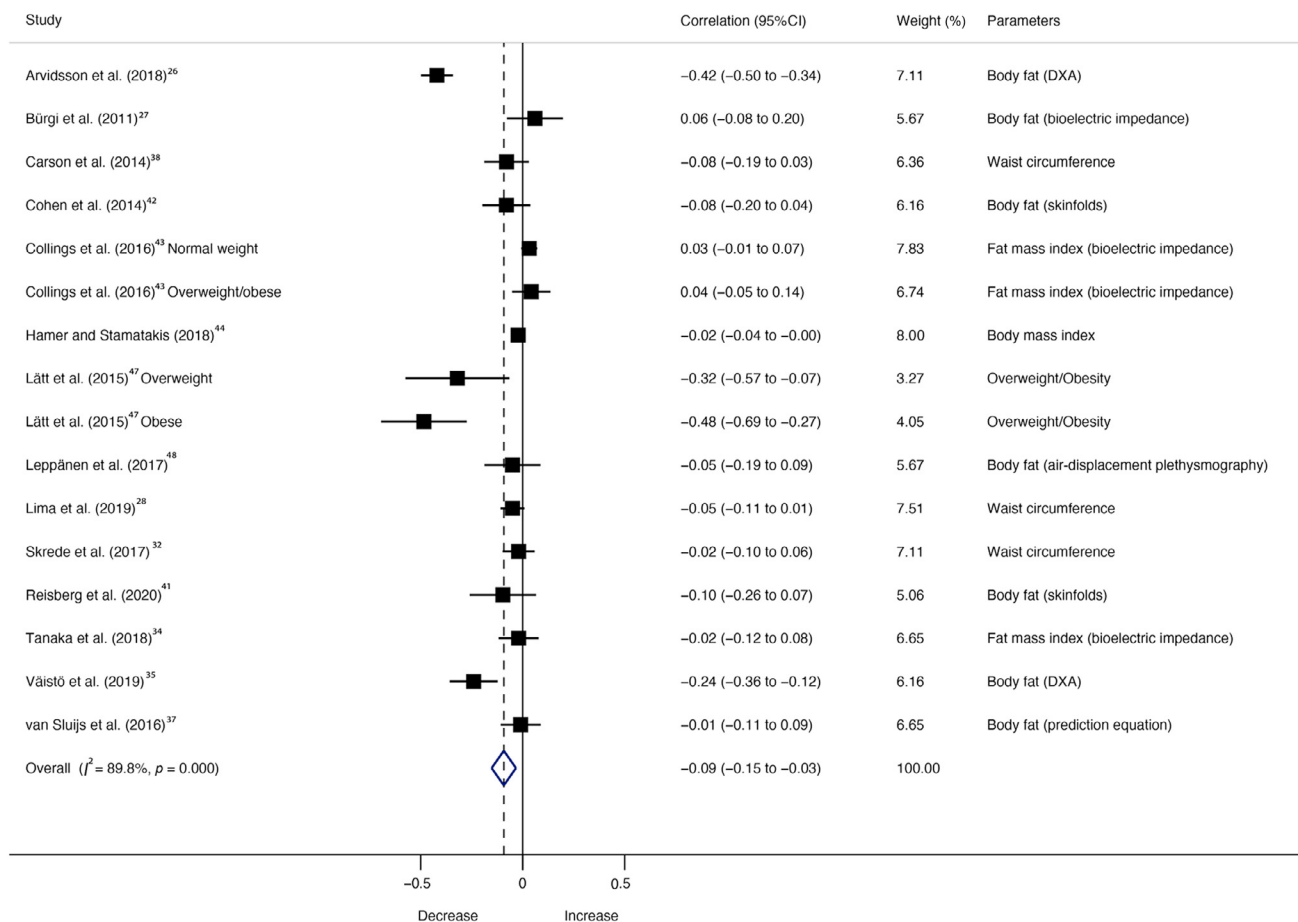
Fig. 2. Forest plot showing the correlation of vigorous physical activity at baseline on adiposity at follow-up for each adiposity study. Weights are from random effects analysis. *p* value represents significance for the heterogeneity test. 95%CI = 95% confidence interval; DXA = dual energy X-ray absorptiometry.
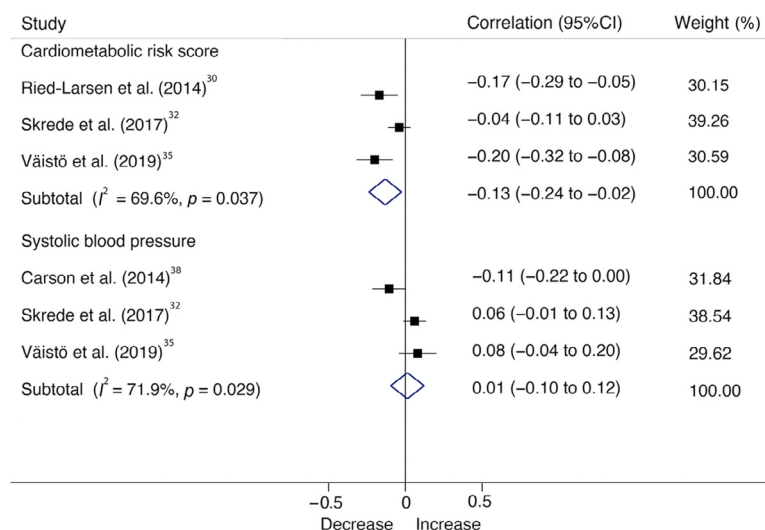

Fig. 3. Forest plot showing the correlation of vigorous physical activity at baseline on cardiometabolic risk score and systolic blood pressure at follow-up for each study. Weights are from random effects analysis. *p* value represents significance for the heterogeneity test. 95%CI = 95% confidence interval.

VPA and fatness parameters cannot be established;[34] it is possible that excess adiposity may cause less VPA.

There is also a growing body of evidence suggesting that VPA may favor a healthier cardiometabolic profile among youth,[7] but equivocal findings were reported in the aforementioned reviews. For example, Gralla et al.[6] reported that VPA does not have a strong relationship with cardiometabolic risk score in youth. By contrast, Owens et al.[12] suggested that VPA is associated with a
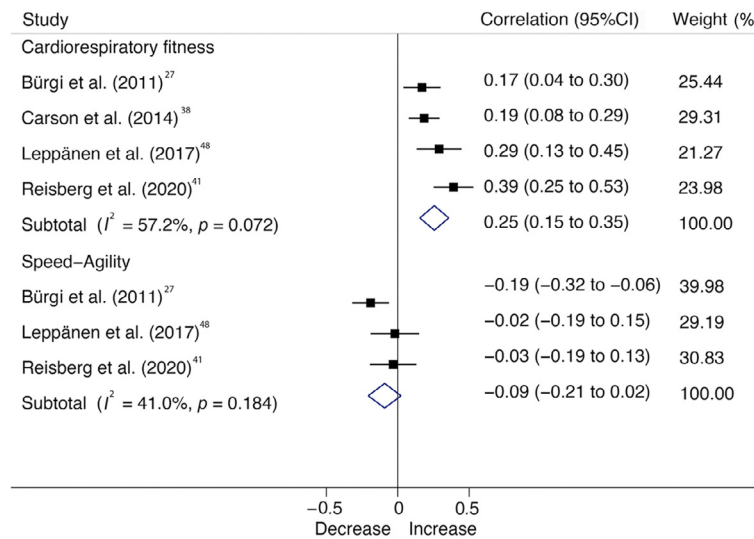
Fig. 4. Forest plot showing the correlation of vigorous physical activity at baseline on cardiorespiratory fitness and speed-agility at follow-up for each study. Weights are from random effects analysis. *p* value represents significance for the heterogeneity test. 95%CI = 95% confidence interval.
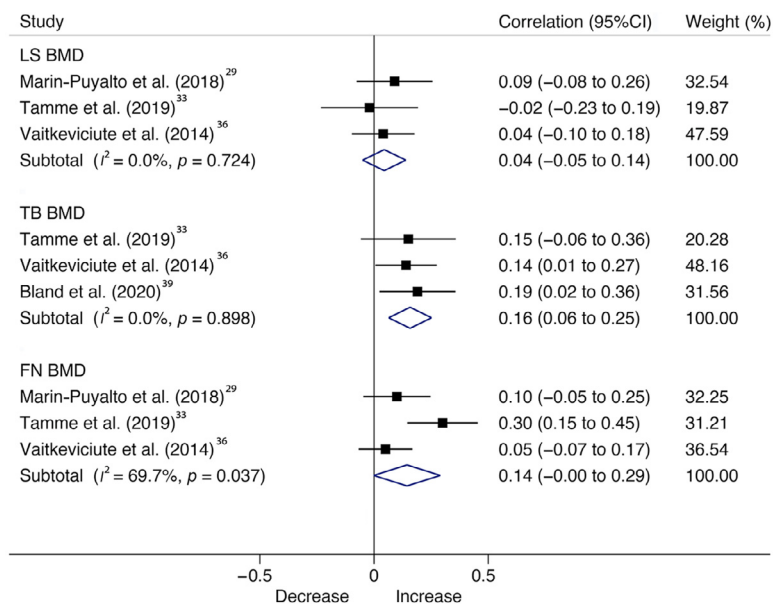

Fig. 5. Forest plot showing the correlation of vigorous physical activity at baseline on bone outcomes at follow-up for each study. Weights are from random effects analysis. *p* value represents significance for the heterogeneity test. 95%CI = 95%confidence interval; BMD = bone mineral density; FN = femoral neck; LS = lumbar spine; TB = total body.

more favorable blood lipid and glucose−insulin profile, which matches the results of Väistö et al.[35] Consistent with the literature about combined moderate and VPA,[4] our meta-analysis reveals that VPA is inversely related to cardiometabolic risk score, which is also supported by experimental studies.[49] There are several possible biological mechanisms that explain our results. For example, PA improves insulin action in skeletal muscle and glucose transport,[50] and also improves fat metabolism and increases blood flow and oxygen supply through the increased density of capillaries and vasodilatation by nitric oxide.[51] In contrast to earlier findings,[51] however, no relationship between VPA and systolic blood pressure was detected in our study, which differs from studies using high-intensity training[52] or even moderate-intensity training among obese youths.[53] This inconsistency may be due to the initial health status of youth in various studies, which may greatly affect the observed association[54] (i.e., associations are more likely to occur in high-risk participants such as obese children and adolescents).[53]

In line with previous reviews,[6,12] we found that VPA is consistently associated with cardiorespiratory fitness. Published experimental studies also indicate that VPA is as effective,[55]

or even superior, to moderate PA for improving cardiorespiratory fitness among children and adolescents.[53] For example, a randomized controlled trial in children with obesity reported that 6 weeks of high-intensity interval training using games-based exercises led to an improvement in cardiorespiratory fitness.[55] In addition, a meta-analysis of randomized controlled trials suggested that high-intensity training in children with obesity is considered a more effective intervention for improving cardiorespiratory fitness than other training protocols with lower intensities.[53] PA at a higher intensity could favor an increase in oxygen availability through central effects (such as maximal cardiac output, total hemoglobin, and blood plasma volume).[56] VPA also seems to increase muscle oxidative potential and the ability to extract and use available oxygen, reflecting peripheral adaptations.[57] Our findings have important implications since cardiorespiratory fitness is a central marker of health status during childhood and adolescence, and also in later life.[58] In light of the small number of studies involving muscular fitness parameters in the meta-analysis, the results could not be pooled to determine their relationship with VPA. However, Leppänen et al.[48] reported that VPA among children 4.5 years old was related to higher muscular strength ($r = 0.20$ and $r = 0.36$ in handgrip and standing long-jump tests, respectively) 1 year later.

Regarding bone health, it is generally acknowledged that weight-bearing activities, more specifically high-impact activities, during youth are effective for promoting bone health.[59,60] Our meta-analysis suggests that VPA favors higher total body BMD later in life. The results of a recent 8-year prospective study by Metcalf et al.[40] showed that accumulating 5 extra minutes per day of VPA was associated with up to 3.0% and 5.1% greater bone structural outcomes by age 19 years in boys and girls, respectively. The Rønne et al's. study[31] meta-analyzed here and the aforementioned Metcalf et al.'s study[40] underpin the notion that greater attention should be placed on promoting high-impact VPA throughout adolescence and emerging adulthood to maximize bone strength and reduce fracture risk. Indeed, Ivuškāns et al.[45] also found that increases in VPA during a 12-month period favors bone mineral acquisition in peripubertal boys. Therefore, although we have included limited studies, the existing data from longitudinal designs and experimental trials[59] point to bone health advantages for children and adolescents engaged in daily high-impact VPA.

Overall, several methodological factors could have potentially influenced our study results and heterogeneity. First, there are discrepancies regarding the reduction of accelerometer data; VPA cut-offs varied from ≥ 842 counts per minute[27] to ≥ 6500 counts per minute[38] in our meta-analysis, which could result in significantly different estimates of time spent in VPA. Also, a recent study recommends the use of short epochs when analyzing accelerometry data in youth in order to mirror their activity patterns and capture VPA correctly.[61] A majority of the included studies in our review used 10−60-s epochs, and therefore we could have underestimated the VPA levels.[62] These choices related to data reduction could impair the true association between VPA and health parameters and complicate comparability between studies. Unfortunately, evidence on reaching consensus on VPA data reduction protocols is currently lacking. Second, and no less important, are the statistical models applied in the included studies. Most of the studies used a determinant model, in which the follow-up outcome or its change is regressed on a baseline value; however, not all studies adjusted for baseline values of the outcome, which is the strongest confounder in prospective analyses.[4] Also, few studies[34,36,43,47,48] adjusted their analysis by time spent in other intensity domains. Conversely, these intensities are codependent and difficult to separate statistically; recent studies suggest more appropriate analytical methods such as compositional data analysis.[63] Therefore, not including both confounding variables could be considered a major methodological flaw. Third, our findings should be interpreted with caution given the short duration of follow-up time in the included studies (the mean follow-up time was 38.5 months). Fourth, many prospective studies in the literature only include MVPA and/or sedentary time levels in their results, creating one of the strongest biases in our study (i.e., selection bias). Fifth, correlation coefficient could be a poor metric because it is difficult to translate into clinical findings; however, this coefficient is standardized and can itself serve as an effect size.[25] Finally, reverse causality could also be possible given that the prospective design of the included studies did not eliminate the possibility of bi-directional associations.

5. Conclusion

Overall, VPA seems to be negatively related to adiposity and cardiometabolic risk score and positively related to cardiorespiratory fitness and total body BMD among children and adolescents at follow-up. Our results support the need to further strengthen VPA recommendations for children and adolescents. However, more studies are warranted, including rigorous experimental trials, to confirm the optimal dose of VPA for overall health status among youth.

Authors' contributions

AGH and YE conceptualized and designed the study, drafted the initial manuscript, and reviewed and revised the manuscript; RRV and JO designed the data collection instruments, collected data, carried out the initial analyses, and reviewed and revised the manuscript; MI conceptualized and designed the study, coordinated and supervised data collection, and critically reviewed the manuscript for important intellectual content. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.jshs.2020.12.001.

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