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REVIEW ARTICLE

Is directly measured physical activity related to adiposity in preschool children?

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Abstract

This review summarizes the association between directly assessed physical activity and adiposity in preschool children (age 1.5–6 years). It includes 17 cross-sectional and longitudinal studies that were published between January 1999 and February 2010. The association between physical activity and obesity seems to depend on the outcome measure of adiposity. In 60% (3/5) of the studies using percentage body fat, an inverse significant relationship with physical activity was found against 18% (2/11) of the studies that used body mass index as method to assess adiposity. Physical activity is inversely related to percentage body fat in preschool children. The associations between physical activity and body mass index as a measure of adiposity in preschool children remain elusive. Further studies using directly measured physical activity and percentage body fat to define adiposity are needed to draw more firm conclusions.

Key words: Adipose tissue, body mass index, child, exercise, obesity, preschool

Abbreviations: %BF, percentage body fat; BMI, body mass index; DLW, double labelled water; DXA, dual energy X-ray absorptiometry; FM, fat mass

Introduction

Obesity is a growing epidemic worldwide, not only in adults but also in children (1,2). From the perspective of prevention, the findings in very young children are of particular relevance. The global prevalence of overweight and obesity is estimated to be 6.7% in very young children of age 0–5 years of age. In developed countries, overweight and obesity are currently more common in this young age group, leading to an estimate of 11.7% in developed countries (3). Similar as in adults, children with overweight or obesity have a substantially increased health risk (4–6). This applies to metabolic impairments such as hypertension, hyperinsulinaemia, poor glucose tolerance and a raised risk for type 2 diabetes. In addition to metabolic impairments, psychological (anxiety, depression or low self-esteem) and social consequences (peer rejection) are important in children with obesity (4). Furthermore, it is known that children with overweight or obesity have a high chance to be obese in adulthood (7–10). An important difference between children and adults is that children

experience growth, and not only current weight is a risk factor for future overweight, but also the increase in body mass index (BMI) over a certain period of time. Studies have found that BMI change between the age of 2 and 6 is related to overweight and cardio metabolic risk in adulthood (11,12). For prevention of obesity and related comorbidities in adulthood it is therefore important to prevent overweight and obesity early in life.

Obesity is the result of a disturbed balance between energy intake and energy expenditure. Physical activity is therefore an important factor related to overweight and obesity in adults (13), and recent reports on children ranging in age from 2–18 years show that this is also relevant during growth and development at younger age (14,15). In addition, physical activity may track from childhood into adulthood (16). In the preschool period, physical activity may have a protective effect because of the ‘adiposity rebound’. The onset of the second period of rapid growth in BMI, the adiposity rebound, starts at about the age of six (17,18). An early adiposity rebound is associated with

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adult obesity (19). High levels of physical activity may delay the onset of the adiposity rebound. Therefore, the level of physical activity before the age of six, the preschool age, might play a pivotal role in the development of obesity in adulthood (20).

Little is known about the association between physical activity and adiposity in preschool children, mainly due to methodological issues (21). However, a recent increase in studies using objective devices such as accelerometers to assess physical activity is seen and advances in accelerometry and automated data processing. Physical activity can be defined as any bodily movement produced by the contraction of skeletal muscle that increases energy expenditure above a basal level. To assess physical activity, an instrument must be sensitive enough to detect all activities that are executed by the child. Some methods are only able to assess total physical activity, while others are also able to assess differences in frequency, duration and intensity of physical activity. To assess physical activity in children, indirect subjective measures can be used, such as parent/teacher questionnaires and parental recall (22,23). The disadvantages of these measurements are that teacher or parent questionnaires have not been sufficiently evaluated for the assessment of physical activity in preschool children (23). This can be caused by the sporadic nature of movement behaviour in preschoolers. Self-report, also a subjective measure, is not recommended for children under the age of 10 (24). Alternatives that have been developed in the past years are direct methods such as accelerometers and pedometers, whereas the more traditional validated methods include the double labelled water (DLW) method, heart rate monitoring and direct observation (23,25). An increased amount of studies arise using accelerometers to assess physical activity. Accelerometers are validated objective measures to assess physical activity in preschool children (26). Some of these studies investigated whether a lack of physical activity in children below six years is already related to adiposity, but the results appear inconsistent. The aim of this review is to summarize findings on the association between physical activity, assessed by direct methods and adiposity in preschool children aged 1.5–6 years.

Method

Search procedures

Relevant studies were identified through searches of Pubmed, Embase, Medline and Web of Science with the following Keywords: (children or preschool or 'young children') and ('body mass index' or BMI or overweight or obesity or 'body fat' or 'body composition' or 'weight status') and ('physical activ-

ity' or 'activity level' or exercise). The reference lists of the identified studies including reviews were searched until no further studies were identified. A summary of the characteristics of the studies relevant for this review were composed in Table I.

Inclusion and exclusion criteria

The inclusion criteria were: (i) physical activity measured with direct methods (accelerometer, pedometer, DLW method, heart rate monitoring or direct observation), (ii) adiposity measured as BMI, percentage body fat (%BF) or fat mass (FM) as outcome measure, (iii) the association between physical activity and adiposity was investigated, (iv) children in the study were aged 1.5–6 years at baseline, (v) the study was published between January 1999 and February 2010, and (vi) the study had a cross-sectional or longitudinal design. The exclusion criteria were: (i) the study contained children with disabilities, (ii) the study was not published in English, (iii) anthropometric measures reported by the parents. No criteria were applied for study size, ethnicity, gender distribution or duration of physical activity measurement.

Analysis

A quantitative meta-analysis was not possible due to lack of studies and heterogeneity with regard to methods to assess physical activity or adiposity. Therefore this review aims to give a complete descriptive overview of previous findings relating to the topic, confined to studies that assess daily physical activity using direct methods. The authors who did not present correlation coefficients and *p*-values were contacted to obtain this information. The results of the authors who responded were added in Table I.

The included studies were stratified by outcome measure for adiposity. The relation of physical activity with %BF, FM and BMI were described separately and gender differences were analyzed if possible. To summarize the consistency of evidence a scheme proposed by Sallis et al. (27) was used; 0–33% of studies supporting the association stand for no association, 34–59% stands for an inconsistent association and 60–100% stands for a positive or negative association (27).

Results

Study selection

A flow diagram for the selection of studies is provided in Figure 1. Sixty studies were identified based on the title and abstract, of which 17 articles

Table I. Studies on the association between physical activity, assessed by direct methods, and adiposity in preschool children.

Author (publication year)	Methods to assess PA	Methods to assess adiposity	Study subjects	Statistical analysis and results
<i>Studies using %BF and/or FM to assess adiposity</i>				
Al-Hazzaa and Al-Rasheedi (2007) (39)	Pedometer (Step counts per day)	%BF (triceps and sub-scapular skin fold measurements) Obesity is defined as: • Boys: $\geq 25\%$ BF, • Girls $\geq 30\%$ BF	$n = 224$ Age: 3.4–6.4 yr Location: Jeddah, Saudi Arabia	Independent t -test Obese: 5375 ± 3754 steps/day Non-obese: 7065 ± 5495 steps/day $p: 0.109$ Pearson correlation Steps/day – %BF $r: 0.078; p: 0.27$
Janz et al. (2002) (35)	Uni-axial accelerometer (Total PA (average counts/min); MVPA (min/day); VPA (min/day))	%BF, FM and trunk FM (DXA)	$n = 434$ Age: 4–6 yr Location: Iowa, USA	Pearson correlation Total PA – %BF boys: $r: -0.19; p < 0.01^*$; girls $r: -0.25; p < 0.01^*$ Total PA – FM boys: $r: -0.15; p < 0.05^*$; girls: $r: -0.19; p < 0.01^*$ MPA – %BF boys: $r: -0.10; p > 0.05$; girls: $r: -0.12; p > 0.05$ MPA – FM boys: $r: -0.07; p > 0.05$; girls: $r: -0.06; p > 0.05$ VPA – %BF boys: $r: -0.26; p < 0.01^*$; girls: $r: -0.30; p < 0.01^*$ VPA – FM boys: $r: -0.22; p < 0.01^*$; girls: $r: -0.25; p < 0.01^*$
Janz et al. (2005) (37) ^a	Accelerometer (average counts/min; VPA (min/day) MPA (min/day); 5-min bouts VPA, MPA)	%BF (DXA)	$n = 379$ Age at baseline: 5.6 ± 0.5 yr Age at follow-up: 8.6 ± 0.5 yr Location: Iowa, USA	Wilcoxon rank sum test Average counts/min – quartiles of follow-up %BF Lower quartile: 748; upper 3 quartiles: 700; $p < 0.05^*$ lower 3 quartiles: 725; upper quartile: 670; $p < 0.005^*$ VPA – quartiles of follow-up %BF Lower quartile: 32; upper 3 quartiles: 27; $p < 0.005^*$ lower 3 quartiles: 30; upper quartile: 24; $p < 0.005^*$ MPA – quartiles of follow-up %BF Lower quartile: 217; upper 3 quartiles: 213; $p > 0.05$ lower 3 quartiles: 215; upper quartile: 211; $p > 0.05$ 5 min bouts VPA – quartiles of follow-up %BF Lower quartile: 1.3; upper 3 quartiles: 1.0; $p < 0.05^*$ lower 3 quartiles: 1.1; upper quartile: 0.7; $p < 0.005^*$ 5 min bouts MPA – quartiles of follow-up %BF Lower quartile: 22; upper 3 quartiles: 21; $p > 0.05$ lower 3 quartiles: 22; upper quartile: 20; $p > 0.005$

(Continued)

Table I. (Continued)

Author (publication year)	Methods to assess PA	Methods to assess adiposity	Study subjects	Statistical analysis and results
Heelan and Eisenmann (2006) (28)	Uni-axial accelerometer (total PA [average counts/min]; MPA [min/day]; MVPA [min/d]; VPA [min/day])	%BF and FM (DXA) BMI	n = 100 Age: 4–7 yr Location: a rural Midwestern US community (population: 30,000)	Partial correlation coefficients adjusting for chronological age TPA – BMI boys: $r = -0.17$; $p > 0.05$; girls: $r = -0.10$; $p > 0.05$ TPA – %BF boys: $r = -0.06$; $p > 0.05$; girls: $r = -0.08$; $p > 0.05$ TPA – FM boys: $r = -0.13$; $p > 0.05$; girls: $r = -0.08$; $p > 0.05$ MVPA – BMI boys: $r = -0.25$; $p > 0.05$; girls: $r = 0.04$; $p > 0.05$ MVPA – %BF boys: $r = -0.12$; $p > 0.05$; girls: $r = -0.09$; $p > 0.05$ MVPA – FM boys: $r = -0.22$; $p > 0.05$; girls: $r = -0.08$; $p > 0.05$ GLM analysis with average PA as a dependent variable. FM was no predictor of PA, F: unknown; $p: 0.617$
Jackson et al. (2009) (29)	Uni-axial accelerometer (average counts/min)	FM (DXA)	n = 89 Age: 2–6 yr Location: Scotland, UK	Multiple regression analysis with dietary intake variables and PAL as predictors of %BF PAL – %BF Coefficient: -8.18 ; t ratio: -3.45 ; $p < 0.001^*$
Atkin and Davies (2000) (41)	DLW method (TEE) BMR PAL: TEE/BMR	%BF (^{18}O dilution method)	n = 77 Age: 1.5–4.5 yr Location: UK	Mixed models ANOVA PA measured in 1 year before take-off Average PA (mean CARS score) – take-off/non-take-off Take-off: 2.0 ± 0.2 non-take-off: 2.0 ± 0.2 ; $p = 0.77$ MVPA (%min) – take-off/non-take-off Take-off: 33.7 ± 14.5 non-take-off: 27.0 ± 19.3 ; $p = 0.30$ VPA (%min) – take-off/non-take-off Take-off: 1.5 ± 1.7 non-take-off: 1.2 ± 1.8 ; $p = 0.70$
Robertson et al. (1999) (43) ^a	Children’s Activity Rating Scale (CARS); only in time interval 15:00–18:00 h.	FM (sum of 7 skinfolds)	Take-off group: n = 14 Control group: non-take-off group n = 30 Age: 3–7 yr Location: Texas, USA	Forward-backward stepwise regression analysis average daily counts – BMI partial r^2 : unknown; $p: 0.4$ counts between 9 AM and 5 PM – BMI partial r^2 : unknown; $p: 0.9$ %time VPA – BMI partial r^2 : unknown; $p: 0.3$
<i>Studies using BMI and/or BMI Z-score to assess adiposity</i>				
Finn et al. (2002) (30)	Bi-axial accelerometer (average daily counts; counts between 09:00 and 17:00 h; % time spent in VPA)	BMI	n = 214 Age: 3–5 yr Location: South Dakota, USA	

(Continued)

Table I. (Continued)

Author (publication year)	Methods to assess PA	Methods to assess adiposity	Study subjects	Statistical analysis and results
Firriniceli et al. (2005) (31)	Omni directional accelerometer (average counts/min; amount VPA; amount sustained VPA)	BMI	n = 54 Age: 3–5 yr Location: Richmond, Virginia, USA	Correlation PA – BMI r: unknown; $p > 0.05$
Jackson et al. (2003) (32)	Uni-axial accelerometer (average counts/min)	BMI BMI Z-score	n = 104 (60) Age: 3–4 yr Location: Scotland, UK	Correlation PA – BMI Z-score r: 0.19; $p: 0.04^*$
Jones et al. (2009) (38)	Uni-axial accelerometer (average count/min; MVPA (min/day)	BMI NOW and OW was classified based on the IOTF reference for children	n = 58 Age: 2–6 yr Location: New South Wales, Australia	Independent <i>t</i> -test Average counts/min – BMI OW: 961.08 ± 213.05 counts/min NOW: 865.71 ± 226.18 counts/min $p: 0.297$ MVPA OW: 28.99 ± 22.55 min/day NOW: 32.95 ± 25.24 min/day $p: 0.696$
Kelly et al. (2006) (33)	Uni-axial accelerometer (average counts/min)	BMI BMI Z-score	n = 339 Age: 4.2 ± 0.5 yr Location: Scotland, UK	Univariate analysis PA – BMI Z-score Coefficient: 17.4; $p: > 0.05$
Metallinos-Katsaras et al. (2007) (34)	Uni-axial accelerometer (Light PA [min/day]; MPA [min/day]; VPA [min/day]; very VPA [min/day]; active time [min/day]; very active time [min/day]; TPA [average counts/min])	BMI BMI Z-score OW is defined as: BMI Z-score ≥ 85 th percentile according to the CDC Growth Charts	n = 56 Age: 2–5 yr Location: Massachusetts, USA	Logistic regression analysis Adjusted for age, race and sex 2 groups: NOW and OW children Light PA – NOW /OW Adjusted odds ratio (95% CI): 1.00 (0.99–1.01); $p: 0.36$ MPA – NOW /OW Adjusted odds ratio (95% CI): 1.00 (0.99–1.02); $p: 0.97$ VPA – NOW /OW Adjusted odds ratio (95% CI): 0.94 (0.88–0.99); $p < 0.05^*$ Very VPA – NOW /OW Adjusted odds ratio (95% CI): 0.68 (0.48–0.96); $p: 0.03^*$ MPA – NOW /OW Adjusted odds ratio (95% CI): 1.00 (0.99–1.02); $p: 0.97$ Active time – NOW /OW Adjusted odds ratio (95% CI): 1.00 (0.98–1.01); $p: 0.54$ Very active time – NOW /OW Adjusted odds ratio (95% CI): 0.94 (0.89–0.997); $p: 0.04^*$ TPA – NOW /OW Adjusted odds ratio (95% CI): 1.00 (0.99–1.00); $p: 0.43$

(Continued)

Table I. (Continued)

Author (publication year)	Methods to assess PA	Methods to assess adiposity	Study subjects	Statistical analysis and results
Toschke et al. (2007) (44)	Uni-axial accelerometer (average counts/min)	BMI	n = 192 Age: 5–6 yr Location: Munich, Germany	Pearson correlation PA – BMI r = -0.06; p > 0.05
Trost et al. (2003) (36)	Uni-axial accelerometer (total counts/hour; number 15 s-intervals of MVPA; number 15 s-intervals of VPA); only during preschool hours Observational System for Recording Physical Activity in Children- Preschool version (OSRAC-P); only 1 hour/day (mean activity rating)	BMI Overweight is defined as: BMI ≥ 85th percentile according to the CDC Growth Charts	n = 245 Age: 3–5 yr Location: Columbia, South Carolina, USA	Two-way ANCOVA with sex and OW or NOW as grouping variables; parent education as covariate TPA – NOW /OW boys, OW: 50.5 × 10 ³ ; NOW: 60.0 × 10 ³ ; p < 0.05* girls, OW: 51.9 × 10 ³ ; NOW: 52.1 × 10 ³ ; p > 0.05 % time MVPA – NOW /OW boys, OW: 39.0; NOW: 47.6; p < 0.05* girls, OW: 42.2; NOW: 41.6; p > 0.05 MVPA intervals – NOW /OW boys, OW: 27.2; NOW: 33.7; p < 0.05* girls, OW: 28.3; NOW: 28.5; p > 0.05 VPA intervals – NOW /OW boys, OW: 4.9; NOW: 6.7; p < 0.05* girls, OW: 4.7; NOW: 5.6; p > 0.05 mean activity rating – NOW/OW boys, OW 2.4; NOW: 2.6, p < 0.05* girls, OW 2.5; NOW: 2.5, p > 0.05
Jago et al. (2005) (40)	HR monitoring: HR PA/h (min/hour with mean HR of > 140 bpm)	BMI	n = 142 in year 1 n = 141 in year 2 n = 137 in year 3 Age: 3–6 yr Location: Texas, USA	Pearson correlation HR PA/h – BMI yr 1, r: 0.105; p > 0.05 yr 2, r: 0.027; p > 0.05 yr 3, r: 0.027; p > 0.05
Pate et al. (2008) (42)	Observational System for Recording Physical Activity in Children- Preschool version (OSRAC-P); only during preschool hours	BMI	n = 438 Age: 3–5 yr Location: Colombia, South Carolina, USA	Multiple regression analysis with gender, age, BMI, race and preschool as predictors of % time active and of % time MVPA % time active – BMI (age 3–5) Beta: 0.17; F: 15.41; p < 0.001* % time MVPA – BMI (age 4–5) Beta: 0.14; F: 9.08; p: 0.003*

%BF, percentage body fat; BMI, body mass index; BMIR, basal metabolic rate; bpm, beats per minute; CDC, Centers for Disease Control and Prevention; CI, confidence interval; DLW, double labelled water; DXA, dual energy X-ray absorptiometry; FM, fat mass; HR, heart rate; IOTF, International Obesity Taskforce; min, minutes; MPA, moderate physical activity; MVPA, moderate-to-vigorous physical activity; NOW, non overweight; OW, overweight; PA, physical activity level; TEE, total energy expenditure; TPA, total physical activity; UK, United Kingdom; USA, United States of America; VPA, vigorous physical activity; yr, year. *p < 0.05. ^aA longitudinal design in stead of a cross-sectional design in the other studies.

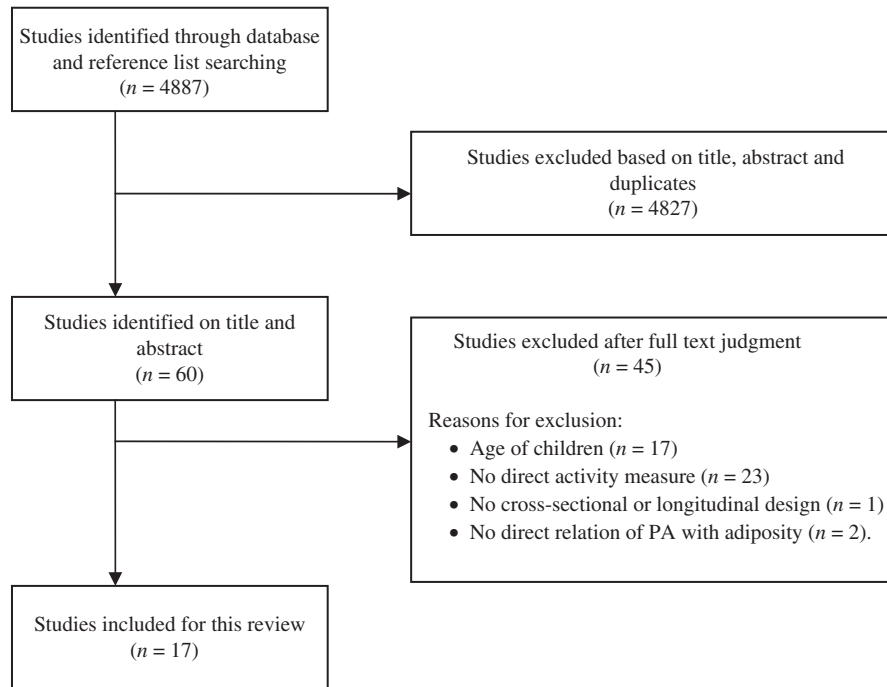


Figure 1. Flow diagram of the literature review strategy.

fitted the inclusion criteria. Participants' age, sample size, percentage boys and girls, countries where the studies were conducted, methods to assess physical activity and adiposity, statistical analysis and results are presented in Table I. In short, physical activity was mostly measured using accelerometers (28–38), but also using pedometers (39), heart rate monitoring (40), DLW method (41) and direct observation (36,42,43). Adiposity was measured with BMI, %BF or FM as outcome measures. %BF and FM were assessed by DXA, skin fold measurement and ^{18}O dilution method. The participants' age ranged from 1.5–7 years. Study size ranged from 44–438 participants. The studies were conducted in the USA, Europe, Asia and Australia.

The relation between physical activity and adiposity

Of all included studies, 29% (5/17) found an inverse relationship between physical activity and adiposity (34–37,41). One study found this relationship in boys, but not in girls (36); 12% (2/17) found a positive relationship between physical activity and adiposity (32,42); 59% (10/17) found no relationship between physical activity and adiposity (28–31,33,38,38–40,43). Since the inconsistency of the findings may be due to the methodology used to assess adiposity, the results are split by outcome measure of adiposity in the next sections.

Physical activity and percentage body fat

Of the eligible studies, 29% (5/17) used %BF to express adiposity (28,35,37,39,41). Sixty percent (3/5) of these found a significant inverse relationship between physical activity and %BF (35,37,41). Of those that found a significant relationship, two studied this relation cross-sectionally (35,41) and one studied this relation longitudinally (37). The other 40% (2/5) found a non-significant but inverse relationship between physical activity and %BF (28,39).

Physical activity and BMI

Of the eligible studies, 65% (11/17) used BMI and/or BMI Z-score to express adiposity (28, 30–34,36,38,40,42,44). Eighteen percent (2/11) of these found a significant inverse relationship (34,36). One of these two significant studies measured physical activity only during preschool hours and found this relationship only in boys, but not in girls (36). Sixty-four percent (7/11) found no significant relationship between BMI and/or BMI Z-score and physical activity (28,30,31,33, 38,40,44). Eighteen percent (2/11) found a positive significant relationship between BMI Z-score and physical activity (32,42). When taking BMI or BMI Z-score as a measure for adiposity, no association was found between physical activity and adiposity.

Physical activity and fat mass

Of the eligible studies, 24% (4/17) calculated the relation between physical activity and FM (28,29, 35,43). Twenty five percent (1/4) of them found an inversely significant relationship of total and vigorous physical activity with FM (35); 75% (3/4) found no significant relationship between physical activity and FM (28,29).

Gender differences

Only three out of 17 studies analyzed the relation between physical activity and %BF (35) or BMI (28,36) for boys and girls separately. Janz et al. found a similar significant inverse relationship of physical activity with %BF and FM for boys and girls (35). Trost et al. found that overweight boys were significantly less physically active compared to non-overweight boys, whereas in girls they found no differences (36). Heelan and Eisenmann found no relation between physical activity and BMI for both boys and girls (28).

Discussion

In contrast to the studies that used BMI as the outcome measure for adiposity, most studies (60%) that used %BF as outcome measure for adiposity found evidence for an inverse relationship between physical activity and adiposity in preschool children.

Physical activity and percentage body fat

According to the scheme proposed by Sallis et al. (27) there is enough evidence to state that there is an inverse association between %BF and physical activity. This is supported by the finding that the other 40% found inverse associations as well, although not significant. One (39) of the two studies that did not find a significant relationship used pedometers instead of accelerometers to assess physical activity. Pedometers may be less accurate than accelerometers in preschool children because they only detect the number of steps and not the intensity of vertical acceleration like in accelerometers (23). Furthermore, the daily physical activity of preschool children consists partly of walking but includes many other movements as well.

With regard to the type of physical activity, it has been suggested that vigorous physical activity may have a larger effect on adiposity in children than milder forms of activity (45). The participants in the cross-sectional study of Janz et al. (35) are the same as the baseline participants of the longitudinal study

of Janz et al. (37). They found in their cross-sectional analysis that in contrast to moderate physical activity, vigorous physical activity was related to the %BF. In addition in the longitudinal study this effect was also found in the relation with vigorous physical activity when the rate of change in %BF between baseline and follow-up was used. This is in line with studies in older children and adolescents that found that after adjustment for demographic factors, vigorous physical activity contributed to a lower %BF. For moderate physical activity this effect was not found (46,47).

The relationship between objectively measured physical activity and adiposity has been reviewed to a limited extent before by Jimenez-Pavon et al. (21). Due to the low number of studies in preschool children, they were not able to distinguish between the use of %BF or BMI in their analysis. In preschool children they found in three out of five studies a significant inverse relationship between physical activity and adiposity (21). In the total age group (age 0–18) they distinguished between adiposity measures. In 81% (25/31) of the studies that used simple proxies of adiposity as outcome measure (e.g., BMI), and in 76% (13/17) of the studies that used more precise body composition methods (e.g., DXA, skin folds and impedance) a significant inverse relationship between habitual physical activity and adiposity was found (21). Hawkins and Law (48) reviewed the relation between physical activity and adiposity in preschool children using studies that report on physical activity assessed by direct measurement of energy expenditure, observation or parental report. Only 41% reported an inverse relationship. This can be caused by the inclusion of studies using parental report to assess physical activity (48).

Physical activity and BMI

The studies that used BMI and/or BMI Z-score to express adiposity showed no relationship between physical activity and adiposity. In children, BMI is commonly used as an easy measure to identify adiposity. Cole et al. provided age and sex specific cut-off points for BMI in children that correspond to the adult cut off points of 25.0–29.9 kg/m² for overweight and above 30 kg/m² for obesity (49). These reference curves have become known as the International Obesity Taskforce standards (50). Another method to define overweight and obesity is by using percentiles. A BMI percentile from the 85th–95th percentile may be defined as overweight and a BMI above the 95th percentile is defined as obesity (e.g., Centers for Disease Control and Prevention (CDC) 2000 growth charts) (50). In addition to BMI, BMI Z-scores (BMI SD scores) are used to evaluate a child's BMI in terms of standard deviations from the mean for

children of the same age and gender. In children below 2 years of age, the weight-for-length percentiles are used to evaluate weight relative to linear growth. Weight-for-length above the 95th percentile in these children is defined as overweight (50). Despite that BMI is a commonly used measure to define overweight and obesity, its reliability is uncertain for this age group, in particular because BMI is not only dependent on fat mass but also on muscle mass. In relatively fat children, BMI can be a good indicator of excess adiposity. However, in children classified as overweight, a high BMI is more often explained by relatively large muscle mass (51,52) leading to frequent misclassification. Since more children in the included studies were overweight rather than obese, it is possible that misclassification for mild excess adiposity obscured the relation between BMI and physical activity. %BF may therefore be more useful to identify children with mild excess adiposity classified as overweight (53). The possibility for the use of waist circumference in this young age group should be explored as well for the future (54,55).

Physical activity and fat mass

The relationship between physical activity and fat mass (FM) is not clear from the published studies. The disadvantage of FM is that it is an absolute value. Since it does not take into account total body size, a large fat mass may be accompanied by a large muscle mass, which confounds the outcomes, especially for determinants like physical activity that are partly dependent on muscle mass. %BF is a better method, because it better reflects the body proportions.

Gender differences

Is there a difference in the relation of physical activity with adiposity between boys and girls? It is often found that preschool boys are more active than preschool girls (56), and girls have more body fat than boys (29,35,39). Of the three studies included in this review that analyzed the relation between physical activity and %BF (35) or BMI (28,36) for boys and girls separately, only one (36) found that overweight boys were significantly less physically active compared to non-overweight boys, whereas in girls they found no differences. This study measured physical activity only during preschool hours. As explanation the overall low activity levels in girls (floor effect) is suggested (36). An alternative explanation given is related to reverse causation, i.e., that boys engage in more vigorous-intensity activities, play in larger groups in more open settings, engage in more risk-taking behaviour, and play rougher games involving

greater amounts of body contact than girls (36). These types of activities may be more influenced by excess adiposity.

Methods to assess physical activity

When studying the relation between adiposity and physical activity, the challenge is to define both aspects as accurate as possible. Most of the included studies in this review used accelerometers to assess physical activity. Accelerometers measure time-varying differences in force or accelerations. They are able to assess total physical activity and differences in frequency, duration and intensity of physical activity (57). Accelerometers are small and lightweight and have been calibrated and validated in children (26,58–60). Most of the accelerometers in this review were uni-axial, measuring accelerations only in the vertical plane, to assess physical activity. In school-aged children there is no evidence that tri-axial or omni-directional accelerometers are more reliable than uni-axial accelerometers (61). In preschoolers, limited research has been carried out into the difference in capturing physical activity with either uni-axial or tri-axial accelerometers (62). It is possible that tri-axial accelerometers could be better at capturing total children's activity in young children since they tend to move in more directions at the same time than older children and adults (23). For example, the walking pattern in young children contains more horizontal components, because of a bigger step width (63). Tri-axial accelerometers seem to have a good reproducibility and a good validity, but there is limited information about the reproducibility and validity of tri-axial accelerometers in preschool children (61). We did not find studies using tri-axial accelerometers to assess the relation between physical activity and adiposity in preschool children.

Other methods used in the included studies in addition to accelerometers and pedometers were heart rate monitoring, PAL calculated from the DLW method and direct observation. Heart rate monitoring provides information about total energy expenditure and about the amount of time spent in high-intensity activity. It is a relatively cheap method to assess physical activity, but less feasible to use in preschool children. Another disadvantage is that heart rate is also affected by other factors than physical activity, such as emotional stress and high ambient temperature (64). The DLW method does not directly measure activity but is a valid and reliable measure for total energy expenditure in adults and children (65). After intake of double labelled water ($^2\text{H}_2^{18}\text{O}$), the ^{18}O is lost in body water and carbon dioxide, whereas ^2H is lost only in body water. The energy expenditure can be calculated from the

decays of ^2H and ^{18}O enrichment in body water, easily sampled as urine or saliva. Total energy expenditure can be used to calculate the physical activity level if the basal metabolic rate is assessed (66,67). In direct observation a researcher watches the subject and directly records physical activity. It assesses detailed information on children's physical activity patterns and types in variety of settings, including the ability to measure upper body movement. A disadvantage is the time-consuming and thus expensive data collection, so direct observation is less feasible for large-scale studies, or for individual data collections over extended periods of time (23). We expect that, in contrast with the issues on methodology to assess adiposity, the different direct methods to assess physical activity should all find a result in the same direction, despite the differences regarding their interpretation.

Longitudinal versus cross-sectional studies

From the cross-sectional studies in this review no definitive conclusion can be made about causal relationships. Two longitudinal studies were found on the relation between physical activity and adiposity measures. Only one study used %BF as measure for adiposity. They found an inverse relation between vigorous physical activity at baseline with the rate of change in %BF between baseline and follow-up (37). The other longitudinal study found no relation between physical activity, measured between 15:00 and 18:00 h, and the sum of 7 skinfold in mm as indicative measure for fat mass (43). In a review focused on the longitudinal association between physical activity and adiposity in adolescence, most studies showed protective effects of physical activity against adiposity, mainly in the participants who were already obese at baseline (68). Some studies in older children, adolescents and adults found no prospective association between physical activity and the development of adiposity (69). More longitudinal research on the predictive effect of physical activity of preschoolers on childhood obesity is necessary.

Strengths and limitations

As opposed to previous reviews, in this review it was possible to distinguish between studies using %BF or BMI in their analysis, with important consequences for the conclusion. A limitation is the low availability of longitudinal studies. Most studies in this review are cross-sectional and no definitive conclusions on cause and effect can be drawn. However these results indicate that longitudinal and intervention studies are needed and indicated. Another limitation is that relevant studies may have been

missed due to publication bias or because they were not published in English.

Conclusion

The present evidence suggests that physical activity is inversely related to %BF at very young age. The associations between physical activity and BMI as a measure of adiposity in preschool children remain elusive. Further studies using direct methods to measure physical activity and using %BF to define adiposity are needed to draw firm conclusions.

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