Original Article
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Obesity

A Longitudinal Study of Gross Motor Coordination and Weight Status in Children

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Objective: This longitudinal study investigated the interrelationship between children's weight status and level of gross motor coordination over time, taking baseline physical activity (PA) into account as a possible mediator.

Methods: Baseline measurements were collected in 2517 children (5-13 years, 52.8% boys), including (1) body height and weight to calculate body mass index (BMI) *z*-scores, (2) gross motor coordination using the Körperkoordinationstest für Kinder (KTK), (3) total PA estimated by a questionnaire. At follow-up, 754 participants (7-13 years, 50.8% boys) underwent anthropometric and KTK assessments again. Two hypothesized partial mediation models (i.e., KTK $\leftrightarrow$ PA $\leftrightarrow$ BMI *z*-score) were examined by multiple linear mixed models.

Results: A lower performance on the KTK at baseline significantly predicted an increase in BMI *z*-score ($B = -0.003$, $P = 0.027$). Conversely, a higher baseline BMI *z*-score also predicted a decrease in KTK performance ($B = -1.792$, $P < 0.001$). Since total PA at baseline was not significantly related to initial KTK performance ($B = 1.628$, $P = 0.134$) nor BMI *z*-score ($B = 25.312$, $P = 0.130$), its mediating effect was not further explored.

Conclusions: Our results strongly suggest that children's weight status negatively influences future level of gross motor coordination, and vice versa. Prevention and intervention initiatives should consider this reciprocal causal relationship across developmental time.

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Introduction

In the past few decades, a number of worrying findings occurred concerning the pediatric population across the world. Although some geographical variation is shown, the overall prevalence of childhood overweight and obesity is considerably high (1,2). Despite the well known and important health benefits of physical activity (PA) for youth, many of today's children do not meet established PA guidelines and spend a considerable amount of their time on sedentary pursuits (3-5). In addition, there are also indications for a secular decline in children's motor skill performance and coordination as early as preschool age (6,7). To date, however, it is still unclear to what extent these global changes are interconnected and/or mutually reinforcing.

Only in the past decade, there has been an increasing interest in the relationship of motor competence and weight status from (early) childhood to adolescence. Evidence from multiple cross-sectional studies clearly indicates an inverse association between both factors (8,9). Regardless of motor assessment tool and body mass index (BMI) based classification method being used, lower fundamental motor skill mastery (i.e., qualitative measures related to movement execution) as well as poorer performances on gross motor skill and coordination tests (i.e., quantitative measures related to motor outcome) have been consistently reported in overweight and obese children as compared to healthy-weight peers and/or age-related standards (10-16). Such weight status related impairment in motor development starts to manifest itself in the preschool population (17-20). In addition, it has been suggested that—if no action is taken—a widening gap in gross motor performance occurs over time with a more pronounced detrimental effect of excess body weight and fatness with increasing age (12). Cross-sectional studies using BMI (*z*-score) as a continuous rather than a categorical variable also demonstrated negative correlations with gross motor skill and coordination in typically developing (young) children (11,16,17,21,22).

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Many authors have already stressed the crucial need for longitudinal research on the topic to understand the causal nature of this adverse relationship (13,14,16,18,23). Given that both childhood overweight and obesity as well as lower motor skill levels have been linked with less active lifestyles (24-27), PA might act as an important mediator (8,28,29). As noted by Wrotniak et al. (30), children with poorer motor skills are less likely to be physically active and probably drawn to more sedentary pursuits, which subsequently may lead to the development of overweight and obesity. Conversely, excess body weight and fatness could also make movement more difficult hindering the development of adequate motor skill levels as children become more inactive. Therefore, lower motor competence can be considered both a precursor and/or a consequence of being overweight or obese with reduced PA levels as the possible influencing mechanism (28,29,31). Hence, the purpose of this 2-year longitudinal study was to clarify the potentially reciprocal causal relationship between weight status and level of gross motor coordination in a representative sample of primary school children, taking into account related changes over time as well as the possible mediating role of baseline PA.

Methods

Study design and participants

This longitudinal study represents a secondary analysis of data from a large-scale project (i.e., the Flemish Sports Compass) in which anthropometric characteristics and gross motor coordination levels of primary school children were evaluated at two points in time (i.e., baseline and follow-up), separated by an interval of 2 years. Baseline data were collected in the autumn of 2007, covering a total sample of 2517 pupils (aged 5 to 13 years, with 52.8% boys) from 28 randomly selected primary schools for general education across Flanders and the Brussels-Capital region (Belgium) with geographic area (i.e., rural/city) and school type (i.e., Catholic/public) evenly distributed. From a time-economic point of view, it was not possible to retest all pupils so that only about half of the schools ($N = 13$) was invited for the longitudinal monitoring using the same selection criteria to ensure a representative sample. Accordingly, at follow-up in the autumn of 2009, 754 (i.e., 30.0%) of the original participants (aged 7-13 years, with 50.8% boys) underwent anthropometric and gross motor coordination assessments again at their respective schools. Written informed consent was obtained from the parent(s) or guardian of every child included in the study, which was also approved by the Ghent University Hospital Ethical Committee.

Measurements

Assessments of anthropometry and children's level of gross motor coordination took place in the gymnasium of the school at the moment of physical education classes and were conducted by a group of qualified examiners using standardized instructions. During the test administration, participants wore light sportswear and were barefoot. At baseline, all children were also asked to complete a self-administered questionnaire at home together with their parent(s) or guardian to obtain socio-demographic information and to determine PA levels in diverse domains. The filled out questionnaires were collected back in school.

Anthropometry. Body height (0.1 cm) was measured using a portable stadiometer (Harpenden, Holtain, Crymych, UK) and body weight (0.1 kg) was determined by means of a digital scale (Tanita, BC-420 SMA, Tokyo, Japan). From these measurements, participants' BMI was calculated as body weight divided by squared height (kg/m^2). Additionally, BMI z-scores were computed based upon the Flemish growth curves (32) to serve as a proxy measure of adiposity adjusted for age and gender, expressing the number of standard deviation units an individual child's BMI is deviated from the reference population mean. The use of BMI z-scores does not only allow to determine one's relative position with respect to peers at a single occasion, but has the additional advantage to point out positive or negative changes in adiposity within subjects over time.

Gross motor coordination. The level of gross motor coordination was evaluated by means of the Körperkoordinationstest für Kinder (KTK), which is a standardized German test battery consisting of four test items: (1) walking backward along balance beams of decreasing width: 6.0, 4.5, and 3.0 cm (KTK_{BEAM}), (2) moving sideways on wooden boards during 20 sec (KTK_{BOARD}), (3) one-legged hopping over a foam obstacle with increasing height in consecutive steps of 5 cm (KTK_{HOP}), and (4) two-legged jumping from side to side during 15 sec (KTK_{JUMP}) (33,34). Using age- and gender-specific reference values, the raw performance score on each item can be converted into a standardized score. The addition of these latter scores yields a total motor quotient (MQ) that reflects a child's overall level of gross motor coordination, ranging from "talented" to "motor-impaired" (33,34). Given that all items of this nonsport specific test battery are identical regardless of age within the range of 5-15 years, the KTK is a very useful tool for longitudinal research and has been shown to be a highly reliable and valid instrument (7,33-35).

Physical activity questionnaire. Socio-demographic data and information on children's PA levels were obtained only at baseline using a self-administrated questionnaire based on the Flemish physical activity questionnaire (FPAQ) (36). The pen-and-paper version of this questionnaire has been shown to be a reliable and reasonably valid instrument to assess different dimensions of usual PA and sedentary behavior in children, especially when completed with parental assistance (37). The FPAQ consists of items regarding active transportation (i.e., average time spent on cycling, walking, and/or skating to and from school and during leisure time; expressed in minutes per week), PA at school (i.e., average time spent in sports or physical activities during playtime, lunch and after school hours as well as during physical education lessons; expressed in minutes per week), and PA in leisure time (i.e., average time spent in both organized and nonorganized sport during leisure time; expressed in minutes per week). Combining the aforementioned PA related items, the amount of total PA (min/week) at baseline could be determined. Within the total sample of 2517 pupils, this particular variable could only be calculated for 795 children (i.e., 31.6%), including 242 of the 754 followed-up participants (i.e., 32.1%), who correctly completed and returned the questionnaire.

Statistical analysis

Data were analyzed using SPSS Statistics 20.0 (SPSS, Chicago, IL), with the significance level set at $P < 0.05$. Independent samples t-tests were used to compare the descriptive statistics of the main variables at baseline between participants who were not followed-up and/or dropped-out of the study (i.e., subsample 1) and the followed-up participants (i.e., subsample 2). Within this latter

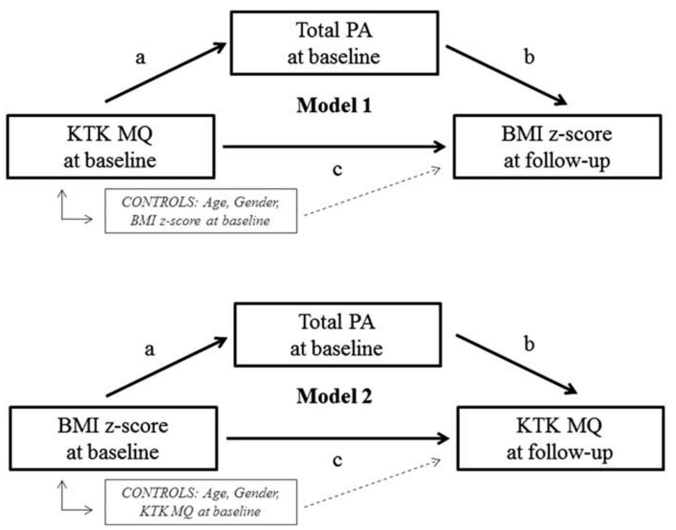

Figure 1 The hypothesized partial mediation models 1 and 2 of this study, in which "a" represents the relation of the predictor variable to the mediator variable, "b" the relation of the mediator variable to the criterion variable, and "c" the relation of the predictor variable to the criterion variable.

subsample, between-group differences on baseline variables for respondents vs. nonrespondents to the PA questionnaire were examined in the same way.

Pearson correlation coefficients were also calculated within the subsample of followed-up participants to study the association between anthropometric, gross motor coordination and baseline PA measures and, where applicable, to evaluate the stability over time. Subsequently, multiple linear regression analyses were conducted to investigate the potentially reciprocal causal relationship between children's BMI z-scores and KTK MQ, also examining whether total PA at baseline acts as a mediator variable between both factors (see Figure 1).

The hypothesized partial mediation models were tested by means of the causal steps introduced by Baron and Kenny (38). More specifically, linear mixed models were used with school included as the random factor to consider clustering of children within schools. Accordingly, the first series of linear regression analyses examined (1) the c-coefficient or the relation of baseline KTK MQ with BMI z-score at follow-up after controlling for age, gender, and BMI z-score determined at baseline, (2) the a-coefficient or the relation of baseline KTK MQ with baseline total amount of PA, and (3) the b-coefficient or the relation of total PA at baseline with BMI z-score at follow-up (i.e., Model 1). Likewise, the second series of linear regression analyses examined (1) the c-coefficient or the relation of baseline BMI z-score with KTK MQ at follow-up after controlling for age, gender, and KTK MQ measured at baseline, (2) the a-coefficient or the relation of baseline BMI z-score with baseline total amount of PA, and (3) the b-coefficient or the relation of total PA at baseline with KTK MQ at follow-up (i.e., Model 2). Finally, the mediated effect of the total amount of PA at baseline had to be estimated for both models.

Results

Descriptive statistics of the main variables are presented in Table 1 for both subsamples of participants measured at baseline and/or follow-up. Independent samples t-tests revealed significantly higher age, ($t_{(2000.636)} = 19.040$; $P < 0.001$) and BMI ($t_{(1806.562)} = 7.824$; $P < 0.001$) at baseline in the subsample of participants that were not followed-up or dropped-out ($N = 1763$) compared to the subsample that could be followed longitudinally ($N = 754$), with a similar trend found for baseline BMI z-score ($t_{(1547.430)} = 1.775$; $P = 0.076$). Baseline KTK MQ ($t_{(1532.152)} = -0.821$; $P = 0.412$) and body fat percentage ($t_{(1752.435)} = 1.395$; $P = 0.163$) were found to be comparable between both groups. Within the subsample of followed-up participants ($N = 754$), significant between-group differences were also found for respondents ($N = 242$) vs. nonrespondents ($N = 512$) to the PA questionnaire at baseline. The respondents had a significantly lower BMI (16.12 ± 1.95 vs. 16.48 ± 2.28 kg/m^2; $t_{(752)} = 2.094$; $P = 0.037$), BMI z-score (-0.10 ± 0.90 vs. 0.06 ± 0.90; $t_{(752)} = 2.352$; $P = 0.019$) and body fat percentage (17.9 ± 4.6 vs. $19.2 \pm 5.2\%$; $t_{(752)} = 3.366$; $P = 0.001$) as well as higher KTK MQ (98.0 ± 14.0 vs. 95.3 ± 14.7; $t_{(752)} = -2.358$; $P = 0.019$) at baseline as compared to the nonrespondents. No significant age difference between both groups of followed-up children was found (8.3 ± 1.1 vs. 8.2 ± 1.2 years; $t_{(752)} = 1.539$; $P = 0.130$).

TABLE 1 Descriptive characteristics of both subsamples of participants measured at baseline and/or follow-up.

	Subsample 1 (~ not followed-up and/or dropped-out)			Subsample 2 (~ followed-up)					
	BASELINE			BASELINE			FOLLOW-UP		
Variables	N	Mean ± SD	Range	N	Mean ± SD	Range	N	Mean ± SD	Range
Age (years)	1763	9.4 ± 1.7	5.8-13.4	754	8.3 ± 1.2	5.9-11.0	754	10.3 ± 1.2	7.9-13.0
BMI (kg/m^2)	1763	17.18 ± 2.80	11.65-34.13	754	16.37 ± 2.18	12.63-28.89	754	17.45 ± 2.89	12.72-32.54
BMI z-score	1763	0.08 ± 0.98	−5.19-3.31	754	0.01 ± 0.90	−2.79-2.78	754	−0.01 ± 0.99	−2.83-2.71
KTK MQ	1763	95.6 ± 15.7	35.0-138.0	754	96.1 ± 14.5	48.0-138.0	754	101.5 ± 15.8	38.0-141.0
Body fat (%)	1761	19.1 ± 6.3	7.2-44.1	754	18.8 ± 5.1	8.1-40.0	754	18.8 ± 6.4	6.5-42.4
Total PA (min/week)	553	496.2 ± 258.3	54.0-1522.0	242	432.0 ± 235.1	54.0-1302.0	-	-	-

SD, standard deviation; BMI, body mass index; KTK, Körperkoordinationstest für Kinder; MQ, motor quotient; PA, physical activity.

TABLE 2 Pearson correlations between BMI *z*-score, KTK MQ, and total PA at baseline within the subsample of followed-up participants.

Variables	*N*	BMI *z*-score at baseline	BMI *z*-score at follow-up	KTK MQ at baseline	KTK MQ at follow-up	Total PA at baseline
Anthropometric						
BMI *z*-score at baseline	754	-				
BMI *z*-score at follow-up	754	0.865[a]	-			
Gross motor coordination						
KTK MQ at baseline	754	−0.249[a]	−0.252[a*]	-		
KTK MQ at follow-up	754	−0.297[a]	−0.368[a]	0.797[a]	-	
Physical activity						
Total PA at baseline	242	0.094	0.094	0.103	0.074	-

BMI, body mass index; KTK, Körperkoordinationstest für Kinder; MQ, motor quotient; PA, physical activity.
[a]$P \leq 0.001$.

Table 2 shows the Pearson correlation coefficients of BMI *z*-score and KTK MQ at both test moments as well as total PA at baseline for the participants who were followed-up. Significant and highly positive correlations illustrated good stability for both anthropometric and gross motor coordination measures over time. In addition, significant and moderately negative correlations indicated an inverse association between both variables at each time point as well as over the 2-year period of the study. No significant correlations with total PA at baseline were found.

Results of the first and second series of regressions using linear mixed model analyses are displayed in Tables 3 and 4, respectively. With regard to the first series, the c-coefficient analysis indicated a significant negative effect of baseline KTK MQ on later BMI *z*-score, independent of age, gender, and BMI *z*-score at baseline (i.e., Model 1c). However, the a-coefficient analysis revealed that the total amount of PA at baseline was not related to initial KTK MQ (i.e., Model 1a), excluding any further steps in establishing mediation. Looking at the reverse causal pathway in the second series, the c-coefficient analysis also demonstrated a significant negative effect of baseline BMI *z*-score on later KTK MQ, independent of age, gender, and KTK MQ at baseline (i.e., Model 2c). Yet again, the total amount of PA at baseline was not related to initial BMI *z*-score as shown by the a-coefficient analysis (i.e., Model 2a), which ruled out a further test of mediation.

Discussion

The results of this 2-year longitudinal study indicate the presence of a reciprocal causal relationship between children's weight status and their level of gross motor coordination across developmental time. In particular, a lower KTK performance at baseline translated into an increase in BMI *z*-score over time, while a higher baseline BMI *z*-score in turn predicted a decrease in subsequent KTK performance. In both proposed models, no mediating effect of self-reported PA at baseline could be demonstrated within limits of this particular study.

A substantial number of children for whom data were collected at baseline did not or were unable to take part in both anthropometric and gross motor coordination assessments at follow-up as only half of the schools were part of the longitudinal monitoring. In addition,

TABLE 3 Results of the first series of regressions using linear mixed model analyses (Model 1, c- and a-coefficient [see Figure 1]).

Variable	Unstandardized Coefficient		*t*-test	
	B (SE)	95% CI	*t*-value	*P*-value
Model 1c ($N = 754$), criterion: BMI *z*-score at follow-up				
KTK MQ at baseline	−0.003 (0.001)	−0.005; 0.000	−2.210	0.027
Age	0.008 (0.016)	−0.023; 0.039	0.501	0.616
Gender	0.058 (0.036)	−0.138; 0.129	1.585	0.133
BMI *z*-score at baseline	0.939 (0.021)	0.898; 0.980	45.411	<0.001
Mode 1a ($N = 242$), criterion: Total amount of PA at baseline				
KTK MQ at baseline	1.628 (1.081)	−0.503; 3.759	1.505	0.134

SE, standard error; CI, confidence interval; BMI, body mass index; KTK, Körperkoordinationstest für Kinder; MQ, motor quotient; PA, physical activity.

TABLE 4 Results of the second series of regressions using linear mixed model analyses (Model 2, c- and a-coefficient [see Figure 1]).

	Unstandardized Coefficient		t-test	
Variable	*B* (SE)	95% CI	*t*-value	*P*-value
Model 2c (*N* = 754), criterion: KTK MQ at follow-up				
BMI *z*-score at baseline	−1.792 (0.385)	−2.547; −1.036	−4.655	<0.001
Age	0.385 (0.298)	−0.199; 0.970	1.295	0.196
Gender	−1.282 (0.681)	−2.619; 0.054	−1.883	0.060
KTK MQ at baseline	0.842 (0.025)	0.792; 0.892	33.072	<0.001
Model 2a (*N* = 242), criterion: Total amount of PA at baseline				
BMI *z*-score at baseline	25.312 (16.639)	−7.467; 58.091	1.521	0.130

SE, standard error; CI, confidence interval; KTK, Körperkoordinationstest für Kinder; MQ, motor quotient; BMI, body mass index; PA, physical activity.

a fairly amount of children had already left primary school or moved to another school, while others were absent at school or physically injured on the day of retesting or had no renewed consent. Compared to the subsample of participants who were followed-up, they only showed a trend for higher BMI *z*-scores (adjusted for age and gender) in addition to similar KTK MQ at baseline. Given that the majority of children not taking part in follow-up assessments simply made the transition to secondary school, the finding of their older age and concomitant higher absolute BMI can be easily explained. So, despite the considerable loss of participants from baseline to follow-up, a very comparable group of 754 children continued to participate in the study and was subjected to our further statistical analyses.

Significant inverse associations within the subsample of followed-up participants between BMI *z*-scores and KTK MQ at each point in time (i.e., baseline and follow-up) as well as over the 2-year course of this study add to the body of evidence from numerous cross-sectional studies (11,16,17,21,22). However, to determine the causal and/or bidirectional nature of this adverse relationship longitudinal research is required (13,14,16,18,23). To our knowledge, only two of such studies using the same nonsport specific test battery were conducted in middle to late childhood (23,39). D'Hondt et al. (23) found that children's actual BMI is a significant predictor of future KTK performance, explaining 37.6% of its variance (with $N = 100$, from 6-10 to 8-12 years of age). The evolution in gross motor coordination level also appeared to be strongly related to their invariant weight status (i.e., being normal-weight, overweight or obese at baseline and continued throughout that study). Furthermore, Lopes et al. (39) documented that the level of gross motor coordination significantly predicts changes in subcutaneous adiposity, with a smaller increase for children who had better KTK performance (with $N = 285$, from 6 to 10 years of age). Accordingly, it seems that a child's weight status negatively influences motor competence, and vice versa.

The present longitudinal study is the first to examine this association more in depth, taking into account changes over time as well as the possible mediating role of baseline PA. This latter factor is more than likely to impact upon motor (in)competence as well as the risk to develop overweight or obesity over time (15,24-27). Our results substantiate the point of reverse causality by demonstrating that among the followed-up participants higher baseline BMI *z*-scores resulted in a decrease in KTK MQ's, whereas at the same time lower baseline KTK MQ's resulted in an increase in BMI z-scores over 2 years. The fact that the parameter estimates for the respective c-coefficient were not very prominent is due to controlling each of these linear mixed model analyses for the criterion variable at baseline and its change to follow-up in addition to age and gender. Furthermore, even stronger effects may be expected when only overweight and obese children would be included to the study sample instead of conducting the research in a general pediatric population. Within the present followed-up subsample, the nonrespondents also appeared to be slightly heavier and less motor competent as compared to the respondents of the PA questionnaire. Since the total amount of PA at baseline was not found to be related to both baseline KTK MQ and BMI *z*-score, this factor could not be considered a mediator variable in the established reciprocal causal relationship within limits of this particular study. Regardless thereof, it can be assumed that children carrying a relatively larger amount of body weight as compared to their peers experience more movement related difficulties yielding a decline in gross motor skill performance (12,15). Based on our results, however, the reverse effect also appears to be true with less motor competent children being more likely to experience relatively greater weight gain (14,39). In summary, there is now evidence that during childhood overweight and low motor competence go together affecting each other across developmental time, while both elements may be caused by unknown, unobserved or not objectively measured factors.

The strengths of this study include its longitudinal design, the presence of a relatively large (sub)sample from randomly selected Flemish primary schools and well-validated outcome measures. It is also noteworthy to establish differences in the evolution of BMI *z*-score dependent on initial KTK MQ, and vice versa, over a limited time frame of only 2 years. However, some limitations should also be mentioned. Given the amount of missing data and the subtle differences between subsamples (i.e., no longer observed and/or drop-out vs. follow-up), some caution is warranted on the interpretation and generalizability of our findings. Using the product-oriented and nonsport specific KTK, we only evaluated gross motor skill performance, which is more likely to be affected by excess body weight and fatness. However, there are also some indications for movement difficulties among overweight and obese children in the area of fine motor and object control skill (11,13,17,40), that may as well be associated with PA participation (29,31). The level of total PA at baseline was not objectively measured (e.g., by accelerometry), but only estimated based on self-reported data with only about 30% of the participants correctly completing and returning the questionnaire. Younger children might have poor recall and parent report of children's PA at school might be confined. Moreover, PA survey data were not collected at follow-up. These shortcomings may explain the somewhat counterintuitive finding of PA not acting as a mediator variable between children's BMI *z*-score and KTK MQ. Based upon current literature (24-29,31), the intermediate role of PA with respect the demonstrated reverse causality between both factors certainly warrants further investigation.

Allowing for limitations, however, the present 2-year longitudinal study strongly suggests that children's weight status negatively influences their future level of gross motor coordination, and vice versa. The provisional finding that self-reported level of total PA at baseline did not mediate this reciprocal causal relationship across developmental time is probably due to particular study limitations. Therefore, it is recommended that future research attempts to reveal the possible intermediate determinants in the interest of targeted interventions preventing the occurrence of such a negative spiral during childhood. Anyhow, an early identification of children with a high BMI (*z*-score) and/or low motor skill competence appears to be critical because of the risk for developing poor(er) motor coordination and overweight or obesity, respectively. O

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References

1. Wang Y, Lobstein T. Worldwide trends in childhood overweight and obesity. *Int J Pediatr Obes* 2006;1:11-25.
2. Low S, Chin MC, Deurenberg-Yap M. Review on epidemic of obesity. *Ann Acad Med Singapore* 2009;38:57-65.
3. Pate RR, Freedson PS, Sallis JF, Taylor WC, Sirard J, Trost SG, et al. Compliance with physical activity guidelines: prevalence in a population of children and youth. *Ann Epidemiol* 2002;12:303-308.
4. Strong WB, Malina RM, Blimkie CJR, Daniels SR, Dishman RK, Gutin B, et al. Evidence based physical activity for school-age youth. *J Pediatr* 2005;146:732-737.
5. Hills AP, King NA, Armstrong TP. The contribution of physical activity and sedentary behaviours to the growth and development of children and adolescents—Implications for overweight and obesity. *Sports Med* 2007;37:533-545.
6. Roth K, Ruf K, Obinger M, Mauer S, Ahnert J, Schneider W, et al. Is there a secular decline in motor skills in preschool children? *Scand J Med Sci Sports* 2010; 20:670-678.
7. Vandorpe B, Vandendriessche J, Lefevre J, et al. The Körperkoordinationstest für Kinder: Reference values and suitability for 6- to 12-year old children in Flanders. *Scand J Med Sci Sports* 2011;21:378-388.
8. Lubans DR, Morgan PJ, Cliff DP, Barnett LM, Okely AD. Fundamental movement skills in children and adolescents—Review of associated health benefits. *Sports Med* 2010;40:1019-1035.
9. Tsiros MD, Coates AM, Howe PRC, Grimshaw PN, Buckley JD. Obesity: the new childhood disability? *Obes Rev* 2011;12:26-36.
10. Okely AD, Booth ML, Chey T. Relationships between body composition and fundamental movement skills among children and adolescents. *Res Q Exerc Sport* 2004;75:238-247.
11. D'Hondt E, Deforche B, De Bourdeaudhuij I, Lenoir M. Relationship between motor skill and body mass index in 5- to 10-year-old children. *Adapt Phys Activ Q* 2009;26:21-37.
12. D'Hondt E, Deforche B, Vaeyens R, Vandorpe B, Vandendriessche J, Pion J, et al. Gross motor coordination in relation to weight status and age in 5- to 12-year-old boys and girls: a cross-sectional study. *Int J Pediatr Obes* 2011;6:e556-e564.
13. Cliff DP, Okely AD, Morgan PJ, Jones RA, Steele JR, Baur LA. Proficiency deficiency: mastery of fundamental movement skills and skill components in overweight and obese children. *Obesity (Silver Spring)* 2012;20:1024-1033.
14. Poulsen AA, Desha L, Ziviani J, Griffiths L, Heaslop A, Khan A, et al. Fundamental movement skills and self-concept of children who are overweight. *Int J Pediatr Obes* 2011;6:e464-e471.
15. Hardy LL, Reinten-Reynolds T, Espinel P, Zask A, Okely AD. Prevalence and correlates of low fundamental movement skill competency in children. *Pediatrics* 2012;130:e390-e398.
16. Castetbon K, Andreyeva T. Obesity and motor skills among 4 to 6-year-old children in the United States: nationally-representative surveys. *BMC Pediatr* 2012;12:28-36.
17. Morano M, Colella D, Caroli M. Gross motor skill performance in a sample of overweight and non-overweight preschool children. *Int J Pediatr Obes* 2011;6:42-46.
18. Nervik D, Martin K, Rundquist P, Cleland J. The relationship between body mass index and gross motor development in children aged 3 to 5 years. *Pediatr Phys Ther* 2011;23:144-148.
19. Krombholz H. The motor and cognitive development of overweight preschool children. *Early Years* 2012;32:61-70.
20. Logan SW, Scrabis-Fletcher K, Modlesky C, Getchell N. The relationship between motor skill proficiency and body mass index in preschool children. *Res Q Exerc Sport* 2011;82:442-448.
21. Graf C, Koch B, Kretschmann-Kandel E, Falkowski G, Christ H, Coburger S, et al. Correlation between BMI, leisure habits and motor abilities in childhood (CHILT-Project). *Int J Obes* 2004;28:22-26.
22. Lopes V, Stodden DF, Bianchi MM, Maia JAR, Rodrigues LP. Correlation between BMI and motor coordination. *J Sci Med Sport* 2012;15:38-43.
23. D'Hondt E, Deforche B, Gentier I, et al. A longitudinal analysis of gross motor coordination in overweight and obese children versus normal-weight peers. *Int J Obes* 2013;37:61-67.
24. Jimenez-Pavon D, Kelly J, Reilly JJ. Associations between objectively measured habitual physical activity and adiposity in children and adolescents: systematic review. *Int J Pediatr Obes* 2010;5:3-18.
25. Deforche B, De Bourdeaudhuij I, D'Hondt E, Cardon G. Objectively measured physical activity, physical activity related personality and body mass index in 6- to 10-yr-old children: a cross-sectional study. *Int J Behav Nutr Phys Act* 2009;6: 25-33.
26. Wrotniak BH, Epstein LH, Dorn JM, Jones KE, Kondilis VA. The relation between motor proficiency and physical activity in children. *Pediatrics* 2006;118:e1758-e1765.
27. Kambas A, Michalopoulou M, Fatouros IG, Christoforidis C, Manthou E, Giannakidou D. The relationship between motor proficiency and pedometer-determined physical activity in young children. *Pediatr Exerc Sci* 2012;24: 34-44.
28. Stodden DF, Goodway JD, Langendorfer SJ, Roberton MA, Rudisill ME, Garcia C, et al. A developmental perspective on the role of motor skill competence in physical activity: An emergent relationship. *Quest* 2008;60:290-306.
29. Barnett LM, Morgan PJ, van Beurden E, Ball K, Lubans DR. A reverse pathway? Actual and perceived skill proficiency and physical activity. *Med Sci Sports Exerc* 2011;43:898-904.
30. Wrotniak BH, Littlefield M. Commentary on "The relationship between body mass index and gross motor development in children aged 3 to 5 years". *Pediatr Phys Ther* 2011;23:149.
31. Barnett LM, van Beurden E, Morgan PJ, Brooks LO, Beard JR. Childhood motor skill proficiency as a predictor of adolescent physical activity. *J Adolesc Health* 2009;44:252-259.
32. Roelants M, Hauspie R, Hoppenbrouwers K. References for growth and pubertal development from birth to 21 years in Flanders (Belgium). *Ann Hum Biol* 2009;36: 680-694.
33. Kiphard EJ, Schilling F. *Körperkoordinationstest für Kinder: Manual*. Weinheim, Germany: Beltz Test GmbH; 1974.
34. Kiphard EJ, Schilling F. *Körperkoordinationstest für Kinder. Überarbeitete und ergänzte Auflage*. Göttingen, Germany: Beltz Test GmbH; 2007.
35. Smits-Engelsman BCM, Henderson SE, Michels CGJ. The assessment of children with developmental coordination disorders in the Netherlands: the relationship between the movement assessment battery for children and the Körperkoordinationstest für Kinder. *Hum Mov Sci* 1998;17:699-709.
36. Philippaerts RM, Matton L, Wijndaele K, Balduck AL, De Bourdeaudhuij I, Lefevre J. Validity of a physical activity computer questionnaire in 12- to 18-year-old boys and girls. *Int J Sports Med* 2006;27:131-136.

37. Verstraete SJM, Cardon GM, Trost SG, De Bourdeaudhuij I. Reliability and validity of a questionnaire to measure usual physical activity in children with and without parental assistance. In: Verstraete SJM, ed. *The Effectiveness of an Intervention Promoting Physical Activity in Elementary School Children*. Zelzate, Belgium: DCL Print & Sign; 2006.

38. Baron RM, Kenny DA. The moderator-mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. *J Pers Soc Psychol* 1986;51:1173-1182.

39. Lopes VP, Maia JAR, Rodrigues LP, Malina R. Motor coordination, physical activity and fitness as predictors of longitudinal change in adiposity during childhood. *Eur J Sport Sci* 2012;12:384-391.

40. D'Hondt E, Deforche B, De Bourdeaudhuij I, Lenoir M. Childhood obesity affects fine motor skill performance under different postural constraints. *Neurosci Lett* 2008;440:72-75.