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ABSTRACT

REMMERS, T., E. F. C. SLEDDENS, J. S. GUBBELS, S. I. DE VRIES, M. MOMMERS, J. PENDERS, S. P. J. KREMERS, and C. THIJS. Relationship between Physical Activity and the Development of Body Mass Index in Children. *Med. Sci. Sports Exerc.*, Vol. 46, No. 1, pp. 177–184, 2014. **Purpose**: Studies estimating the contribution of physical activity (PA) to the development of body mass index (BMI) in critical periods of childhood are warranted. Therefore, we have prospectively investigated this relationship in boys and girls of the KOALA Birth Cohort study, the Netherlands, in the period around adiposity rebound (i.e., 4–9 yr old). **Methods**: PA was assessed in 470 children (231 boys, 239 girls) using accelerometers at the ages of 5 and 7 yr, and height and weight were measured at 5, 7, and 9 yr. BMI *z*-scores were calculated to standardize for age and sex. Leaner and heavier children were classified according to the 25th and 75th percentile of our study sample. To examine longitudinal relationships between PA and BMI *z*-scores, generalized estimating equation analyses were performed and stratified for sex and baseline weight status (leaner, normal weight, and heavier children). **Results**: In heavier children, an increment of 6.5 min of moderate to vigorous PA (MVPA) was related to a subsequent decrease of 0.03 BMI *z*-scores both in boys (95% confidence interval = −0.07 to −0.001) and girls (95% confidence interval = −0.05 to −0.002). Light PA was also associated with a decrease of BMI in heavier boys but not girls. In normal weight children, MVPA was associated with decrease of BMI in boys but not girls. **Conclusion**: Increments of MVPA were associated with decreases in BMI *z*-score in heavier children, both boys and girls. Promoting MVPA should remain a major prevention vehicle for improving body composition in 4- to 9-yr-old children. **Key Words:** CHILD, BODY MASS INDEX, COHORT STUDIES, ACCELEROMETER, PHYSICAL ACTIVITY

The Netherlands is no exception to the worldwide trend of rising childhood overweight and obesity. In 2- to 21-yr-old Dutch boys, overweight and obesity rose from 9.4% in 1997 to 13.3% in 2009. In girls of the same age, prevalence rose from 11.9% to 14.9% (32).

Childhood overweight and obesity leads to various risk factors, both short-term (e.g., decreased cardiovascular fitness, depression, body dissatisfaction, and social isolation) (11) and long-term consequences (e.g., decreased insulin sensitivity) (7), resulting in a higher combined metabolic- and cardiovascular risk. In addition, childhood overweight and obesity, and the accompanying consequences, tend to persist into adolescence and adulthood (34), leading to considerably higher healthcare costs for the general population (35). Hence, the improvement of childhood body composition will provide major benefits for the current and future health of these children. Examining key determinants and critical periods for the prevention of an unhealthy body composition is an important topic in pediatric research.

Children may be more vulnerable to the development of overweight at certain stages of childhood (23). After a rapid increase in body fat in the first 2 yr, a second naturally occurring increase in body fat (i.e., the adiposity rebound) is identified as a critical period in the development of subsequent adiposity (9). In normal circumstances, the adiposity rebound initiates at around the age of 5–6 yr. An earlier occurrence of this rebound period has been found to be associated with a greater skinfold thickness and body mass index (BMI) at later ages (27,39). Hence, 5- to 6-yr-old children are an important target group for examining the effect of determinants on the development of body composition (9).

Considering the relatively high incidence of overweight in children in the last two decades, the etiology of the present epidemic is more likely to be caused by energy metabolism-related behaviors than genetic influences (25). Earlier studies that have investigated the relationship between energy expenditure and body composition have generally found that higher energy expenditure is related to less accumulation of body fat in children (14); however, more recent evidence for this association is less clear (40). Research concerning more

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specific measures of energy metabolism-related behaviors, such as physical activity (PA), may therefore provide more meaningful results (14).

PA behavior can be specified according to its duration, frequency, type, and intensity (23). The PA behavior of children is considered less structured than of adults, containing relatively short bouts of intense, spontaneous PA behavior (23,40). Because this type of PA behavior is difficult to observe, the usage of subjective measurements (e.g., parental reports) is prone to significant measurement errors (30). Objective measurements (e.g., accelerometers) are independent of these biases and are therefore able to provide more reliable and valid estimates of a child's daily PA behavior (8,20).

Because reversed causation plays a major role in the interpretation of cross-sectional research concerning the relationship between PA and body composition, longitudinal designs are superior. Only a small number of longitudinal studies investigating primary prevention of weight gain have measured PA objectively, which makes the available evidence insufficient and inconclusive (40). Three studies have previously examined this relationship longitudinally in prepubertal children using objective measurements of PA. First, the study of Moore et al. (22) followed a sample of 103 four-year-old children for 7 yr. They reported that higher levels of PA at baseline were associated with lower BMI scores and lower skinfold thicknesses in later childhood. Second, the study of Jago et al. (17) reported a significant inverse relationship between PA and the development of BMI over 3 yr in 3- to 4-yr-old children. Finally, Metcalf et al. (21) did not find a significant relationship between complying with health-enhancing PA recommendations and development of BMI scores, waist circumferences and skinfold thicknesses over 3 yr in 5- to 8-yr-old children.

The effect of PA on the development of body composition has a different clinical implication for children with a heavier initial (baseline) body composition compared with children with a leaner initial body composition. Because possible influences from dietary compensation or the additional accumulation of muscle mass as a result of strenuous PA may influence the association between PA and BMI development, acknowledging a differential effect in these subgroups may provide new insights. As energy intake is considered to cluster considerably with PA, controlling for energy intake would lead to unwanted indirect controlling for PA. Moreover, as a higher level of PA leads to higher energy intake, controlling for energy intake would annul the observed relations. Therefore, we decided to focus solely on the effect of PA, and energy intake was not controlled for in this study. The acknowledgment of potential sex differences is also important in studies concerning PA and the development of body composition in children because girls are considered to be less active compared with boys (38) and display a considerable decline in activity energy expenditure before puberty compared with boys (15).

The aim of this study was to contribute toward a better understanding of how PA and the development of BMI are related. Compared with other studies, this study is unique in investigating a time span including the adiposity rebound period (i.e., 4–9 yr old), its acknowledgment of potential sex differences, the investigation of differences in children with a high initial versus low initial BMI, and the categorization in various intensities of objectively measured PA. We hypothesize that the relationship between PA and BMI decreases in initially heavier boys and girls.

METHODS

Study design and population. The longitudinal relationship between PA and BMI (Fig. 1) was examined in two subsequent periods (diagonal arrows in Fig. 1). In the first period (i.e., first diagonal line in Fig. 1), we measured a child's PA level at 4–5 yr (T_0) and body height and weight at both 4–5 (T_0) and 6–7 yr (T_1). In the second period (i.e., second diagonal line in Fig. 1), we measured a child's PA level at 6–7 yr (T_1) and body height and weight at both 6–7 (T_1) and 8–9 yr (T_2). All parents gave written informed consent. The present study was approved by the Medical Ethics Committee of Maastricht University Medical Center.

The present study is a prospective study, nested in the KOALA Birth Cohort study. The study started in 2000 with the recruitment of healthy pregnant women from the general population who participated in an ongoing prospective cohort study on pregnancy-related pelvic girdle pain (conventional recruitment group, N = 2343). In addition, healthy pregnant women with an alternative lifestyle were recruited through Steiner schools, organic food shops, and anthroposophic doctors, midwives, and magazines (alternative recruitment group, N = 491) (16).

The current study was performed in a subsample of the KOALA cohort. Children were eligible for the first assessment period (T_0) if all questionnaires in the child's first 2 yr of age were complete and if the child resided within 20 km of six selected study locations, an inclusion criterion for a prior study within the KOALA cohort (7). Children were eligible for the second assessment period (T_1) if accelerometer data were available from the first period, and if the mother had participated in blood sampling at 36 ± 1 weeks of pregnancy (6). Figure 2 depicts the number of children participating in each assessment period.

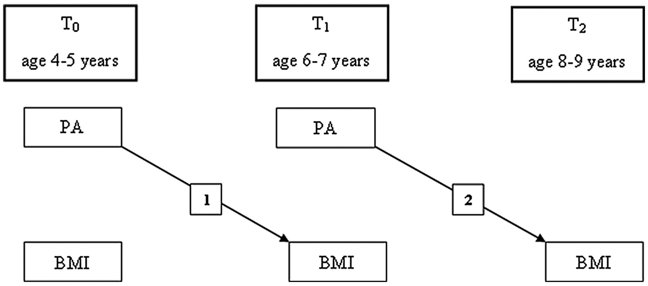

FIGURE 1—Conceptual model, presenting longitudinal relationships between PA and body composition (BMI). 1, first period; 2, second period.

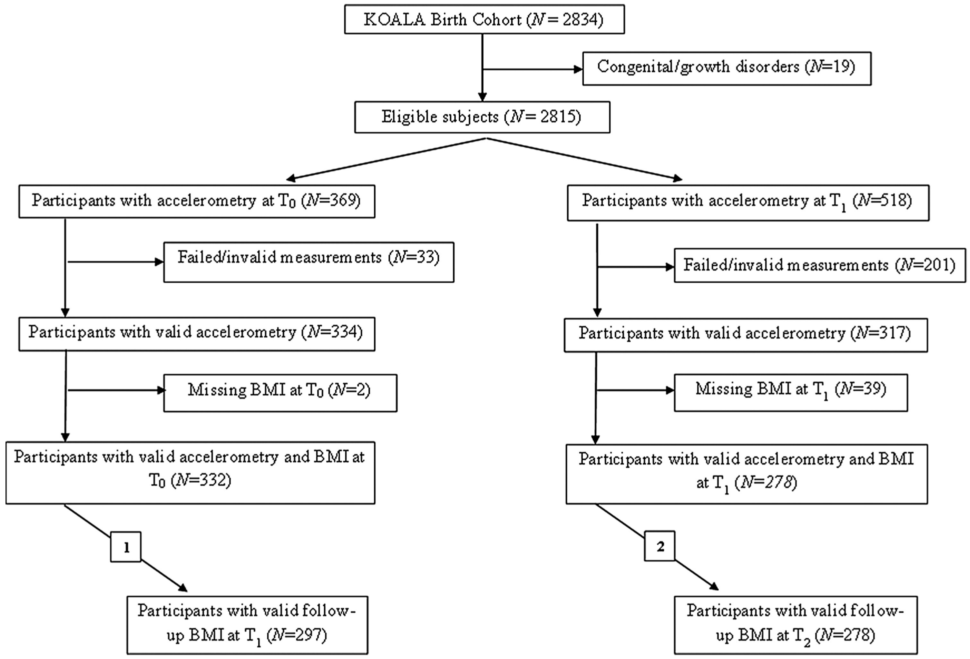

FIGURE 2—Flowchart.

PA. PA was measured with the uniaxial ActiGraph 7164 in the first assessment period, and with the ActiGraph 7164 and GT1M accelerometers (ActiGraph, Fort Walton Beach, FL) in the second assessment period. Participants were instructed to wear the accelerometer during waking hours on the right hip for 7 d and to remove the accelerometer during activities in which water was involved, such as swimming. Accelerometers express PA in "counts" and were initialized to capture the frequency of these counts every 15 s (i.e., epochs). Although efforts were made to prevent the occurrence of measurements in nonregular weeks, occasional measurement days within holidays were excluded from further analyses. In addition, the exact dates at which PA measurement commenced were categorized into spring (March, April, and May), summer (June, July, and August), autumn (September, October, and November), and winter (December, January, and February) to control for seasonality effects.

Only measurements that contained at least two weekdays and one weekend day were considered to be valid and were used in the analyses (37). Each day should consist of at least 400 min of registration time. Periods of 10 consecutive minutes of no accelerometry counts were considered to be nonwearing time (37). We used the thresholds of Evenson et al. (12) to distinguish between sedentary behavior (0–25 counts per epoch) and PA of light (26–573 counts per epoch), moderate (574–1002 counts per epoch), and vigorous intensity (≥1003 counts per epoch). The validation study by Evenson et al. was performed in 5- to 8-yr-old children, which is comparable with our study sample. Time spent in the moderate and vigorous categories was summed into moderate to vigorous PA (MVPA), as internationally recommended (24).

As accelerometers tend to underestimate cycling and cannot measure swimming/water activities, parents were asked to directly report the minutes that their child spent on these activities in a diary. The daily average number of minutes of cycling and swimming was calculated from weekly totals. As these activities were nonnormally distributed, they were categorized into three categories (cycling: ≤10, 11–30, and ≥31 min·d^{-1}; swimming: 0, 1–20, and ≥21 min·d^{-1}).

BMI. Parental height and weight were assessed in an annual questionnaire at the child's age of 4–5 yr old. The child's body height and weight were measured by trained research assistants with a portable stadiometer (Leicester height measure) and digital scale (CAS personal scale, HE-5) and recorded as millimeters and grams (rounded off to 100 g), respectively. This was done at T_0 in all children and at T_1 and T_2 in those children who wore the accelerometer at that time. At other times, parents were asked to measure height and weight as part of annual questionnaires. The method of measurement of height and weight at follow-up (i.e. objectively measured or parent reported) was controlled for in multivariate analyses. Children's BMI *z*-scores were calculated using reference values from the Fourth Dutch Growth Study to standardize for age and sex (13).

In both periods, we combined objectively and parent-reported height and weight measurement methods. In the first period, all height and weight measurements were obtained by research assistants at baseline (i.e., T_0), and 24.6% measurements were obtained by research assistants at follow-up (i.e., T_1). In the second period, 49.3% of measurements were obtained by research assistants at baseline (i.e., T_1), and 24.8% of measurements were obtained by research assistants at follow-up (i.e., T_2).

TABLE 1. Timing and results of measurements of PA and BMI.

	Baseline		Follow-up	
	Boys	Girls	Boys	Girls
First period	T_0 (n = 150)	T_0 (n = 147)	T_1 (n = 150)	T_1 (n = 147)
% time spent in light	46.19 ± 5.42	44.37 ± 4.53	—	—
% time spent in MVPA	7.97 ± 2.73	7.19 ± 2.38	—	—
Age at measurement	4.86 ± 0.34	4.86 ± 0.31	7.22 ± 0.38	7.22 ± 0.35
BMI z-score[a]	−0.07 ± 0.84	0.02 ± 0.92	−0.26 ± 0.94	−0.20 ± 0.93
Second period	T_1 (n = 133)	T_1 (n =145)	T_2 (n = 133)	T_2 (n = 145)
% time spent in light	39.88 ± 5.04	39.19 ± 3.90	—	—
% time spent in MVPA	8.00 ± 2.49	7.32 ± 2.34	—	—
Age at measurement	7.21 ± 0.47	7.12 ± 0.39	9.09 ± 0.67	9.04 ± 0.65
BMI z-score[a]	−0.26 ± 0.99	−0.16 ± 0.90	−0.03 ± 0.97	−0.07 ± 0.96

Values are presented as mean ± SD.
[a]Standardized against the age- and sex-specific reference values of the Fourth Dutch Growth Study (11).

Data analyses. Data from both periods were combined using the Statistical Package for the Social Sciences for Windows (version 19; SPSS Inc., Chicago, IL). The distributions of the main continuous variables (BMI z-scores, percentage time spent in different PA intensity categories) were approximately normal, so no transformations were needed.

The relationship between PA and the development of BMI z-scores was investigated, controlling for period, recruitment group, sex, method of height and weight measurement, cycling, swimming, seasonality, maternal BMI, and paternal BMI. In the first period (arrow 1 in Fig. 1), the child's BMI z-score at T_0 was subtracted from the BMI z-score at T_1 and divided by the time in years between the two BMI measurements. By doing so, the dependent variable reflected the mean change in BMI z-score per year, between T_0 and T_1. The second period (arrow 2 in Fig. 1) was treated in the same way, but here the BMI z-score at T_1 was subtracted from the BMI z-score at T_2. The fraction of time spent in each of the PA intensity categories was modeled separately. In the first period, relative PA intensity at T_0 was used and in the second period relative PA intensity at T_1 was used (see Fig. 1).

A proportion of the children (n = 105) contributed to both periods, depending on the availability of the measurements at each time point. To account for the correlation between these repeated periods, we performed generalized estimation equation (GEE) analyses with an exchangeable correlation structure. The period was used as the within-subject variable. In addition, GEE analyses assume that the effect of PA on BMI development is similar for the first and second period. To test this assumption, the period was used to test for statistical interaction with PA (period–PA interaction). The most complete models were adjusted for origin of BMI measurement (research assistant/parents), cycling, swimming, season, paternal BMI, maternal BMI, and recruitment group (conventional/alternative). Because of optimal readability of Table 2 and realistic increments in PA in children (i.e., 5% roughly corresponds to 30 $\mathrm{min \cdot d^{-1}}$), a PA increment of 5% was chosen to correspond to BMI z-score development.

The randomness of missing values in the covariates (i.e., cycling, swimming, maternal BMI, and paternal BMI) was checked by Little's missing completely at random tests and accompanying missing value analyses. Because none of the covariates with missing values showed strong deviations from the completely at random scenario, all missing values were imputed using multiple regression imputations. In total, 76 missing values of covariates were imputed. The percentage of imputed values per covariate at T_1 ranged between 0.6% for maternal BMI and 10.7% for cycling and swimming.

Analyses were stratified for weight status at the first measurement of the period (i.e., initial weight status), as the effect of PA on the development of BMI was expected to be more favorable in children with a high initial weight status, compared with those with a low initial weight status. Because of statistical power arguments, relative lean weight status was defined as the 25th percentile of our study sample, and relative heavier weight status was defined as the 75th percentile. Subsequently, children equal to or lower than the 25th percentile were defined as "leaner," and children equal to or higher than the 75th percentile were defined as "heavier."

The effect of potential confounders was checked by inspecting the difference in unstandardized regression coefficients of the PA variable, in absence versus presence of the individual confounder. A confounding effect was considered when the unstandardized beta values differed by ≥10% or when the confounder was considered to be essential to the study design (i.e., recruitment group). Potential effect modifiers (i.e., age–PA, sex–PA, period–PA) were checked separately from the regression coefficients of the interaction terms, in a complete model containing the main effects and the interaction term. When effect modification was not statistically significant, the interaction term was deleted from the model. When statistically significant interaction was present, we subsequently stratified the analyses. The theoretically considered interaction between initial weight status and PA was stratified irrespective of significance of the interaction term. Goodness of fit statistics were computed to compare models. In all analyses, statistical significance was assumed at $P < 0.05$.

RESULTS

In total, 334 children provided valid PA measurements at T_0, and 297 of these participants also provided valid BMI scores at T_0 and T_1. At T_1, 317 children provided valid PA measurements, and 278 of these participants also provided

TABLE 2. Associations between PA level and change in BMI z-scores between age 4–5 and 8–9 yr, stratified for baseline weight status.

PA Level		Total PA Beta (95% CI)	Light PA Beta (95% CI)	MVPA Beta (95% CI)
Boys and girls[a]				
Leaner (n = 145)	Unadjusted	−0.02 (−0.07 to 0.03)	−0.03 (−0.09 to 0.02)	0.03 (−0.09 to 0.14)*
	Adjusted	−0.01 (−0.06 to 0.04)	−0.03 (−0.08 to 0.02)	0.04 (−0.07 to 0.15)
Normal weight (n = 286)	Unadjusted	0.02 (−0.01 to 0.06)	**0.05 (0.002 to 0.09)**	−0.04 (−0.11 to 0.03)
	Adjusted	0.01 (−0.03 to 0.05)	0.03 (−0.01 to 0.07)	−0.05 (−0.13 to 0.02)
Heavier (n = 144)	Unadjusted	−0.04 (−0.09 to 0.00)*	−0.03 (−0.08 to 0.03)*	**−0.13 (−0.26 to −0.01)**
	Adjusted	**−0.06 (−0.11 to −0.02)***	−0.05 (−0.11 to 0.004)*	**−0.16 (−0.27 to −0.04)**
Boys				
Leaner (n = 74)	Unadjusted	−0.02 (−0.09 to 0.05)	−0.04 (−0.12 to 0.03)	0.05 (−0.13 to 0.23)*
	Adjusted	0.00 (−0.06 to 0.06)	−0.03 (−0.09 to 0.04)	0.12 (−0.06 to 0.31)
Normal weight (n = 146)	Unadjusted	−0.01 (−0.08 to 0.06)	0.03 (−0.04 to 0.10)	**−0.11 (−0.22 to −0.01)**
	Adjusted	−0.01 (−0.08 to 0.06)	0.03 (−0.05 to 0.10)	**−0.13 (−0.24 to −0.02)**
Heavier (n = 63)	Unadjusted	**−0.10 (−0.17 to −0.02)***	**−0.10 (−0.19 to −0.01)***	−0.17 (−0.36 to 0.01)
	Adjusted	**−0.11 (−0.18 to −0.04)***	**−0.13 (−0.23 to −0.04)***	**−0.17 (−0.33 to −0.004)**
Girls				
Leaner (n = 71)	Unadjusted	−0.01 (−0.07 to 0.04)	−0.02 (−0.10 to 0.05)	−0.00 (−0.14 to 0.13)*
	Adjusted	−0.01 (−0.08 to 0.06)	−0.02 (−0.11 to 0.07)	0.02 (−0.12 to 0.16)
Normal weight (n = 140)	Unadjusted	**0.05 (0.004 to 0.09)**	**0.07 (0.01 to 0.12)**	0.04 (−0.05 to 0.13)
	Adjusted	0.04 (−0.01 to 0.08)	0.04 (−0.01 to 0.10)	0.06 (−0.04 to 0.16)
Heavier (n = 81)	Unadjusted	−0.01 (−0.06 to 0.04)*	0.01 (−0.05 to 0.07)*	−0.10 (−0.24 to 0.04)
	Adjusted	−0.01 (−0.05 to 0.05)*	0.03 (−0.05 to 0.10)*	**−0.14 (−0.27 to −0.01)**

Regression coefficients (beta) represent the change in BMI z-scores per year for an absolute increment of 5% of PA. Results of GEE linear regression with PA measured at age 4–5 yr and 6–7 yr and BMI z-score (standardized for age and sex) measured at age 4–5 yr, 6–7 yr, and 8–9 yr, using an exchangeable correlation structure to account for the repeated measurements. Since 105 participants were measured at both periods, this table represents the number of measurements instead of participants.
Unadjusted models: only PA and time (age period) in the model; adjusted models: adjusting for origin of BMI z-score, bicycling, swimming, season, recruitment group, and paternal and maternal BMI. Weight status was categorized at the first measurement of BMI available at age 4–5 or 6–7 yr (baseline), into leaner (lowest quartile), heavier (highest quartile), and normal-weight (middle two quartiles) children.
Bold numbers indicate statistical significance of the regression coefficient at $P < 0.05$.
*sex interaction term was statistically significant at $P < 0.05$.
[a]Included an interaction term for sex–period in the adjusted models.
CI, confidence interval.

valid BMI scores at T_1 and T_2. Children participating in either period 1, 2, or both periods were comparable with the total KOALA Birth Cohort (N = 2834) in terms of sex (49.7% versus 51.2% boys, respectively) and recruitment group (87.7% versus 82.7% participants with a conventional lifestyle, respectively). In total, 105 participants provided valid measurements for all PA and BMI variables.

Participant characteristics. The characteristics of PA behavior and BMI measurements are presented in Table 1. The mean duration of the first period was 2.36 yr (mean age at T_0: 4.86 yr; mean age at T_1: 7.22 yr for both boys and girls), and the mean duration of the second period was 1.90 yr (mean age at T_1: 7.21 yr for boys and 7.12 yr for girls; mean age at T_2: 9.09 yr for boys and 9.04 yr for girls) (see Table 1). At both T_0 (i.e., baseline period 1) and T_1 (i.e., baseline period 2), boys spent a somewhat higher percentage of time on light PA and MVPA than girls, but in boys, light and MVPA showed more variation (higher standard deviations, Table 1). Except for T_2, boys showed slightly lower BMI z-scores than girls. At all times the study participants were somewhat leaner than the Dutch reference population (BMI z-scores <0, except girls at T_0, BMI z-score +0.02).

The leaner category corresponded to ≤ -0.70 BMI score standard deviations, and the heavier category corresponded to $\geq +0.42$ BMI score standard deviations. In total, 63 boys (22.3%) and 81 girls (27.7%) were classified as heavier, whereas 74 boys (26.1%) and 71 girls (24.3%) were classified as leaner. Boys and girls did not differ significantly in terms of BMI z-scores within all periods. All remaining participants were classified as normal weight. When this classification was compared against the international obesity taskforce (IOTF) thresholds, 46.20% of leaner children and 31.25% of heavier children were classified as normal weight according to the IOTF (4).

Longitudinal relationship between PA behavior and BMI development. First, the effect of potential effect modifiers (age–PA, sex–PA, period–PA) was checked. We found that interaction with PA was not statistically significant for age and period ($P > 0.05$ for all PA categories). Sex significantly interacted with PA in heavier children ($P < 0.05$ for all PA categories except MVPA) and normal weight children ($P < 0.05$ for MVPA). Consequently, we decided to perform both pooled (top part of Table 2) and stratified GEE analyses for sex and to identify significant sex interactions with a dagger (see Table 2).

In heavier children, a 5% increment of MVPA was associated with a 0.16 decrease in BMI z-score, and this was of similar size in boys (0.17) and girls (0.14) and statistically significant in both (Table 2). In heavier boys, a 5% increment of light PA was also related to a statistically significant decrease of 0.13 BMI z-scores per year. When combining light PA and MVPA into total PA, this amounted to a 0.11 BMI decrease in heavier boys for a 5% increment in total PA. In normal weight boys, only MVPA was associated with a decrease of BMI z-score. Girls generally did not show any decrease in BMI related to PA in the adjusted models, except for MVPA in heavier girls (similar to boys as noticed earlier).

DISCUSSION

This study showed that increments of MVPA were associated with decreases in BMI z-score in heavier children, both

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boys and girls. In heavier boys, increments in light PA were also related to a significant decrease in BMI *z*-scores, and in normal weight boys, somewhat similar decreases were found.

Our finding concerning the association between MVPA and BMI in heavier children is supported by previous studies (17,22), although more recent evidence is less clear for this association (40). As high BMI *z*-scores and low MVPA percentages at baseline are likely to subsequently regress to a mean value because of natural causes, this finding may also be influenced by the regression to the mean principle. However, the differential effects of PA in initially leaner, normal weight, and heavier subgroups of children, between boys and girls, and within different intensities of PA, strengthen the impression that these results are not an artificial relationship caused by regression to the mean.

In this study, the intensity of PA was based on accelerometry-based counts. One should bear in mind that equal levels of MVPA do not necessarily mean equal energy expenditure. A disadvantage of accelerometers is their inability to detect arm movements and external work (8). Thereby, they underestimate the energy cost of certain activities, such as rowing, cycling, weight lifting, or using the stairs. In addition, the energy expenditure depends on the child's motor ability or physical fitness. Specifically, a physically fit child with high motor abilities may expend less energy during PA of equal intensity compared with their relatively unfit counterparts. The advantage of using PA intensity levels instead of energy expenditure is that PA is not dependent upon these factors. Future studies should use objectively measured PA, accompanied by measures of activities that accelerometers are unable to detect.

The differential effect of PA on BMI development between boys and girls is supported by one study (2). Although it is nowadays well understood that most boys spend more time being physically active than girls (38), it is unknown why girls seem to be less sensitive to changes in PA. Future studies are therefore encouraged to investigate this more thoroughly.

In contrast to MVPA, light PA showed somewhat weaker associations with BMI development. This discrepancy is supported by several studies (10,16,28), which generally reported that the PA of the highest intensity (i.e., vigorous PA) was more strongly related to decreases in adiposity compared with less intensive PA. One study showed that the effect of MVPA was independent of the time spent sedentary (33), which may indicate that vigorous PA may provide more benefit than just increasing energy expenditure.

Strengths and weaknesses. One of the strengths of this study is the longitudinal design, containing two periods of repeated measurements, representing a period in childhood that included an important developmental stage in childhood adiposity (27). In total, 105 children contributed to both periods, providing accelerometry and anthropometry at three subsequent time points. Accelerometers are considered to be a valid measure of children's daily PA behavior (3). By the parental reports of cycling and swimming, we controlled for uncertainty regarding these activity types when using accelerometer measurements. Furthermore, as we measured PA for a minimum of two weekdays and one weekend day, the between-day intraclass reliability coefficient of PA in 4- to 5-yr-old children (irrespective of intensity) was 0.62 when applied for the first three days of measurement. Similarly, the intraclass reliability coefficient for 6- to 7- and 8- to 9-yr-old children was 0.63 and 0.54, respectively. In addition, we showed that the present sample did not differ significantly from the total KOALA Birth Cohort ($N = 2834$) in terms of sex and recruitment group. In total, 13.3% of the children in our sample had an alternative lifestyle. As these children may be exposed to alternative dietary patterns, the relationship between PA and BMI development may be different in these children. However, we found no evidence for a statistically significant interaction in this relationship. Finally, we controlled for the potential confounding effect of the recruitment group in all analyses. By including these participants, our results are generalizable to a population with diverse views of health and life.

The present study was also prone to some weaknesses. The type of measurement (e.g., parent-reported versus measured height and weight to calculate BMI) may have biased our results. One study comparing measured and parent-reported height and weight on a national scale in the United States reported that parents of 2- to 11-yr-old children overestimated their child's overweight by underestimating their child's height (1). Another study showed that parents underestimated their child's overweight by underestimating weight and overestimating height (31). In addition, a study that used 64.4% of the total KOALA cohort reported that parents underestimated their 6- to 7-yr-old child's overweight (36). When examining longitudinal associations, this potential bias may be differential, depending on the combination of origins present. For example, a child's height and weight may be measured at 6–7 yr and parent-reported at 8–9 yr or vice versa. Such differential bias was not possible in the first period, as all participants' height and weight were measured at 4–5 yr old. In the second period, we found that the combination of parent-reported and measured anthropometry over time (e.g., parent-reported at baseline versus measured at follow-up) differed between boys and girls, and we therefore included this interaction in the adjusted models. Furthermore, the selection of participants to measure (instead of report) was based on the availability of accelerometry at 6–7 yr old, and not based on any PA or BMI trait. This was supported by an intraclass correlation coefficient of -0.08 (95% confidence interval = -0.30 to 0.11) between origins from 6 to 7 and from 8 to 9 yr old. Therefore, we can cautiously suggest that it is unlikely that this bias has significantly inflated our results. In addition, as we have adjusted for the origin of the measurements in all analyses, any potential systematic bias was controlled for.

We decided to focus solely on the effect of PA and not to control for energy intake as this would lead to unwanted indirect controlling for PA and therefore would annul the observed associations. However, as some children compensate

MVPA with specific unhealthy dietary habits (e.g., sugar sweetened drinks), this would be interesting to investigate in future studies but was beyond the scope of the present study.

We used 25th and 75th percentiles for the classification of relative leaner and heavier children, respectively. We were unable to use the IOTF thresholds (4) for classification of overweight, underweight, and normal weight because this would have resulted in too small group sizes. This study showed that children with relatively smaller deviations from normal weight can benefit from MVPA.

When interpreting results from accelerometers, some discussion arises concerning thresholds for PA intensities. In the present study, the thresholds of Evenson et al. (12) were used because of the similarity of the age of children in our sample and in the validation study of Evenson et al. and the advantage of using one threshold for all age categories. However, the thresholds of Evenson et al. (12) are notably lower compared with other thresholds. Our results, therefore, may have overestimated the percentage of light PA in children and underestimated the percentage of sedentary behavior. Some studies suggest that differences in accelerometry thresholds predominantly occur in teenage years (29); other studies suggest that these differences are also present in the age categories in our study sample (26,38). However, because the age range was rather narrow in our study sample, the magnitude of this potential bias was expected to be small. In addition, one may suggest that small but significant differences exist between the two ActiGraph accelerometer models used in our study. One previous study found that the GT1M model reported an average 9% lower counts per epoch compared with the 7164 model. However, both models did not significantly differ when counts were conceptualized as time spent in moderate or vigorous category (5). This comparability is supported by two other studies, of which one reported no differences at all (18), and the other reported only slight differences that were not meaningful in activity intensity classification (19). If one did suppose that differences existed, then this potential bias would be randomly distributed over the entire sample, as we were unaware of a child's BMI when handing out the accelerometers. Discrepancies between the two ActiGraph models are therefore unlikely to have significantly biased our results.

Impact. A 5% daily increment of MVPA per year (i.e., 32.5 min) may be difficult for children to achieve. Alternatively, a 1% daily increment of MVPA per year corresponds to only 6.5 min. In this case, a heavier child has to spend approximately 6.5 more minutes per day in MVPA to achieve an average subsequent decrease of 0.03 BMI *z*-scores per year. Although this is a small decrease, when sustained through entire childhood, such a decrease may become relevant for the primary prevention of obesity. In conclusion, we found that increments of MVPA were associated with decreases in BMI *z*-score in heavier children, both boys and girls.

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The authors declare that they have no competing interest.

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