Physical Activity and Sedentary Behavior From 6 to 11 Years

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abstract

OBJECTIVES: Physical activity (PA) is presumed to decline during childhood and adolescence, but only few long-term studies about PA development during this period of life exist. We assessed PA and sedentary behavior (SB) over a 5-year period to gain a better understanding of the extent of change in activity and potential influencing factors.

METHODS: PA and SB of 600 children from the Childhood Obesity Project were objectively measured with the SenseWear Armband 2 at the ages of 6, 8, and 11 years, resulting in 1254 observations. Longitudinal changes of total PA, moderate-to-vigorous physical activity (MVPA), light physical activity (LPA), and SB were modeled with mixed-effects models.

RESULTS: Total PA revealed a significant quadratic decline with age ($P < .001$), resulting in a change of total PA by −75.3 minutes per day from 6 to 11 years. LPA linearly declined ($P < .001$) by 44.6 minutes per day, MVPA quadratically declined ($P < .001$) by an overall 30.7 minutes, whereas SB increased significantly (+107 minutes; $P = .001$). Boys showed a steeper decline in LPA ($P = .003$) and MVPA ($P < .001$) than did girls. Higher fat mass index and BMI z scores were associated with lower levels of total PA and MVPA and higher levels of SB (all $P < .001$).

CONCLUSIONS: We showed that PA decreased, and SB increased in earlier years than previously thought. MVPA remained relatively stable until 8 years, but revealed a drop-off at 11 years, identifying this period as a crucial time for intervention.

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WHAT'S KNOWN ON THIS SUBJECT: Physical activity and sedentary behavior are thought to decline with the start of adolescence. Decline can be influenced by biological or environmental factors. Low levels of activity during childhood can be the cause of the increasing inactivity in adults.

WHAT THIS STUDY ADDS: In our study, the decline of physical activity and increase of sedentary behavior started well before adolescence. The only major influencing factors were sex, country, and body size. Interventions to prevent inactivity might need to focus more on younger children.

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An increase of sedentary behavior (SB) and lack of physical activity (PA) is connected to a number of noncommunicable diseases worldwide.[1,2] Because of the continuance of PA and SB from childhood into adulthood,[3] the transition period from childhood to adolescence is the focus of many PA interventions.[4,5]

A natural and biologically determined decline of total PA throughout the life span seems likely.[6] This decline is also represented in recommendations from the World Health Organization (WHO): preschool-aged children should accumulate a minimum of 180 minutes per day of total PA, children and adolescents (4–17 years old) at least 60 minutes per day, and adults only a minimum of 30 minutes per day in moderate-to-vigorous physical activity (MVPA).[7] For a long time, the prevailing opinion about the development of total PA and SB in youth was that the steepest decline of total PA happens between 12 and 18 years.[8,9] Authors of recent studies, however, suggest that an early decline of total PA already starts at 6 years of age.[10,11] Most of these longitudinal studies are focused on total PA and MVPA, excluding light physical activity (LPA) and SB.[12–15] The analysis of SB has become more important because of the massive increase in sitting activities in children over the last decades.[16] The development of accelerometers has made it possible to measure SB and LPA as separate behaviors and has changed the understanding of LPA and its influence on health.[17] MVPA is thought to have a higher impact on health, but far longer periods of time are spent on LPA. Yet reliable data of LPA levels and development in children are scarce.

To get deeper insight into the origins of activity and inactivity, prospective studies are needed in which authors differentiate between intensity levels and identify influencing factors.[18] Most studies used to look at influencing factors of PA and SB are cross-sectional, precluding statements about causal relationships.[19] Evidence from longitudinal studies will give better insight into potential causal relationships and will thus improve the target selection of interventions. The aim of this study, therefore, is to analyze the change of total PA, MVPA, LPA, and SB from 6 to 11 years and to identify factors that influence this development with age.

METHODS

Study Subjects and Design

The underlying sample of children is part of the Childhood Obesity Project (NCT00338689). The design and results of this European double-blind, randomized controlled trial are reported elsewhere.[20] Briefly, 1678 infants, who were born between October 2002 and July 2004, entered the trial during their first 8 weeks of life. Children were randomly assigned to 2 formula-fed groups, with either a lower or higher protein content for the first year of life. Additionally, an observational group of children who were exclusively breastfed was included. The aim was to test whether early protein intake predicts infant growth and later risk of childhood obesity.

Data for this analysis were collected during the 6- (time point 1; T1), 8- (time point 2; T2), and 11- (time point 3; T3) year follow-up examinations. Data collection was performed in the following 5 European countries: Germany, Italy, Belgium, Poland, and Spain. The sample for the following analysis combines intervention and control groups into a single longitudinal cohort, treating possible intervention effects as a covariate. The trial was approved by the ethics committee in each study center, and informed consent was obtained from parents and children. All research was performed in accordance with the Declaration of Helsinki.

Activity Assessment (Outcome Variable)

PA was measured with the SenseWear Armband 2 (BodyMedia, Inc, Pittsburgh, PA). The device is worn over the right triceps muscle and incorporates 5 sensors: 2-axis accelerometer, galvanic skin response, skin temperature, near–body temperature sensor, and heat flux.[21] Following the study protocol, children were told to wear the armband on 3 consecutive days for at least 20 hours per day. The data processing was done with the Professional InnerView Software 6.1 (BodyMedia, Inc), already described elsewhere.[22] Briefly, total PA was categorized into the following 2 groups on the basis of recommendations by Trost et al[23]: LPA (1.5–3.9 metabolic equivalents of task) and MVPA (≥4 metabolic equivalents of task). Time spent in activity <1.5 metabolic equivalents of task (minus the time lying down and sleeping) was considered to be SB. Studies have revealed that the SenseWear Armband is a valid tool to measure energy expenditure (EE) and PA in children and adolescents.[24,25]

Time-Varying Covariates

Weight and height were measured during each follow-up visit at the study sites. Standard operating procedures relied on the WHO's Multicentre Growth Reference Study.[26] BMI (weight [kilograms] divided by height [meters squared]) was transformed into BMI *z* score (*z*BMI), adjusted for sex and age according to the WHO growth standards.[26] Body fat mass and fat mass index (FMI) (total body fat mass [kilograms] divided by height [meters squared]) were calculated from bioelectrical impedance assessed in duplicate with the octopolar Tanita BC-418 (Tanita Corporation, Tokyo, Japan). This has been validated for use in children.[27]

Time Invariant Covariates

In addition to sex and study country, data from parents were collected during the initial study visit. The educational status of parents was assessed with the help of the International Standard Classification of Education 1997 levels and defined as low (level 0–3), middle (level 3–4), and high (level 5–6); it included the highest education level of both parents.[28] Housing type was asked and defined as either house (free standing or semidetached) or flat (flat, maisonette, or apartment). Additionally, the prepregnancy BMI of mothers was calculated from self-reported prepregnancy weight and on-site measurements of height after study recruitment. Family status (single mother or living with partner) and smoking during pregnancy were assessed at the initial study visit. At 11 years, puberty status was assessed with the "Pubertal Development Scale" and categorized as "pre-pubertal" and "pubertal."[29]

Data Analyses

Data are reported as mean and SD for continuous variables and as number (*n*) and percentage (%) for factors. Differences in accelerometer measurement participation rate were calculated with χ^2 tests and Student's *t* tests. Observations are defined as 1 accelerometer measurement of each child at 1 of the 3 time points. Observations at any of the 3 time points with just 1 day of recording were excluded. Observations with 2 days of recording revealed no differences to observations with 3 or more days and were therefore kept for analyses.

For each outcome variable, total PA, MVPA, LPA, and SB, mixed models with an individual random intercept and random slope for age were used. Age was centered to the lowest age of any participant (5.89 years) and was included in all models with a quadratic term to analyze the development of outcomes over time. Covariates were entered separately, and all models were optimized by maximum likelihood estimation and likelihood ratio tests for the best model fit.

Because residuals of MVPA models were not normally distributed, MVPA was log transformed for mixed-model analysis and later back transformed for interpretability. For the LPA model, the quadratic age term was removed, because it worsened the model fit. Each model 1 was calculated as the minimal adjusted model, with factor covariates sex (2 levels) and study country (5 levels) added as fixed effects. Country and sex were tested as random factors but revealed no improvement to model fit. Sex and age interactions were added to the LPA and MVPA model, because they revealed significant results and improved the overall fit. In model 2, additional adjustments for season of measurement and time invariant covariates (as described above) were tested. Variables were added separately to the model and were only kept when improving the overall model fit. In model 3, time-varying covariates in the form of *z*BMI (model 3.1) or FMI (model 3.2) were added and tested for interaction with age. For visualization of effects, estimates of model 1 for SB, total PA, LPA, and MVPA in minutes per day from 6 to 12 years (grouped by sex) were plotted. Models were calculated in *R* using the "lme4" package. Significance was assumed at an error probability <.05.

RESULTS

Descriptive Information

Figure 1 reveals the participation flow during the study. Overall, 725 children between 6 and 11 years of age participated; 600 children had valid accelerometer data and were included in the analysis with a total of 1254 observations. The average participation rate for accelerometer measurements (over all time points) was highest in Poland (78.2%) and Belgium (71.8%) and lowest in Italy (64.5%) and Spain (63.8%). There were no differences in anthropometric data between children who participated in accelerometer measurement and those who did not. At T1, accelerometer measurement participation rate of children of parents with low education was significantly (P = .04) lower (50.0%) when compared with children of parents with middle (72.9%) or higher education (71.8%), but no significant differences were seen at T2 and T3.

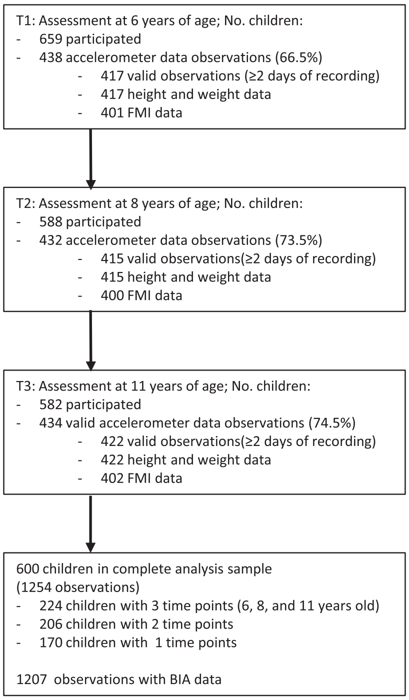

FIGURE 1
Flowchart of participating children and available data. BIA, bioelectric impedance analysis.

Times in different activity levels and anthropometric data by time point are presented in Table 1. The total sample had more observations from girls (n = 680; 54.2%) than boys (n = 574; 45.8%), and girls had a significantly (P < .001) higher

TABLE 1 Characteristics and Activity Levels of Participants

	6 y, *n* = 417	8 y, *n* = 415	11 y, *n* = 422
Age, y, mean (SD)	6.1 (0.1)	8.1 (0.1)	11.2 (0.2)
Boy, *n* (%)	184 (44.1)	199 (48.0)	191 (45.3)
Anthropometry, mean (SD)			
BMI	15.9 (2.0)	16.8 (2.6)	18.7 (3.3)
*z*BMI	0.3 (1.2)	0.4 (1.2)	0.4 (1.2)
FMI	3.4 (1.1)	3.9 (1.6)	4.5 (2.0)
FFMI	12.6 (1.1)	13.0 (1.2)	14.3 (1.6)
Activity levels in min per d, mean (SD)			
Sedentary	299.0 (79.6)	332.0 (79.9)	406.0 (96.7)
Total PA	532.9 (82.3)	519.8 (80.4)	457.6 (100.6)
LPA	418.3 (69.7)	397.8 (71.8)	373.7 (81.1)
MVPA	114.6 (59.5)	122.1 (72.3)	83.9 (53.6)
Adhere to PAGs, *n* (%)	340 (81.5)	329 (79.3)	264 (62.6)

*z*BMI was calculated by WHO reference population; PAGs by WHO: children (4–17 y) should spend 60 min per d in MVPA. FFMI, fat-free mass index (fat mass [kilograms] divided by height [meters squared]).

FMI than boys at all 3 time points. In both girls and boys, mean SB increased by 107 minutes per day from T1 to T3, whereas total PA and LPA decreased (PA: −75 minutes per day; LPA: −48 minutes per day). MVPA development differed by sex, in which boys' MVPA between T1 (mean = 126.0 minutes per day; SD = 59.7 minutes per day) and T2 (mean = 147.0 minutes per day; SD = 75.7 minutes per day) increased and sharply decreased to T3 (mean = 103.8 minutes per day; SD = 53.5 minutes per day). Girls remained steady between T1 (mean = 105.6 minutes per day; SD = 57.8) and T2 (mean = 99.1 minutes per day; SD = 60.6 minutes per day) followed by a steep drop-off by T3 (mean = 67.5 minutes per day; SD = 47.9 minutes per day). Adherence rates to current physical activity guidelines (PAGs) of 60 minutes per day of MVPA were high at T1 (83%) and T2 (81%) and plummeted by almost 20% at T3.

Longitudinal Changes of PA and SB and Influencing Factors

With Table 2, we display results of longitudinal data analysis using model 1. In summary, a significant decline in all PA variables was seen. Total PA and MVPA declined quadratically, whereas LPA declined linearly (all $P < .001$). SB significantly increased ($P < .001$) over the same period. Age-dependent sex effects were visible in LPA and MVPA with opposite directions: boys spent less time in LPA ($P = .003$) and more time in MVPA ($P < .001$) than girls with an increasing difference from 6 to 11 years of age. The complete models with random effects are shown in Supplemental Table 4. All models revealed a negative random intercept-slope covariance and correlation, meaning children with higher intercepts tend to have lower slopes.

When looking at further influencing factors in model 2, adding the season of measurement revealed a significant improvement of LPA and MVPA models but resulted in no major differences in β-estimates or significance (not shown). The addition of time-invariant covariates (educational status, housing, prepregnancy BMI, maternal age, family status and smoking during pregnancy, pubertal status at 11 years, and intervention type) had no influence on any of the 4 models.

Adding a time-varying variable *z*BMI in model 3.1 (Table 3) revealed an association with SB, total PA, and MVPA (all $P < .001$). The interaction between *z*BMI and age was only significant in MVPA ($P = .014$). When the time-varying variable FMI (model 3.2) was added instead of *z*BMI, similar results were obtained with slightly larger effect sizes. Additionally, there was a negative association between LPA and FMI ($P = .012$). However, age and FMI interactions were not significant in all of the models.

Figure 2 reveals the plotted estimates of SB, total PA, LPA, and MVPA in minutes per day from 6 to 12 years, grouped by sex (model 1). When looking at MVPA and comparing it to current PAGs, girls fall on average below the 60 minutes per day of MVPA at the age of 10.7 years and boys at 13.0 years.

DISCUSSION

Principal Findings

We observed a decline in time spent in total PA as well as in low- and high-intensity levels, from 6 to 11 years of age, even after adjustment for various covariates. Total PA and LPA gradually declined, whereas MVPA remained constant between 6 and 8 years but steeply dropped off by 11 years of age. This effect was also visible in the number of children fulfilling current PAGs of 60 minutes per day in MVPA, which revealed a steep decline between 8 and 11 years (T1: 83.1%; T2: 81.4%; T3: 63.9%). Major influencing factors were sex and study country, as well as *z*BMI and FMI.

TABLE 2 Four Separate Mixed-Effects Models With Random Intercept and Slope Examining the Change of PA and SB Between Age 6 and 11 Years (Model 1)

	SB			Total PA			LPA			MVPA		
	β	95% CI	*P*	β	95% CI	*P*	β	95% CI	*P*	β	95% CI	*P*
Fixed effects												
Intercept	274.8	258.8 to 290.9	<.001	520.4	503.9 to 537.0	<.001	428.8	415.2 to 442.3	<.001	82.3	73.0 to 92.8	<.001
Sex (boys)	9.2	−2.2 to 20.6	.115	−1.0	−12.8 to 10.8	.867	−21.7	−34.1 to −9.4	<.001	21.3	10.5 to 32.2	<.001
Country												
Spain	11.7	−6.6 to 30.0	.210	23.6	4.7 to 42.5	.015	6.9	−8.1 to 21.9	.370	10.5	−0.8 to 23.4	.073
Germany	−.8	−21.5 to 19.8	.936	27.9	6.6 to 49.3	.010	6.4	−10.7 to 23.4	.464	14.3	0.8 to 29.9	.034
Italy	39.9	20.9 to 58.9	<.001	5.1	−14.6 to 24.7	.615	−6.0	−21.7 to 9.7	.455	−3.2	−12.9 to 8.7	.610
Poland	39.1	19.3 to 58.9	<.001	4.4	−16.0 to 24.8	.672	−9.7	−26.0 to 6.6	.244	7.8	−4.8 to 21.3	.235
Age (centered)	10.8	4.4 to 17.2	.001	−.6	−7.5 to 6.3	.860	−6.4	−8.7 to −4.0	<.001	3.4	−1.6 to 8.7	.161
Age × age (centered)	1.8	0.7 to 2.9	.001	−2.6	−3.8 to −1.4	<.001	—	—	—	−2.4	−3.2 to −1.6	<.001
Sex × age (centered)	—	—	—	—	—	—	−5.3	−8.8 to −1.8	.003	5.1	2.5 to 7.8	<.001

All values are min per d; reference for "country" variable is Belgium; age was centered to the lowest age of any participant (5.89 y). CI, confidence interval; —, not applicable.

Implications and Comparison With Other Studies

Our study, used to cover the critical transition phase between childhood and adolescence, suggests that a decline of total PA beginning as early as 6 years of age is possible. This is a novel finding, because authors of most current literature suggest that total PA increases between the ages of 3 and 8 years[30] with a steep decline during adolescence (12–18 years).[8,9,31] As a result, most longitudinal studies are focused on PA and SB development in adolescence.[32] Only few longitudinal studies start at an earlier age but are supportive of our observation of an earlier decline in total PA than previously thought.[10,11] The overt explanation for this earlier decline could be the increased sitting times due to school. However, time-specific analysis of PA has revealed that in addition to the increased SB during school hours, there was also a distinct decline on weekends, out-of-school days, and during lunchtime.[12,33] This emphasizes that a precise measurement and detailed analysis of intensity levels already at an early age can give deeper insights into PA development, which are needed for adequate public health planning. In our results, it is further suggested that future intervention programs should already start at earlier ages than school age, to convey the importance of PA when levels of activity are still high.

In our study, SB and LPA were the main components of children's activity during hours awake. LPA decreased from 6 to 11 years of age accompanied by a steady increase of time spent in SB. Other studies have revealed that the trend of increased inactivity is likely to be continued during adolescence[33–35] and is followed into adulthood.[3,36] In light of this observation, it may be more feasible for interventions to replace SB with LPA, to prevent the negative

TABLE 3 Effects of *z*BMI and FMI on PA From 4 Separate Adjusted Mixed-Effects Models (Model 3.1 and Model 3.2)

	SB			Total PA			LPA			MVPA		
	β	95% CI	*P*	β	95% CI	*P*	β	95% CI	*P*	β	95% CI	*P*
*z*BMI	11.5	7.0 to 16.0	<.001	−8.0	−12.7 to −3.3	<.001	−1.8	−5.6 to 2.0	.360	−6.0	−8.1 to −3.0	<.001
FMI	12.1	8.6 to 15.5	<.001	−10.6	−14.2 to −7.0	<.001	−3.8	−6.7 to −0.8	.012	−9.1	−12.0 to −7.1	<.001

All values are min per d; reference for "country" variable is Belgium; age was centered to the lowest age of any participant (5.89 y). All models were adjusted for sex and country and for season in LPA and MVPA; *z*BMI was calculated by WHO reference population. CI, confidence interval.

effects of too much inactivity on health, as suggested by Healy et al.[37]

Sex differences were not visible in total PA and SB but in intensity levels of total PA (LPA and MVPA). Girls seem to be more active in light-intensity activities and boys more in high-intensity activities. Similar effects were also seen in a study by Nader et al,[13] yet it remains unclear whether this has an effect on health outcomes in girls later in life. Differences in total PA and SB between sexes are present in many studies, mostly with girls being less active than boys.[12,13,32] An explanation might be the earlier onset of puberty and sexual maturation in girls[38]; however, sex differences were already present at the 6-year-old mark in our study (well before puberty). This information can be useful when planning activity programs, tailoring suggested activities' intensity and duration.

Higher *z*BMI and FMI values resulted in a significantly lower volume of total PA and a higher volume of SB at baseline but revealed no effect on the development over time. PA is thought to be a major influencing factor in the prevention and management of overweight and obesity in youth. In the literature, there is no certainty about the direction and magnitude of influence. The inverse causality hypothesis assumes that overweight and obesity are not the result but the cause of reduced activity,[39–41] which might explain our findings. In light of these results, an indirect effect of the original nutritional intervention cannot be ruled out, as Weber et al[42] have shown that intake of a higher-protein formula during the first year of life resulted in a higher risk of obesity at 6 years.

Strengths and Limitations

One strength of our study is the longitudinal design. The study can be used to give an insight into the activity development during the critical period between childhood and adolescence. The results are generalizable for Europe because they were based on a birth cohort conducted in 5 countries. However, the population might not be fully representative because children were mainly from metropolitan areas and some were taking part in the intervention during the first year of life. Additionally, results are limited because of the relatively small sample size, the fact that not all children participated in every measurement, and the lack of more measurement points during adolescence. This makes stratification for certain subgroups difficult and challenging and limits the certainty about the continuous PA decrease during puberty.

Furthermore, a lack of common standard cutoffs for intensity levels, either for total PA[17] or SB,[43] results in different databases. This limits the possibility of comparing accelerometer-based studies. We chose cutoffs for LPA and MVPA on the basis of the fact that other studies consistently reveal an EE of 4 metabolic equivalents of task in children and adolescence from brisk walking (a common moderate activity).[23,44] Additionally, the use of different epoch lengths should be treated with caution when comparing PA and SB studies.[45] For our study, the epoch length was chosen on the basis of the storage and energy restrictions of the device used and was similar to many accelerometer-based studies.[46–48] Another limitation of most accelerometers is the inability to measure water-based activities, like swimming, because most devices cannot be worn in water. The SenseWear Armband tries to take this into account by calculating off-body estimates of EE during nonwear time, but this can never fully represent true measurements.

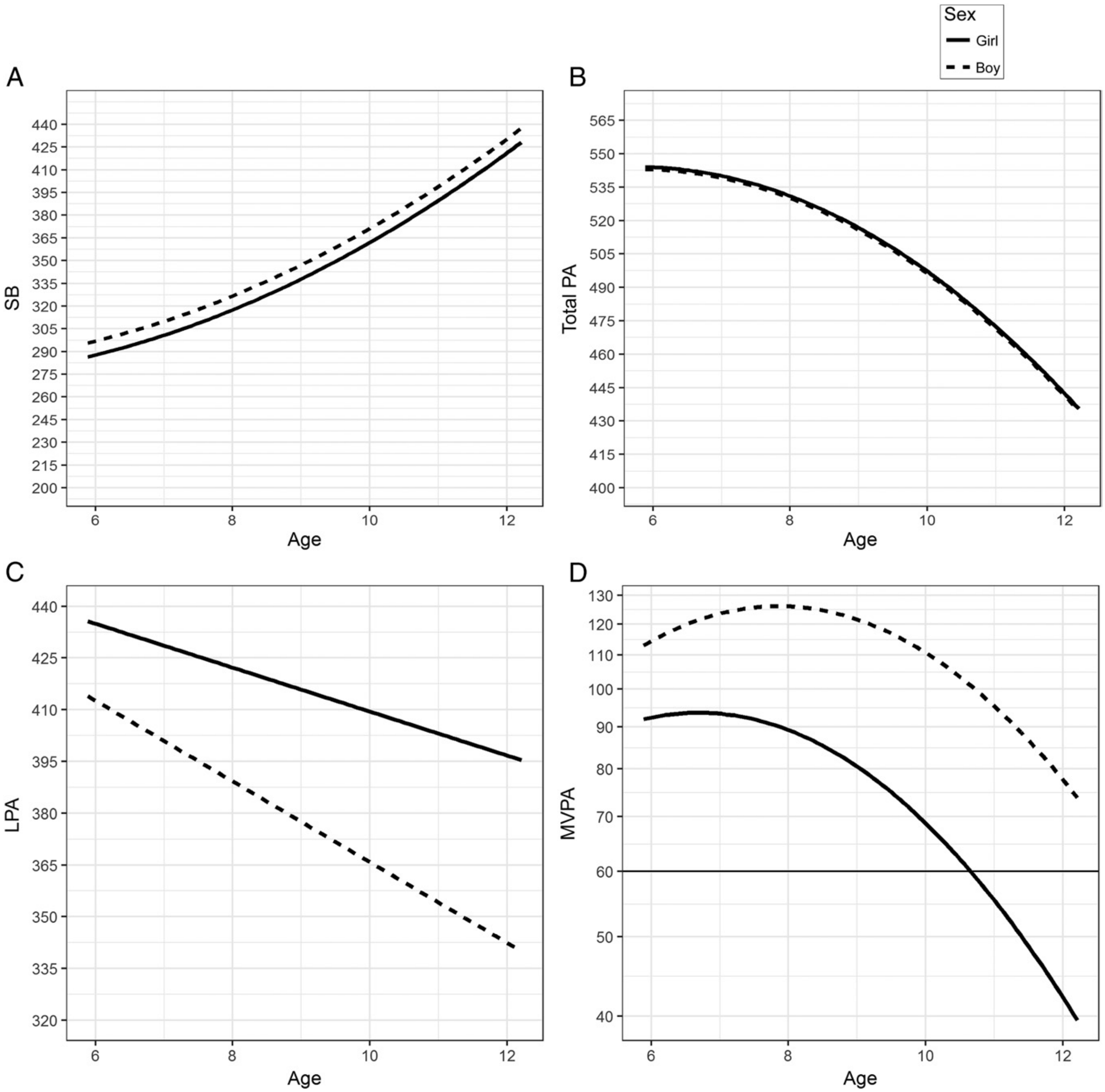

FIGURE 2
Plotted predicted values of mixed-effects models examining the change of PA and SB between age 6 and 11 years (model 1). Factor sex and sex and age interactions were only significant in LPA ($P = .003$) and MVPA models ($P < .001$); the MVPA model was calculated and plotted on log-scale because of the skewness of data; the horizontal line represents 60 minutes per day in MVPA recommended in guidelines. A, SB. B, Total PA. C, LPA. D, MVPA.

CONCLUSIONS

In this study, total PA activity decreased, and SB increased between the ages of 6 and 11 years. When looking at intensity levels of total PA, MVPA revealed a steep decline after 8 years, indicating a possible need for intervention. Sex effects on activity development were seen, which need to be taken in account when planning interventions and future studies.

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ABBREVIATIONS

EE: energy expenditure
FMI: fat mass index
LPA: light physical activity
MVPA: moderate-to-vigorous physical activity
PA: physical activity
PAG: physical activity guideline
SB: sedentary behavior
T1: time point 1
T2: time point 2
T3: time point 3
WHO: World Health Organization
*z*BMI: BMI *z* score

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REFERENCES

1. World Health Organization. *Global Status Report on Noncommunicable Diseases 2014*. Geneva, Switzerland: World Health Organization; 2014
2. Lee IM, Shiroma EJ, Lobelo F, Puska P, Blair SN, Katzmarzyk PT; Lancet Physical Activity Series Working Group. Effect of physical inactivity on major non-communicable diseases worldwide: an analysis of burden of disease and life expectancy. *Lancet*. 2012;380(9838):219–229
3. Jones RA, Hinkley T, Okely AD, Salmon J. Tracking physical activity and sedentary behavior in childhood: a systematic review. *Am J Prev Med*. 2013;44(6):651–658
4. Dobbins M, Husson H, DeCorby K, LaRocca RL. School-based physical activity programs for promoting physical activity and fitness in children and adolescents aged 6 to 18. *Cochrane Database Syst Rev*. 2013;(2):CD007651
5. Lavelle HV, Mackay DF, Pell JP. Systematic review and meta-analysis of school-based interventions to reduce body mass index. *J Public Health (Oxf)*. 2012;34(3):360–369
6. Sallis JF. Age-related decline in physical activity: a synthesis of human and animal studies. *Med Sci Sports Exerc*. 2000;32(9):1598–1600
7. World Health Organization. *Global Recommendations on Physical Activity for Health*. Geneva, Switzerland: World Health Organization; 2010
8. Kimm SY, Glynn NW, Kriska AM, et al. Longitudinal changes in physical activity in a biracial cohort during adolescence. *Med Sci Sports Exerc*. 2000;32(8):1445–1454
9. Caspersen CJ, Pereira MA, Curran KM. Changes in physical activity patterns in the United States, by sex and cross-sectional age. *Med Sci Sports Exerc*. 2000;32(9):1601–1609
10. Nyberg GA, Nordenfelt AM, Ekelund U, Marcus C. Physical activity patterns measured by accelerometry in 6- to 10-yr-old children. *Med Sci Sports Exerc*. 2009;41(10):1842–1848
11. Basterfield L, Adamson AJ, Frary JK, Parkinson KN, Pearce MS, Reilly JJ; Gateshead Millennium Study Core Team. Longitudinal study of physical activity and sedentary behavior in children. *Pediatrics*. 2011;127(1). Available at: www.pediatrics.org/cgi/content/full/127/1/e24
12. Brooke HL, Atkin AJ, Corder K, Ekelund U, van Sluijs EM. Changes in time-segment specific physical activity between ages 10 and 14 years: a longitudinal observational study. *J Sci Med Sport*. 2016;19(1):29–34

13. Nader PR, Bradley RH, Houts RM, McRitchie SL, O'Brien M. Moderate-to-vigorous physical activity from ages 9 to 15 years. *JAMA*. 2008;300(3):295–305
14. Kwon S, Janz KF, Letuchy EM, Burns TL, Levy SM. Developmental trajectories of physical activity, sports, and television viewing during childhood to young adulthood: Iowa bone development study. *JAMA Pediatr*. 2015;169(7):666–672
15. Li K, Haynie D, Lipsky L, Iannotti RJ, Pratt C, Simons-Morton B. Changes in moderate-to-vigorous physical activity among older adolescents. *Pediatrics*. 2016;138(4):e20161372
16. Saunders TJ, Chaput JP, Tremblay MS. Sedentary behaviour as an emerging risk factor for cardiometabolic diseases in children and youth. *Can J Diabetes*. 2014;38(1):53–61
17. Powell KE, Paluch AE, Blair SN. Physical activity for health: what kind? How much? How intense? On top of what? *Annu Rev Public Health*. 2011;32:349–365
18. Atkin AJ, van Sluijs EMF, Dollman J, Taylor WC, Stanley RM. Identifying correlates and determinants of physical activity in youth: how can we advance the field? *Prev Med*. 2016;87:167–169
19. Sterdt E, Liersch S, Walter U. Correlates of physical activity of children and adolescents: a systematic review of reviews. *Health Educ J*. 2014;73(1):72–89
20. Koletzko B, von Kries R, Closa R, et al; European Childhood Obesity Trial Study Group. Lower protein in infant formula is associated with lower weight up to age 2 y: a randomized clinical trial. *Am J Clin Nutr*. 2009;89(6):1836–1845
21. Andre D, Pelletier R, Farringdon J, et al. *The Development of the SenseWear Armband, a Revolutionary Energy Assessment Device to Assess Physical Activity and Lifestyle*. Pittsburgh, PA: BodyMedia Inc; 2006
22. Schwarzfischer P, Weber M, Gruszfeld D, et al. BMI and recommended levels of physical activity in school children. *BMC Public Health*. 2017;17(1):595
23. Trost SG, Loprinzi PD, Moore R, Pfeiffer KA. Comparison of accelerometer cut points for predicting activity intensity in youth. *Med Sci Sports Exerc*. 2011;43(7):1360–1368
24. Welk GJ, McClain JJ, Eisenmann JC, Wickel EE. Field validation of the MTI Actigraph and BodyMedia armband monitor using the IDEEA monitor. *Obesity (Silver Spring)*. 2007;15(4):918–928
25. Calabró MA, Welk GJ, Eisenmann JC. Validation of the SenseWear Pro Armband algorithms in children. *Med Sci Sports Exerc*. 2009;41(9):1714–1720
26. de Onis M, Onyango AW, Borghi E, Siyam A, Nishida C, Siekmann J. Development of a WHO growth reference for school-aged children and adolescents. *Bull World Health Organ*. 2007;85(9):660–667
27. Luque V, Closa-Monasterolo R, Rubio-Torrents C, et al. Bioimpedance in 7-year-old children: validation by dual x-ray absorptiometry - part 1: assessment of whole body composition. *Ann Nutr Metab*. 2014;64(2):113–121
28. United Nations Educational, Scientific and Cultural Organization (UNESCO). *International Standard Classification of Education 1997*. Paris, France: UNESCO; 1997
29. Petersen AC, Crockett L, Richards M, Boxer A. A self-report measure of pubertal status: reliability, validity, and initial norms. *J Youth Adolesc*. 1988;17(2):117–133
30. Dencker M, Andersen LB. Health-related aspects of objectively measured daily physical activity in children. *Clin Physiol Funct Imaging*. 2008;28(3):133–144
31. van Mechelen W, Twisk JW, Post GB, Snel J, Kemper HC. Physical activity of young people: the Amsterdam longitudinal growth and health study. *Med Sci Sports Exerc*. 2000;32(9):1610–1616
32. Dumith SC, Gigante DP, Domingues MR, Kohl HW III. Physical activity change during adolescence: a systematic review and a pooled analysis. *Int J Epidemiol*. 2011;40(3):685–698
33. Harding SK, Page AS, Falconer C, Cooper AR. Longitudinal changes in sedentary time and physical activity during adolescence. *Int J Behav Nutr Phys Act*. 2015;12:44
34. Mitchell JA, Pate RR, Dowda M, et al. A prospective study of sedentary behavior in a large cohort of youth. *Med Sci Sports Exerc*. 2012;44(6):1081–1087
35. Treuth MS, Baggett CD, Pratt CA, et al. A longitudinal study of sedentary behavior and overweight in adolescent girls. *Obesity (Silver Spring)*. 2009;17(5):1003–1008
36. Biddle SJ, Pearson N, Ross GM, Braithwaite R. Tracking of sedentary behaviours of young people: a systematic review. *Prev Med*. 2010;51(5):345–351
37. Healy GN, Dunstan DW, Salmon J, et al. Objectively measured light-intensity physical activity is independently associated with 2-h plasma glucose. *Diabetes Care*. 2007;30(6):1384–1389
38. Marques A, Branquinho C, De Matos MG. Girls' physical activity and sedentary behaviors: does sexual maturation matter? A cross-sectional study with HBSC 2010 Portuguese survey. *Am J Hum Biol*. 2016;28(4):471–475
39. Fröberg A. "Couch-potatoeism" and childhood obesity: the inverse causality hypothesis. *Prev Med*. 2015;73:53–54
40. Hjorth MF, Chaput JP, Ritz C, et al. Fatness predicts decreased physical activity and increased sedentary time, but not vice versa: support from a longitudinal study in 8- to 11-year-old children. *Int J Obes (Lond)*. 2014;38(7):959–965
41. Metcalf BS, Hosking J, Jeffery AN, Voss LD, Henley W, Wilkin TJ. Fatness leads to inactivity, but inactivity does not lead to fatness: a longitudinal study in children (EarlyBird 45). *Arch Dis Child*. 2011;96(10):942–947
42. Weber M, Grote V, Closa-Monasterolo R, et al; European Childhood Obesity Trial Study Group. Lower protein content in infant formula reduces BMI and obesity risk at school age: follow-up of a randomized trial. *Am J Clin Nutr*. 2014;99(5):1041–1051
43. Atkin AJ, Ekelund U, Møller NC, et al. Sedentary time in children: influence of accelerometer processing on health relations. *Med Sci Sports Exerc*. 2013;45(6):1097–1104

44. Treuth MS, Schmitz K, Catellier DJ, et al. Defining accelerometer thresholds for activity intensities in adolescent girls. *Med Sci Sports Exerc*. 2004;36(7):1259–1266

45. Ojiambo R, Cuthill R, Budd H, et al; IDEFICS Consortium. Impact of methodological decisions on accelerometer outcome variables in young children. *Int J Obes (Lond)*. 2011;35(suppl 1):S98–S103

46. Riddoch CJ, Bo Andersen L, Wedderkopp N, et al. Physical activity levels and patterns of 9- and 15-yr-old European children. *Med Sci Sports Exerc*. 2004;36(1):86–92

47. Riddoch CJ, Mattocks C, Deere K, et al. Objective measurement of levels and patterns of physical activity. *Arch Dis Child*. 2007;92(11):963–969

48. Butte NF, Gregorich SE, Tschann JM, et al. Longitudinal effects of parental, child and neighborhood factors on moderate-vigorous physical activity and sedentary time in Latino children. *Int J Behav Nutr Phys Act*. 2014;11:108

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