Objective assessment of levels and patterns of physical activity in preschool children

Martin Brasholt[1], Bo Chawes[1], Eskil Kreiner-Møller[1], Signe Vahlkvist[1], Marianne Sinding[1] and Hans Bisgaard[1]

BACKGROUND: The aim of this study was to examine in detail levels and patterns of physical activity in preschool children and the effects of gender and BMI on this activity.

METHODS: Two hundred and fifty-three children aged 5 y participating in the Copenhagen Prospective Studies on Asthma in Childhood wore an accelerometer day and night over a 4-wk period. The main outcome measure was level of physical activity using the raw data. A secondary measure was time spent in moderate to vigorous physical activity (MVPA). A Fourier series analysis was applied to study in detail patterns over time.

RESULTS: Activity profiles throughout the year were unique for each sex, with boys being overall more active than girls except for winter months. Preschool children also showed distinct patterns of physical activity during weekdays as compared with weekends and were most active during weekdays. Preschool children in the highest tertile of BMI had a flat yearly activity profile and tended to be less active as compared with those in the lowest tertile.

CONCLUSION: Preschool children showed significant gender differences in physical activity, with distinct patterns throughout the year as well as between weekdays and weekends. A high BMI tended to be associated with lower levels of physical activity.

Objective measurements are needed to assess physical activity in preschool children to characterize habitual patterns of physical activity in order to design intervention programs (1) and examine the relationship between physical activity and health problems such as obesity (2) and asthma (3). In asthmatics, improved physical fitness may increase the aerobic capacity, resulting in a reduction of asthmatic symptoms, enhanced asthma control (4), and improved quality of life (5). Overall, physical activity increases quality of life in general and may help prevent cardiovascular disease (6) and diabetes (7) later in life.

Riddoch and coworkers have recently demonstrated variation in physical activity during the day and week as well as throughout the year in 11-y-old children (8). However, the habitual pattern of physical activity has not been described in sufficient detail in preschool children (1). Therefore, we measured the levels and patterns of habitual physical activity over a 4-wk period using accelerometry in 253 preschool children participating in the Copenhagen Prospective Studies on Asthma in Childhood birth cohort (9).

RESULTS

Mechanical Reliability

The motor test of the 39 monitors used in the clinical setting showed an intramonitor reliability of 0.78 (95% confidence interval: 0.68–0.85). Intermonitor reliability was 6.6%. We found mechanical reliability similar to that of another study conducted using the Actical accelerometer (Philips Respironics, Murrysville, PA) (10).

Baseline

Activity data for a period of at least seven consecutive days were available from 253 of the 411 children of the Copenhagen Prospective Studies on Asthma in Childhood cohort (**Figure 1**). There was no statistically significant difference between the children with and without complete data for physical activity regarding gender, BMI, household income, or diagnosis of asthma. In the study group, age, BMI, and days recorded were equally distributed between boys and girls.

The mean age of the study group was 5.2 y (SD: 0.7 y); 126 (50%) were boys. Mean BMI was 15.5 kg/m^2 (SD: 1.28 kg/m^2; range: 12.4–21.4 kg/m^2). In girls, 11.8% were overweight, and 1.6% were obese. In boys, 9.5% were overweight, and 4.0% were obese. The accelerometers were worn for an average of 26.3 d (SD: 3.7 d; range: 7–28 d); 64 children were monitored during spring (March–May), 58 during summer (June–August), 100 during autumn (September–November), and 31 during winter (December–February). Forty-five children (18%) were diagnosed with asthma and received antiasthmatic treatment. No association between level of physical activity and diagnosis of asthma was found.

There was no significant difference in physical activity (range: 486–504 counts/min), intraclass correlation coefficients (range: 0.62–0.70), or coefficients of variation (range: 37–40%) when comparing weeks 1, 2, 3, and 4 of the monitoring period.

Physical Activity Patterns During the Day and Week

The physical activity level was 877 ± 233 counts/min (mean ± SD) from 0800 to 2000 h, which could represent waking hours. Boys

[1]Copenhagen Prospective Studies on Asthma in Childhood, Danish Pediatric Asthma Center, Faculty of Health Sciences, Copenhagen University Hospital Gentofte , Gentofte, Denmark. Correspondence: Martin Brasholt (mbrasholt@hotmail.com)

Received 6 June 2012; accepted 11 February 2013; advance online publication 31 July 2013. doi:10.1038/pr.2013.99

were statistically significantly more active than girls (942 ± 241 vs. 814 ± 206 counts/min; $P < 0.0001$), including the period from 1200 to 1600 h, when the children were most active (1,128 ± 310 vs. 973 ± 253 counts/min; $P < 0.0001$). Activity data are depicted in Figure 2, which is split into weekdays (A) and weekends (B). The activity curve in Figure 2a is illustrative of the typical activity pattern in everyday life of the preschool children examined, with characteristic peaks and troughs throughout the day. Activity was on average lower during weekends than during weekdays (difference 133 counts/min; $P < 0.0001$), and there was no characteristic fluctuation in activity except for a trough around 1800 h.

Physical Activity Patterns During the Year

Figure 3 shows the variation in physical activity during the year for all children as well as for boys and girls separately. The activity patterns of boys and girls were widely different and followed unique courses. Girls' level of physical activity peaked at spring and declined toward winter, whereas boys' activity level had two peaks, one at spring and one at autumn, and showed a characteristic decline later than the girls' activity. Overall, boys were more physically active than girls. Girls were more active than boys during winter months, but this finding was not statistically significant.

Children were significantly less active in winter months as compared with the months of spring, summer, and autumn (e.g., May vs. December; 914 ± 246 vs. 686 ± 157 counts/min; $P = 0.0005$; see Table 1 for all 12 mo).

Figure 4 shows how physical activity along the year varied by BMI status. Children in the highest tertile had a flat course throughout the year and, notably, seemed more physically active during winter months as compared with children in the lowest tertile, indicating a BMI-driven distinct pattern of physical activity. However, the effect BMI had on physical activity was not statistically significant: identical results were found when using BMI or BMI z-score in the analysis ($P = 0.58$ for both). We found no association between age and level of physical activity.

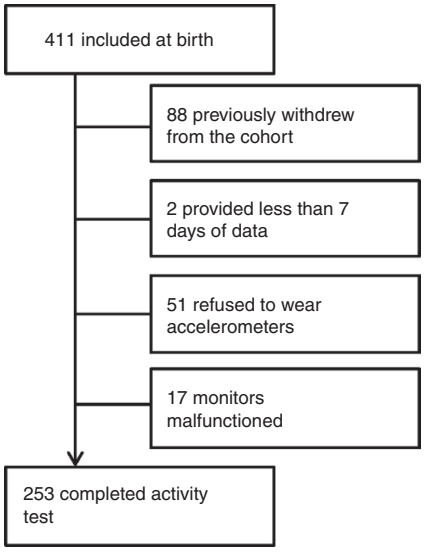

Figure 1. Flowchart of children enrolled into the study.

Time in Moderate to Vigorous Physical Activity

Overall, 39% of the children spent the recommended 60 min in moderate to vigorous physical activity (MVPA) per day (11), boys more so than girls (51 vs. 28%, $P < 0.0001$). The children spent 31 min on average per day in MVPA (boys 35 and girls 26 min per day, $P < 0.0001$).

DISCUSSION

In this study, we describe in greater detail than previous studies the levels and patterns of physical activity of a cohort of Danish preschool children during the day, week, and year.

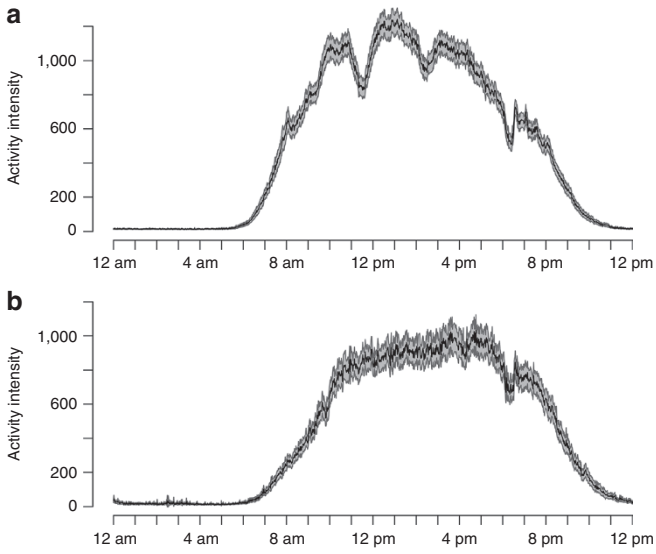

Figure 2. Average physical activity of children during (**a**) weekdays and (**b**) weekends. The average physical activity count per minute for a day and night is represented by the black line and the 95% confidence interval by the gray lines.

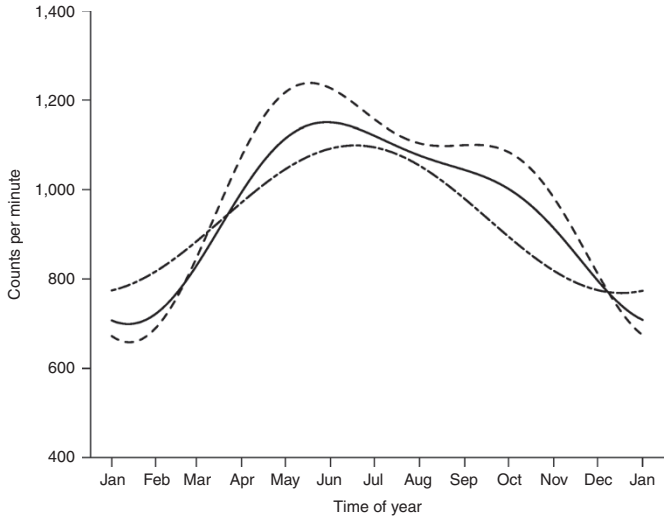

Figure 3. Variation in physical activity throughout the year. Black line: all participants; equally dashed line: boys; unequally dashed line: girls. The figure was made with respect to the exact time of the measurement using a Fourier series analysis.

Table 1. Physical activity from 0800 to 2000 h for each month of the year

Month	Season (as defined in this article)	Temperature (°C)	*n* (*N* = 253)	Physical activity (counts per min; mean ± SD)
December	Winter	1	10	686 ± 157
January		0	12	749 ± 163
February		0	9	695 ± 206
March	Spring	2	10	737 ± 261
April		6	32	1,008 ± 278
May		11	22	914 ± 246
June	Summer	15	29	1,026 ± 200
July		16	7	994 ± 187
August		17	22	937 ± 177
September	Autumn	13	32	922 ± 204
October		9	40	831 ± 163
November		4	28	721 ± 187

Mean temperatures in Denmark according to the Danish Meteorological Institute.

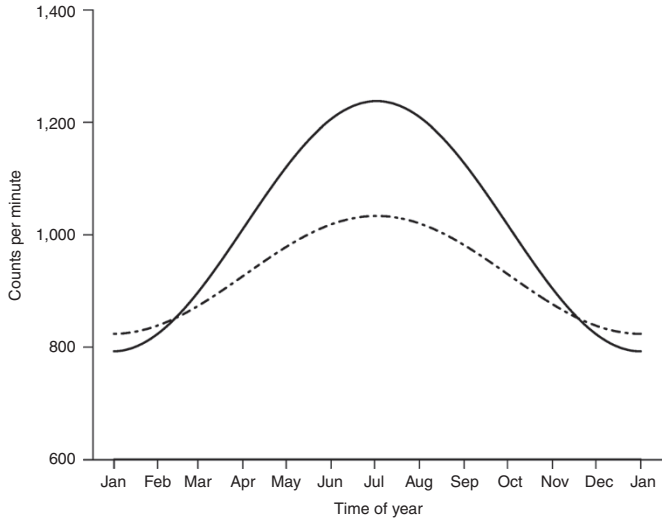

Figure 4. Variation in physical activity throughout the year split up into weight groups. Solid line: BMI < the first tertile; dashed line: BMI > the second tertile. The figure was made with respect to the exact time of the measurement using a Fourier series analysis.

Total Physical Activity

We found that boys were generally more active than girls, which is in agreement with other studies of preschool children (12–15). We also confirmed previous findings of preschool children being less active during weekends as compared with weekdays (16) but in greater detail than other studies because we depicted characteristic variation in physical activity continuously throughout the entire week. We found no association between diagnosis of asthma and level of physical activity. This is as expected because the children were thoroughly and regularly examined for signs of asthma and treated with antiasthmatics if indicated according to a fixed predefined algorithm. Hence, we would expect children with asthma to be able to perform physically as well as children without asthma, which is also a major goal of sufficient asthma control.

Physical Activity During the Year

There are conflicting reports on the effect of season on physical activity in preschool children. Fischer *et al.* examined 209 children aged 4.8 y on average using uniaxial accelerometry over 3–6 d, and found the lowest activity in spring, concluding that seasonality played only a limited role in physical activity (17). Baranowski *et al.* used a rating scale (Children's Activity Rating Scale) to assess physical activity in 191 children aged 3–4 y and found that activity was higher outside than inside, and that outside activity levels were lowest during summer (18). This is somewhat in contrast to a review by Tucker *et al.*, who stated that the decline in activity during the colder season was particularly prominent in studies of children because their time spent playing outdoors is highest in summer and decreases considerably during winter (19). Such increase in unstructured or structured outdoor activities in the warmer months of year could explain our findings of variation during the year because indoor facilities were the same all year in our setting. In addition, it could be part of the explanation for boys being more physically active than girls because boys might take part in more outdoor activities than girls, and it could be seen in conjunction with a review by Hinkley *et al.*, who found that children who spent more time outdoors were more active than children who spent less time outdoors (20).

The gender difference could reflect differences in the way boys and girls play. Boys might prefer play that involves being physically active whereas the play girls prefer could exhibit a less physically active behavior. Following that, boys could be more dependent on good weather to take part in physically demanding outdoor play and when playing indoors might prefer computer games and similar activities that comprise a more sedentary behavior. This could partly explain the fact that boys are less physically active than girls in winter months. We found no papers focusing on behavioral aspects of physical activity in young children to support this theory. This is an important area of further study because such knowledge could improve our understanding of patterns of physical activity in this young age group and thereby strengthen initiatives to make children more physically active.

Finally, an explanation for boys being more active could be that boys took part in more structured activities in the warmer months and as such were more active overall. However, this seems unlikely because they are only 5-y-olds that attended regular kindergarten, and children at this age primarily take part in unstructured activities. We did not, however examine the type of activities carried out, and this makes it difficult to draw conclusions regarding this issue.

Physical activity programs have been proven feasible and potentially efficacious in preschool children (21). Our detailed data could improve the timing of indoor and outdoor activity facilities and interventions at the times of year when levels of physical activity are low. To our knowledge, we are the first to have measured consecutively throughout the year and to

report seasonal variation in such detail in preschool children. However, each subject provided four consecutive weeks of data, and the level of activity did not differ significantly among these 4 wk. We distributed monitors consecutively as the children turned up for clinical visits at the research clinic and did not in any way select children for particular seasons. Therefore, seasonal data on physical activity levels come from different subjects, and we do not have data from multiple seasons on the same subjects. This is a limitation to our study because the seasonal variation could partly be explained by differences in the subjects themselves.

Physical Activity Intensity

We used the raw activity data as the primary outcome measure as recommended by Freedson *et al.* (22). Although cut points between physical activity intensities have not been uniformly established (23), we used 3,000 counts/min as the lower threshold to define MVPA because this has been stated to lie in the range of the most appropriate cut point (24), and it allowed for comparison with other studies using accelerometers in preschool children. Fisher *et al.* found 3.4% of 3–5-y-old children (cut point 3,200 counts/min) (25), Fisher *et al.* found 2–4% of children aged mean 4.8 y (cut point 3,200 counts/min) (17), and Specker *et al.* found 12–14% of children aged 3–5 y do 60 min of MVPA per day (26). These findings are remarkably lower than the 39% demonstrated in our study but may reflect that the abovementioned studies used different accelerometers and placements, and therefore comparisons between studies should be done with great caution because protocols vary considerably between studies. Furthermore, thresholds for MVPA vary considerably between studies. Hence, conclusions based on such thresholds vary accordingly, and different protocols yield different results. The choice of epoch length influences the activity intensity measured and thereby the estimate of MVPA. Our choice of the 1-min epoch may have underestimated activity of vigorous and very vigorous activity, causing our estimate of time spent in MVPA to be too low. This would only enhance the differences between our study and the studies mentioned above.

An important reason for the differences between studies could be considerable international and even national differences in levels of physical activity in young children. We have studied a cohort of Danish preschool children attending kindergarten, which usually offers access to outdoor facilities including a playground. This might be different for other countries, which could limit the generalizability of our results. Differences in physical activity among studies are most likely multifactorial and could be influenced by BMI, climate, social conditions, and whether there is a tradition to be outdoors as well as accessibility to outdoor facilities. Nonetheless, it is still concerning and a major health-care challenge for the society that only a small proportion of preschool children fulfill international criteria for physical activity.

Physical Activity and BMI

We showed that children in the highest tertile of BMI had a flat activity profile throughout the year as compared with children in the lowest tertile, although it was not statistically significant, which could be due to the homogeneity of BMI among the study participants. However, our findings indicate an inverse association between physical activity and BMI, which aligns with a study of 281 children aged 4–6 y in which children with high-intensity physical activity were less likely to be overweight (27). Our finding of no association between BMI and physical activity in the age group studied aligns with a review by Hinkley *et al.* (20). Physical activity is crucial in preventing overweight and obesity, and there is an existing challenge of making children in general more physically active. Our findings indicate that obese children do not increase their level of physical activity come summer as do normal-weight children. It seems that the factors causing normal-weight children to increase their level of physical activity come summer do not work for overweight and obese children. This could constitute an additional challenge of making overweight and obese children as physically active as normal-weight children during the months of summer. Furthermore, it could call for further studies to identify such factors influencing seasonal variation in order to prevent obesity and promote physical activity as early as preschool.

Measurement Period

We objectively measured physical activity for an extended period of 4 wk, which to our knowledge is the longest period monitored in a large cohort of preschool children. In addition, the children were required to wear the monitor during both waking and sleeping hours and during bathing and swimming to ensure capturing all activity carried out. This removed the need to make arbitrary decisions as to the waking period of the children or to individually determine each child's waking period from the accelerometer output (28). The long observation period reduced the risk of Hawthorne effect, i.e., that the process of observation would alter the phenomenon being observed (29), because an initial awareness of observation could cause the children to be more active in the beginning of the measuring period. We found no signs of initial awareness of observation or significant variation week by week in the monitoring period.

Placement of the Monitor

The ideal location for wearing an activity monitor is not universally agreed upon (30). Most studies in children have used the trunk location (hip or lower back) and some have used the wrist or ankle. Studies comparing placements are scarce but would be useful when comparing data on objectively measured physical activity across studies. The ankle placement likely enhanced compliance with the long measurement protocol in this study and was judged appropriate for our cohort of preschool children because children in this age group primarily perform omnidirectional activity. Although it makes little difference whether the monitor is worn on the right or left side of the hip, it is recommended to use one side consistently (30). Although this recommendation is not based on research on ankle-worn monitors, it is a limitation to our study that we did not use one side consistently.

Future Studies

It is a challenge to get a representative measurement of the physical activity carried out in a population of preschool children. This is a process requiring several factors to succeed and it is therefore difficult to standardize methods for measuring physical activity. However, on the basis of our data we recommend using an accelerometer, measuring day and night for at least seven consecutive days, using as short an epoch as possible, and using a high level of detail when analyzing data. Furthermore, we recommend obtaining data from multiple seasons on the same subjects. This would improve data quality and could ease the comparison of data between studies. Ultimately, it could improve the basis on which interventions on physical activity in preschool children are based.

Conclusion

This study provides a detailed description of the levels and patterns of physical activity during the day, week, and year for a cohort of Danish preschool children attending regular kindergarten. Our data suggest weekly and seasonal variation in physical activity and a possible effect of gender and BMI on physical activity levels and patterns. These detailed data and results could help timing of successful intervention programs addressing winter months in general and summer months for vulnerable children with high BMI. In addition, our findings could improve studies associating physical activity with health problems such as asthma.

METHODS

Design and Subjects

The study was nested in the Copenhagen Prospective Studies on Asthma in Childhood, a single-center prospective clinical birth cohort study of 411 children born to mothers with asthma, recruitment of which has been previously described in detail (9). The children examined in this study all attended regular kindergarten, which usually has access to outdoor facilities including a playground. The children were primarily urban or suburban, and came from families with medium to high income. Standardized physical examination and history was obtained by doctors at the research center together with comprehensive objective assessments and lung function tests at half-yearly visits from birth until age 7 y. Asthma was diagnosed by the same doctors on the basis of daily respiratory diary cards and according to the international GINA (Global Initiative for Asthma) guidelines. Diagnosis and treatment have been described in detail previously (3).

Ethics and Consent

The study was conducted according to the Declaration of Helsinki and was approved by the Ethics Committee for Copenhagen (KF 01-289/96) and The Danish Data Protection Agency (2008-41-1754). Written informed consent was obtained from parents of all participating children. Child assent was obtained.

Mechanical Calibration Data

Mechanical reliability of the monitors was investigated before the clinical study by testing the 39 accelerometers used on a motor-driven arm (30). A video of the arm is available in **Supplementary Video S1** online.

Physical Activity Assessment

Accelerometry is a feasible and validated method of assessing physical activity in preschool children (31). Physical activity was assessed using the omnidirectional Actical accelerometer (Philips Respironics, Murrysville, PA), which is sensitive to acceleration of movements in multiple planes. This makes it especially suitable to capture the omnidirectional movements made by preschool children (32), who participate in activities that require less vertical movement (e.g., walking and running during organized activities) and more omnidirectional movement (e.g., rolling and tumbling in play) as compared with school-aged children (1,33). The Actical monitor is small ($28 \times 27 \times 10$ mm, 17 g), waterproof, and easy to wear. We did an equipment check before giving out the monitors as recommended by the manufacturer. The monitors were issued to the families consecutively as they visited the research clinic for routine assessments at age 5 y. This implied getting data from several children for each month of the year. The monitors were placed on the lateral side of the right or left ankle (side was randomly assigned) with a strap, which was fixed with a cable tie to ensure compliance. Each child wore the same monitor for all of the period. The parents and the child were instructed to leave the monitor on day and night for 28 d, including during bathing and swimming (28). Ankle placement was chosen to ensure compliance during the 4-wk measurement period. We used an epoch length of 1 min because we aimed at measuring for as long as 28 d even though an epoch of this length is known to cause underestimation of time spent at vigorous and very vigorous intensity activity (24,34).

Physical Activity Outcome Measures

Minute-by-minute activity counts from the Actical monitor were compiled for the monitoring period and stored in an SQL database. All prints of data were scrutinized manually for errors, and activity measurements lasting less than seven consecutive days were excluded from the analysis. Noncompliance was defined as one or more periods with 240 min of continuous zeros during the day. This would allow children to be sedentary while watching TV or taking a nap and still take into account that longer time without activity would be indicative of noncompliance. Days that included one or more of such periods were excluded. The raw activity counts were used as the primary physical activity end point as advised because the actual acceleration pattern is used to characterize activity behavior (22). We derived time spent in MVPA per valid day as a secondary physical activity end point, with a count threshold for determining MVPA of 3,000 counts/min (22).

Data Analysis

Reliability was defined as the degree to which repeated measurements under unchanged conditions showed the same results. Accelerometers were tested eight at a time to test intermonitor reliability and three times to test intramonitor reliability. Intermonitor reliability was computed as coefficients of variation calculated from mean and SD of the activity counts as mean/SD. Intramonitor reliability was determined as intraclass correlation coefficients calculated from a SAS macro based on one-way ANOVA (35). BMI-for-age was categorized overweight (85th to <95th percentile) and obese (≥95th percentile) to estimate the proportion of children who were overweight/obese, and estimates were based on Centers for Disease Control and Prevention Growth Charts (36).

Activity counts were analyzed by marginal log-linear Poisson regression with log (number of minutes included in activity count) as offset. We used generalized estimating equation models to account for within-child dependence. *P* values are based on robust score tests and robust SEs were used to calculate 95% Wald confidence intervals. The correlation structure assumed for the repeated measurements is the working independence correlation structure. Intrasubject variation of activity counts over the 4-wk monitoring period was investigated using generalized estimating equation models comparing observations from weeks 1, 2, 3, and 4. Gender and month of year variation in physical activity was also investigated by generalized estimating equation models. All analyses were adjusted for current asthma (yes/no). Results are reported as mean ± SD; a P value of < 0.05 was considered statistically significant. Unpaired t-tests and χ^2-tests were used for the dropout analysis. Statistical analyses and figures were done using SAS (version 9.1; SAS Institute, Cary, NC) and R statistical software (version 2.7.0; R Development Core Team, Vienna, Austria). The figures illustrating the variation during the year stratified for sex as well as BMI tertiles were made with respect to the exact time of the

measurement using a Fourier series analysis (37). The date in the middle of the measurement period was used in the Fourier series analysis because this gave us the ability to plot data with 365 intervals on the *x*-axis instead of four seasons.

SUPPLEMENTARY MATERIAL

Supplementary material is linked to the online version of the paper at http://www.nature.com/pr

ACKNOWLEDGMENTS

We thank the children and parents participating in the Copenhagen Prospective Studies on Asthma in Childhood (COPSAC) cohort as well as the COPSAC study team. We also thank senior statisticians Christian Bressen Pipper and Florent Baty, as well as technical assistant Richard Flaaten.

STATEMENT OF FINANCIAL SUPPORT

No financial assistance was received in support of this study.

Disclosure: No disclosures.

REFERENCES

1. Oliver M, Schofield GM, Kolt GS. Physical activity in preschoolers: understanding prevalence and measurement issues. Sports Med 2007;37:1045–70.
2. Oliver M, Schluter PJ, Rush E, Schofield GM, Paterson J. Physical activity, sedentariness, and body fatness in a sample of 6-year-old Pacific children. Int J Pediatr Obes 2011;6:e565–73.
3. Brasholt M, Baty F, Bisgaard H. Physical activity in young children is reduced with increasing bronchial responsiveness. J Allergy Clin Immunol 2010;125:1007–12.
4. Fink G, Kaye C, Blau H, Spitzer SA. Assessment of exercise capacity in asthmatic children with various degrees of activity. Pediatr Pulmonol 1993;15:41–3.
5. Shoup JA, Gattshall M, Dandamudi P, Estabrooks P. Physical activity, quality of life, and weight status in overweight children. Qual Life Res 2008;17:407–12.
6. Andersen LB, Harro M, Sardinha LB, et al. Physical activity and clustered cardiovascular risk in children: a cross-sectional study (The European Youth Heart Study). Lancet 2006;368:299–304.
7. Rachmiel M, Buccino J, Daneman D. Exercise and type 1 diabetes mellitus in youth; review and recommendations. Pediatr Endocrinol Rev 2007;5:656–65.
8. Riddoch CJ, Mattocks C, Deere K, et al. Objective measurement of levels and patterns of physical activity. Arch Dis Child 2007;92:963–9.
9. Bisgaard H. The Copenhagen Prospective Study on Asthma in Childhood (COPSAC): design, rationale, and baseline data from a longitudinal birth cohort study. Ann Allergy Asthma Immunol 2004;93:381–9.
10. Esliger DW, Tremblay MS. Technical reliability assessment of three accelerometer models in a mechanical setup. Med Sci Sports Exerc 2006;38:2173–81.
11. National Board of Health. Physical Activity Recommendations. 2012. (http://www.sst.dk/English/Health_promotion/Physical_activity/Recommendations_for_children_and_young_people.aspx).
12. Finn K, Johannsen N, Specker B. Factors associated with physical activity in preschool children. J Pediatr 2002;140:81–5.
13. Grontved A, Pedersen GS, Andersen LB, Kristensen PL, Moller NC, Froberg K. Personal characteristics and demographic factors associated with objectively measured physical activity in children attending preschool. Pediatr Exerc Sci 2009;21:209–19.
14. Pate RR, Pfeiffer KA, Trost SG, Ziegler P, Dowda M. Physical activity among children attending preschools. Pediatrics 2004;114:1258–63.
15. Toschke JA, von Kries R, Rosenfeld E, Toschke AM. Reliability of physical activity measures from accelerometry among preschoolers in free-living conditions. Clin Nutr 2007;26:416–20.
16. Vale S, Silva P, Santos R, Soares-Miranda L, Mota J. Compliance with physical activity guidelines in preschool children. J Sports Sci 2010;28:603–8.
17. Fisher A, Reilly JJ, Montgomery C. Seasonality in physical activity and sedentary behaviour in young children. Pediatr Exerc Sci 2005;17:31–40.
18. Baranowski T, Thompson WO, DuRant RH, Baranowski J, Puhl J. Observations on physical activity in physical locations: age, gender, ethnicity, and month effects. Res Q Exerc Sport 1993;64:127–33.
19. Tucker P, Gilliland J. The effect of season and weather on physical activity: a systematic review. Public Health 2007;121:909–22.
20. Hinkley T, Crawford D, Salmon J, Okely AD, Hesketh K. Preschool children and physical activity: a review of correlates. Am J Prev Med 2008;34:435–41.
21. Jones RA, Riethmuller A, Hesketh K, Trezise J, Batterham M, Okely AD. Promoting fundamental movement skill development and physical activity in early childhood settings: a cluster randomized controlled trial. Pediatr Exerc Sci 2011;23:600–15.
22. Freedson P, Pober D, Janz KF. Calibration of accelerometer output for children. Med Sci Sports Exerc 2005;37:Suppl 11:S523–30.
23. Trost SG. State of the art reviews: measurement of physical activity in children and adolescents. Am J Lifestyle Med 2007;1:299–314.
24. Reilly JJ, Penpraze V, Hislop J, Davies G, Grant S, Paton JY. Objective measurement of physical activity and sedentary behaviour: review with new data. Arch Dis Child 2008;93:614–9.
25. Fisher A, Reilly JJ, Kelly LA, et al. Fundamental movement skills and habitual physical activity in young children. Med Sci Sports Exerc 2005;37:684–8.
26. Specker B, Binkley T. Randomized trial of physical activity and calcium supplementation on bone mineral content in 3- to 5-year-old children. J Bone Miner Res 2003;18:885–92.
27. Vale SM, Santos RM, da Cruz Soares-Miranda LM, Moreira CM, Ruiz JR, Mota JA. Objectively measured physical activity and body mass index in preschool children. Int J Pediatr 2010 (doi:10.1155/2010/479439).
28. Rowlands AV. Accelerometer assessment of physical activity in children: an update. Pediatr Exerc Sci 2007;19:252–66.
29. Corder K, Ekelund U, Steele RM, Wareham NJ, Brage S. Assessment of physical activity in youth. J Appl Physiol 2008;105:977–87.
30. Ward DS, Evenson KR, Vaughn A, Rodgers AB, Troiano RP. Accelerometer use in physical activity: best practices and research recommendations. Med Sci Sports Exerc 2005;37:Suppl 11:S582–8.
31. Pfeiffer KA, McIver KL, Dowda M, Almeida MJ, Pate RR. Validation and calibration of the Actical accelerometer in preschool children. Med Sci Sports Exerc 2006;38:152–7.
32. Sirard JR, Pate RR. Physical activity assessment in children and adolescents. Sports Med 2001;31:439–54.
33. Dwyer GM, Baur LA, Hardy LL. The challenge of understanding and assessing physical activity in preschool-age children: Thinking beyond the framework of intensity, duration and frequency of activity. J Sci Med Sport 2009;12:534–6.
34. Nilsson A, Ekelund U, Yngve A et al. Physical activity among children with the accelerometers using different time sampling intervals and placements. Pediat Exer Sci 2002;14:87–96.
35. Li Lu NS. Reliability Analysis: Calculate and Compare Intra-class Correlation Coefficients (ICC) in SAS. Hyattsville, MD: The NorthEast SAS Users Group (NESUG), 2007;1–4.
36. Centers for Disease Control and Prevention. Growth Charts. 2000. (http://www.cdc.gov/growthcharts/html_charts/bmiagerev.htm).
37. Asmar N. Partial differential equations with Fourier series and boundary value problems. 2nd edn. Columbia, MO: Pearson Prentice Hall, 2005.