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ORIGINAL COMMUNICATION

Physical activity pattern of children assessed by triaxial accelerometry

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Objectives: Accelerometry was used to assess the relationship between the physical activity level (PAL) and time spent on activities of various intensities in children.
Design: A total of 20 children aged 8.6 ± 3.3 y wore a triaxial accelerometer (Tracmor2) for 2 weeks. PAL was calculated with Tracmor2 output data. The fraction of time spent on activities with a given level of intensity (low, moderate, high) was calculated. The fractions of time spent on activities of different intensities were compared with previously obtained data for young adults and elderly persons.
Results: PAL showed an inverse relation with the percentage of time spent on low-intensity activities ($r = -0.76$; $P < 0.0001$) and a positive relation with the percentage of time spent on high-intensity activities ($r = 0.93$; $P < 0.0001$). The fraction of time spent on low-intensity activities was smaller in children than in young adults ($P < 0.05$) and elderly persons ($P < 0.0001$), while the fraction spent on high-intensity activities ($P < 0.0001$) was larger.
Conclusions: The present data are important for a better understanding of physical activity in children, which is necessary for education and prevention about physical (in)activity in childhood. Our observations suggest that to obtain a higher PAL in children, they should be given the opportunities to perform high-intensity activities.
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Introduction

Physical inactivity is becoming more and more a characteristic of our modern way of life. At the same time, obesity is becoming an increasing problem among adults and even among children (James *et al*, 2001).

In the Netherlands, 10% of the children between ages 5 and 11 y are obese (Raad van de volksgezondheid en zorg, 2002) and obesity in childhood is predictable for obesity at adult age (Molnar & Livingstone, 2000; Steinberger *et al*, 2001). Therefore, the prevention of physical inactivity should begin in early life. However, bringing about changes in the habitual lifestyle of children requires an understanding of their current levels and patterns of activity.

Physical activity can be assessed in different ways. With use of the doubly labeled water (DLW) method, physical activity can be measured over a 1–2-week period, without interfering with the subject's natural activity behavior (Westerterp *et al*, 1995). The technique is easily applicable and requires only the collection of some urine samples for the subject. The DLW method is regarded as the 'gold standard' for the validation of other instruments measuring physical activity. However, a practical limitation of large-scale application of the DLW technique is the high costs. In addition, the DLW method can only be used to measure the average physical activity level. Accelerometers, on the other hand, are able to measure physical activity intensity and physical activity patterns, that is, the time spent on activities of low- (sitting), moderate- (walking) and high-intensity (running) activities. The CSA (Computer Science and Applications Inc. Monitor) and Tracmor have been validated against DLW and proven to be reliable tools for the

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assessment of physical activity (Bouten *et al*, 1996; Ekelund *et al*, 2001; Hoos *et al*, 2003b). The CSA is a uniaxial accelerometer. Uniaxial accelerometers measure the occurrence and intensity of movements in the horizontal plane (Ekelund *et al*, 2001). The Tracmor, a triaxial accelerometer, registers movements in three dimensions (Bouten *et al*, 1996).

The Tracmor has been used to measure physical activity patterns in adults (Bouten *et al*, 1996; Westerterp, 2001). These studies showed that spending more time on moderate-intensity activities and thereby reducing the time spent on low-intensity activities is more effective in increasing overall activity levels than spending more time on high-intensity activities. This is most likely explained by the fact that high-intensity activities are usually performed for a short period of time.

In children, less is known about physical activity patterns. Although it is generally assumed that children are more active than adults, no studies exist comparing physical activity patterns of children to those of adults. The present study was aimed at the measurement of levels and patterns of physical activity in healthy children, using a triaxial accelerometer.

Methods

Subjects

A total of 20 healthy children (13 female, 7 male) with a mean age of 8.6 ($\pm$3.3) y wore the Tracmor2, a triaxial accelerometer, for 2 weeks. The children were healthy and free from any medical condition that could restrict their physical activity. Body weight was 27.7 ($\pm$10.8) kg and height 1.3 ($\pm$0.2) m. Body weight expressed as SDS according to Dutch reference data (Gerver & de Bruin, 2001) was −0.46 ($\pm$1.2), height SDS was –0.82 ($\pm$1.2) and weight for height SDS was −0.02 ($\pm$1.1). Parents and children were informed about the study before written informed consent was obtained. The study was approved by the Ethical Committee of the University Hospital Maastricht.

Tracmor2

The physical activity level (PAL) was assessed with a trixial accelerometer for movement registration (Tracmor2, Philips Research, Eindhoven, The Netherlands). Tracmor output expressed as counts per minute (c.p.m.) was converted into PAL values according to a regression equation based on DLW data in children: $\mathrm{PAL} = 1.156\ 10^{-5}$ * Tracmor2 average counts/day + 0.978 ($r = 0.79$, $P < 0.01$) (Hoos *et al*, 2003b). The Tracmor2 is a small ($7 \times 2.8 \times 0.8$ cm) and light (30 g) device, which is worn on a belt at the back of the waist. The triaxial accelerometer calculates the sum of the rectified and integrated acceleration curves from the anteroposterior, mediolateral and vertical directions of the trunk. The integration period was set at 1 min and the final output was expressed as c.p.m. (Bouten *et al*, 1996).

The Tracmor was worn during waking hours, except while showering and during swimming. The parents of the children recorded the time when the children woke up, put the Tracmor2 on and off and went to bed. If the time during which they wore the device and the time spent sleeping did not add up to at least 22 h, the day was excluded from the analysis (mean number of recorded days 11).

Activities were divided into three intensity levels as described before (Bouten *et al*, 1996; Meijer *et al*, 2001). Low-intensity activities, associated with accelerometer outputs $\leq$200 c.p.m. include lying, sitting and standing. Moderate-intensity activities included walking up to 2.0 km/h as observed in five children walking on a treadmill with simultaneous measurement of tracmor counts and resulted in the higher cut-off level of 500 c.p.m. The different studies used different Tracmor versions with respect to the number of counts for the same activity. However, all Tracmor versions were calibrated against DLW and for each version cutoff points were defined for the same activities using a validation test on a motor-driven treadmill as described elsewhere (Bouten *et al*, 1996; Meijer *et al*, 2001). In the present study, the same Tracmor version has been used as in the study of Meijer *et al*, while the study of Bouten *et al* applied an earlier Tracmor version. The fraction of time spent at a given intensity level was calculated as the time spent at that intensity level divided by the total activity time.

Statistics

PAL values were calculated on the basis of Tracmor output according to a regression equation as published before (Hoos *et al*, 2003b). The fraction of time spent on activities at the three different intensity levels was correlated to PAL values as measured by accelerometry. To strengthen these results the same analysis has been performed in the patient group described elsewhere ($n = 11$) (Hoos *et al*, 2003b), in which besides accelerometry DLW measurements were performed. So PAL values calculated according to DLW were correlated to the fraction of time spent on activities at the three different intensity levels. Activity intensities were compared with previously published data on elderly persons (mean age 61 y, $n = 28$) (Meijer *et al*, 2001) and young adults (mean age 27 y, $n = 27$) (Bouten *et al*, 1996) using a Mann–Whitney U–Wilcoxon Rank Sum test.

Results

The amount of Tracmor counts was not significantly different between boys and girls; therefore, all children were taken together in the analysis. The fraction of time spent on low-intensity activities was inversely correlated to PAL, while time spent on high-intensity activities was positively correlated ($r = -0.76$; $P < 0.0001$ and $r = 0.93$; $P < 0.0001$, respectively). The fraction of time spent on moderate-intensity activities was not significantly correlated to PAL

(Figure 1). Figure 2 shows the same results based on DLW measurements. For the percentage of low-intensity activities $r=-0.54$; $P=0.09$, for the percentage of high activities $r=0.68$; $P=0.02$. Also, this analysis shows no correlation for the percentage of time spent on moderate-intensity activities.

Children spend 56% of their time on low-intensity activities, 25% on moderate-intensity activities and 19% on high-intensity activities. This activity pattern was compared to previously published activity patterns of adults (Bouten *et al*, 1996) and the elderly (Meijer *et al*, 2001). The fraction of time spent on low intensity activities was significantly lower in children than in adults ($P<0.05$) and elderly persons ($P<0.0001$), while the fraction of time spent on high-intensity activities was significantly higher in children than in adults and elderly persons ($P<0.0001$) (Table 1). The fraction of time spent on moderate-intensity activities was significantly higher in the children than in the elderly ($P<0.0001$), although it did not differ significantly from that in adults.

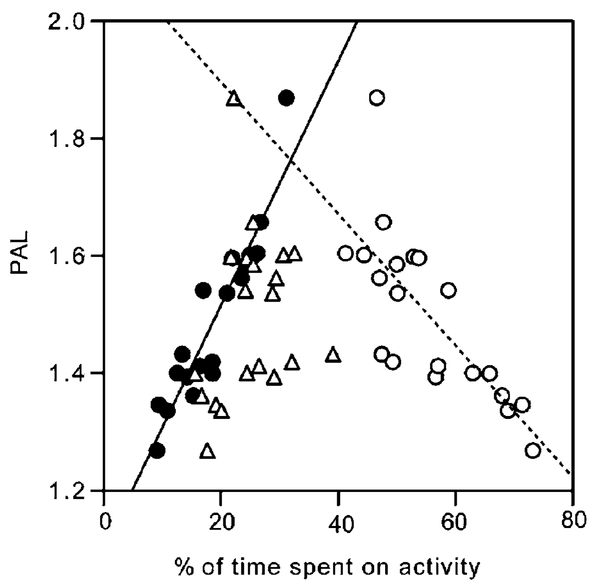

Figure 1 PALs as a function of the fraction of daytime hours spent on low- (circles), moderate- (triangles) and high-intensity (closed circles) activities. Tracmor output expressed as c.p.m. was converted into PAL values according to a regression equation based on DLW data in children: PAL$=1.156\times10^{-5}$ * Tracmor2 average counts/day $+0.978$ ($r=0.79$, $P<0.01$) (Hoos *et al*, 2003b).

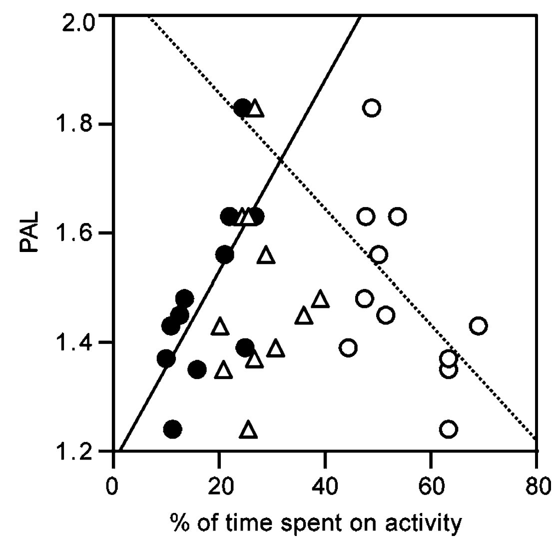

Figure 2 PALs as a function of the fraction of daytime hours spent on low- (circles), moderate- (triangles) and high-intensity (closed circles) activities. PAL was established according to DLW data in a study population published elsewhere (Hoos *et al*, 2003b).

Discussion

Owing to the negative effects that physical inactivity may have on health, the interest in methods to measure physical activity levels increases. Although an increasing number of health promotion programs aim to change activity patterns, few data are available about the physical activity pattern and of the factors that affect the physical activity level, especially in children. The present study was aimed to assess the physical activity pattern in children using the Tracmor2

Table 1 Daily amount of sleep and activity time, physical activity level (PAL) and percentage of time spent on activities of low, moderate and high intensity

	Children		*Adults*		*Elderly*	
Variable (unit)	*Mean*	*Range*	*Mean*	*Range*	*Mean*	*Range*
Sleeping time (h/day)	11.2	9.4–12.2	8.3	6.7–10.5	8.5	6.4–11.5
Activity time (h/day)	12.3	11.1–14.7	13.7	10.9–16.1	14.4	11.7–17.2
PAL	1.5	1.3–1.9	1.77	1.5–2.0	1.65	1.4–2.0
Low activity (%)	56	41–73	65**	52–82	82*	66–95
Moderate activity (%)	25	16–39	25	11–36	15*	3–22
High activity (%)	19	9–31	9*	3–15	4*	1–12

Data for young adults and elderly persons obtained from previous studies (Bouten *et al*, 1996; Meijer *et al*, 2001). *Significant difference between adults or elderly persons and children $P<0.0001$. **Significant difference between children and adults $P<0.05$.

accelerometer. Tracmor2 has been proven to be a reliable method to measure physical activity patterns (Meijer *et al*, 2001; Hoos *et al*, 2003b). Compared to other accelerometers, Tracmor2 is a small ($7 \times 2.8 \times 0.8$ cm) and light (30 g) device, which optimizes subject comfort (Westerterp, 1999).

In the present study among children, it was found that the fraction of time spent on moderate-intensity activities did not contribute significantly to PAL, unlike the fraction spent on low- and high-intensity activities. These results were found by acclerometry and could also be confirmed by data analysis based on DLW data. In contrast to the findings in adults, where the amount of overall physical activity can be increased by expanding the amount of time spent on activities of moderate intensity and reducing low-intensity activities (Westerterp, 2001), children should be stimulated to perform more high-intensity activities because those activities belong to their habitual activity pattern.

Comparing physical activity patterns of children to those of adults and the elderly shows that the children spend more of their active time on high-intensity activities. Young adults spend an average of 9% of their active time on high-intensity activities, while the corresponding percentage among the elderly was found to be 4%. In contrast, the present study found that children spend an average of 19% of their total active time on high-intensity activities.

The difference in the time spent on high-intensity activities between children and adults reflects the different activity patterns among children, which are characterized by short, intermittent bouts of vigorous physical activity (Bailey *et al*, 1995; Council for Physical Education for Children, 1998; Rowland, 1998; Molnar *et al*, 2000). Probably because of their lower body weight, it is easier for children to perform high-intensity activities.

Even though children spend more time on high-intensity activities, the PAL values we found among children were lower than those reported for young adults and the elderly. In addition to the fact that because of their lower body weight, high-intensity activities costs them less energy (Hoos *et al*, 2003a), this can probably be explained by the difference in the amount of sleep. The children slept an average of 11.2 h a day, while adults have been found to sleep for an average of 8.3 h, implying a longer total activity time for adults.

It would be of interest to measure the physical activity pattern of obese children using the Tracmor2 and to compare those with the activity pattern of healthy children. As we found PAL to be influenced by changes in low- and high-intensity activities in children, a decreased amount of time spent on high intensity activities is expected in obese children. If this would appear to be true, health programs should be aimed at educating parents of obese children to stimulate their children to perform more high-intensity activities (playing outside) instead of low-intensity activities (playing computer games).

In conclusion, our observations suggest that to obtain a higher PAL in children, they should be given the opportunities to perform high-intensity activities. In addition, children should be educated about the importance of regular physical activity to prevent inactivity in adulthood.

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