Abstract  The purpose of the present study was to evaluate moderate-to-vigorous physical activity using triaxial accelerometry in Japanese preschool children. The relationship between daily step counts as a convenient measure of physical activity and minutes of engagement in moderate-to-vigorous physical activity was also examined. Physical activity was assessed using a triaxial accelerometer (ActivTracer, GMS) and daily steps using a uniaxial accelerometer for 6 consecutive days, including weekdays and weekend days, in 157 four- to six-year-old Japanese children attending kindergarten or nursery school. Using triaxial and uniaxial accelerometers, nonlocomotive activities and step counts for young children can be evaluated, respectively. Average daily moderate-to-vigorous physical activity (physical activity ratio ≥3) and step counts were 102 (±32) min/day and 13,037 (±2,846) steps/day, respectively. A strong and significant correlation was observed between minutes of moderate-to-vigorous physical activity and step counts (r = 0.832, p < 0.001). The daily step counts corresponding to 60 min, 100 min, and 120 min of moderate-to-vigorous physical activity were 9,934, 12,893, and 14,373 steps/day, respectively. The correlation coefficient between minutes of higher intensity activities (physical activity ratio ≥4) and step counts was slightly lower (r = 0.604, p < 0.001). The daily step count corresponding to 30 min of the higher intensity activities was 14,768 steps/day. These results suggest that approximately 13,000 steps/day are required for preschool children to engage in more than 100 min of moderate-to-vigorous physical activity. J Physiol Anthropol 28(6): 283–288, 2009 http://www.jstage.jst.go.jp/browse/jpa2 [DOI: 10.2114/jpa2.28.283]

Keywords: physical activity, accelerometry, preschool children, pedometer, total steps

Introduction

Physical activity (PA) guidelines for young people have been available since the 1980s. Currently, most of the PA guidelines recommend at least 60 min per day of at least moderate-intensity PA (Biddle et al., 1998; National Association for Sport and Physical Education, 2002, 2004; Strong et al., 2005). Therefore, an accurate evaluation of daily PA in young children is important. The questionnaire (e.g., activity diary) and accelerometer methods are relatively noninvasive. Recently, Wareham et al. (2005) and Blair and Haskell (2006) have argued that objective measurements are necessary to accurately evaluate PA. Self-reported measures for PA are particularly difficult in young children, because the questionnaire is subjective and the measures for PA depend on the observer. An objective measurement approach using an accelerometer avoids these limitations, and an accelerometer can be used to predict energy expenditure and to classify levels of PA (Chen and Bassett, 2005; Freedson et al., 2005; Matthews, 2005; Treuth et al., 2004).

Accelerometers may be particularly useful for measuring physical activity in preschool-aged children, because they are not usually engaged in prolonged exercise. Validation studies of accelerometers have been performed in preschool children (Pate et al., 2006; Pfeiffer et al., 2006; Reilly et al., 2003; Sirard et al., 2005; Tanaka et al., 2007a, b). Moreover, Eston et al. (1998) showed that three-dimensional accelerometers may provide a better evaluation of children’s free-play activities than uniaxial accelerometers. One of the reasons is that movement within the anteroposterior plane as measured with triaxial accelerometry is the main component of physical activity of typical children (mean age 9.2 +/- 0.8 yr). Moreover, Oliver et al. (2007) pointed out that preschoolers participate in activities that require less vertical movement and more omnidirectional movement. Thus, triaxial accelerometers may capture total body movement better than uniaxial devices.
(Chen and Bassett, 2005; Matthews, 2005). However, little data on PA intensity, especially in preschool-aged children in free-living conditions, has been obtained using triaxial accelerometers (see reviews by Oliver et al. (2007) and Hinkley et al. (2008)). In addition, a recent study of ours has shown that discrimination between ambulation and play in preschool children (e.g., ball tossing) using a triaxial accelerometer (ActivTracer, GMS) contributes to better evaluation of PA intensity (Tanaka et al., 2007a). Similar results were reported in adults (Midorikawa et al., 2007). These studies suggest that relationships between PA intensity and acceleration counts are different between locomotion and the other types of PA, and that previous studies (even with a triaxial accelerometer) did not assess types of PA other than locomotion. However, the ActivTracer is expensive (about $2,000 (USD)) and does not have specific software to calculate energy expenditure for evaluating PA. Thus, for research studies with large sample sizes, more convenient devices such as pedometers are more useful than the triaxial accelerometer, although pedometers cannot evaluate levels of PA.

Two recommendations for the average daily number of steps have been suggested for elementary school-aged children (Tudor-Locke et al., 2004; Vincent and Pangrazi, 2002). Vincent and Pangrazi (2002) recommended 13,000 steps/day for boys and 11,000 steps/day for girls. Tudor-Locke et al. (2004, 2008) recommended 15,000 and 12,000 steps/day, respectively. Eisenmann et al. (2007) examined the utility of these recommendations in predicting childhood adiposity. They found that the likelihood of being classified as overweight was greater for subjects who did not meet the recommendation for steps per day than for those who did meet it. Locomotion is one of the important parts of PA in free-living conditions and daily step counts have been used as an index of PA in many studies. However, data on daily PA and total steps in representative samples of preschool-aged children using the accelerometer remain insufficient, particularly for Japanese (Cardon and De Bourdeaudhuij, 2007; Fisher et al., 2005; Jackson et al., 2003; Montgomery et al., 2004; Pate et al., 2004), and data on the relationship between total steps and minutes of engagement in moderate-to-vigorous physical activity (MVPA), except for data reported by Cardon and De Bourdeaudhuij (2007), are lacking. Cardon and De Bourdeaudhuij (2007) found a relatively strong correlation (r=0.73) between daily step counts and minutes of engagement in MVPA using a uniaxial accelerometer (MTI Actigraph) in 4- and 5-year-old children. However, accelerometers with a single regression equation based on locomotive activity underestimate the energy expenditure of nonlocomotive activities in adults (Matthews, 2005) and young children (Tanaka et al., 2007a). Unlike adults, children engage in types of PA other than locomotion (Oliver et al., 2007). Therefore, the present study used a vertical/horizontal counts ratio as a classification criterion and to discriminate between different types of medium-intensity activities including walking and nonlocomotive activities (Tanaka et al., 2007a).

The purposes of this study were 1) to describe the patterns of PA classified according to intensity using a triaxial accelerometer (ActivTracer, GMS), which can discriminate locomotive from nonlocomotive activities, and 2) to measure total daily number of steps using uniaxial accelerometry (Lifecorder EX, Suzuken) in Japanese preschool children. We also examined the relationship of daily step counts (a simple method for measuring PA) to minutes of engagement in MVPA.

**Methods**

**Subjects**

The subjects were 212 four- to six-year-old Japanese preschool children (85 girls and 127 boys; mean age 5.8±0.6 years, range 4.5–6.8 years), living in the Tokyo metropolitan area and attending kindergarten or nursery school. All of the subjects reported being in good health, without any anamnesis of conditions affecting energy expenditure, such as abnormal thyroid gland function. Informed consent was obtained from a parent, and the Ethical Committee of J. F. Oberlin University approved the study protocol.

**Measurement items and methods**

Body height and weight were measured to the nearest 0.1 cm and 0.1 kg, respectively. Habitual PA was measured using a triaxial accelerometer (ActivTracer, GMS, Tokyo) and a uniaxial accelerometer (Lifecorder EX, Suzuken, Nagoya). The subjects wore a 57-gram ActivTracer and a 60-gram Lifecorder EX on the left side of the waist, as previously described (Tanaka et al., 2007a, b). The ActivTracer was set to record in 1-min epochs; the Lifecorder EX was set to measure exercise intensity in 4-sec epochs and step counts in 1-min epochs. PA was monitored continuously for 6 days (generally, 4 weekdays plus 2 weekend days). Subjects were requested to wear these devices except during unavoidable circumstances, such as dressing and bathing. The times that the subjects did not wear the equipment and sleeping times were recorded by their parents. The Lifecorder EX records a signal of 0.5 or 1 to 9 every 4 seconds while being worn, even if the subjects are asleep. When no signal was detected for more than one hour by the Lifecorder, the period was regarded as nonwearing time for both the ActivTracer and Lifecorder. We excluded days during which more than 2 hours of non-wearing time had accrued, not counting time allowed for the above-mentioned unavoidable reasons, and days during which subjects were absent from kindergarten or nursery school. Subjects with at least two weekdays and at least one weekend were used in the analyses. As a result, PA was measured successfully in 157 of 212 children (74%).

Synthetic activity counts were recorded every 1 min by the ActivTracer, and PAR (physical activity ratio), a multiple of basal metabolic rate, was estimated as previously described (Tanaka et al., 2007a). When the synthetic activity counts were in the range corresponding to medium-intensity activities
(between 130 and 600 mG), classification criteria using the vertical/horizontal counts ratio (as previously described) were used to discriminate different types of medium-intensity activities, because the PAR for some medium-intensity activities (i.e., non-locomotive activities) are underestimated (Tanaka et al., 2007a): The vertical/horizontal ratio for 1) walking is ≥1.19 and for 2) nonlocomotive activities, <1.19.

Furthermore, daily step counts were evaluated using a Lifecorder EX. With this device, if the second step is not recognized within 1.5 seconds, the first step is not counted.

Analyses

Average number of weekday and weekend minutes spent in MVPA (PAR ≥3), PAR ≥4, and medium-intensity activities, number of steps, and physical activity level (PAL; total energy expenditure/basal metabolic rate) were calculated for each individual, and then the average weekly values were calculated by weighting for 5 weekdays and 2 weekend days. The relationship between the two variables was evaluated by Pearson’s correlation and a linear regression model. A Student’s t-test was carried out to assess the influence of gender. All results are shown as the mean ± standard deviation (SD). Statistical analyses were performed with SPSS version 15.0J for Windows (SPSS Inc, Japan, Tokyo). All statistical tests were regarded as significant when the p-values were less than 0.05.

Results

The physical characteristics of the subjects are shown in Table 1. Most of the subjects in the present study were of normal weight. The numbers of overweight girls and boys based on body mass index (Cole et al., 2000) were 2 and 5, respectively. One girl was obese. Morphological variables did not show a gender difference.

Table 1  Physical characteristics of subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>All subjects (n=157) Mean±SD</th>
<th>Girls (n=69) Mean±SD</th>
<th>Boys (n=88) Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>5.9±0.5</td>
<td>5.9±0.5</td>
<td>5.9±0.5</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>112.0±5.6</td>
<td>112.3±4.7</td>
<td>111.8±6.2</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>19.0±2.8</td>
<td>18.9±2.6</td>
<td>19.0±3.0</td>
</tr>
<tr>
<td>Body mass index (kg/m²)</td>
<td>15.1±1.3</td>
<td>15.0±1.4</td>
<td>15.1±1.2</td>
</tr>
</tbody>
</table>

Table 2  Characteristics of daily physical activity

<table>
<thead>
<tr>
<th>Activity</th>
<th>All subjects (n=157) Mean±SD</th>
<th>Girls (n=69) Mean±SD</th>
<th>Boys (n=88) Mean±SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time in MVPA (min/day)</td>
<td>102.0±32.0</td>
<td>88.8±28.9</td>
<td>112.3±30.7*</td>
</tr>
<tr>
<td>Time in PAR ≥4 (min/day)</td>
<td>19.9±10.1</td>
<td>16.4±9.0</td>
<td>22.6±10.1*</td>
</tr>
<tr>
<td>Step counts (counts/day)</td>
<td>13037±2846</td>
<td>12255±2823</td>
<td>13659±2726*</td>
</tr>
<tr>
<td>PAL</td>
<td>1.54±0.08</td>
<td>1.51±0.07</td>
<td>1.55±0.08*</td>
</tr>
</tbody>
</table>

MVPA: moderate-to-vigorous physical activity, PAR: physical activity ratio, PAL: physical activity level, *: girls vs boys p<0.05.
51.6%, and 27.4% of the children attained these levels of MVPA, respectively. Furthermore, a significant correlation was also observed between minutes of PAR $\geq$4 and step counts ($r=0.604$, $p<0.001$). The daily step count corresponding to 30 min of PAR $\geq$4 activity (engaged in by 12.7% of the children) was 14,768 steps. When synthetic activity counts corresponding to medium-intensity activity (between 130 and 600 mG) were obtained, the amount of time spent in walking-type and nonlocomotive-type activities was 74$\pm$41 min/day and 167$\pm$47 min/day, respectively.

Discussion

Comparison with previous studies

This study evaluated MVPA using triaxial accelerometry in preschool-aged Japanese children. The association between daily step counts measured by uniaxial accelerometry and minutes of engagement in MVPA was also examined, as the uniaxial accelerometer is a more conventional method for measuring PA. Tanaka et al. (2007a) defined an MVPA cutoff point of PAR $\geq$3 for preschool-aged children; the average value of PAR for normal walking is 2.6. Therefore, in the present study, MVPA would have consisted of activities such as brisk walking, ball tossing, or more vigorous activities.

The current international guidelines recommend at least 60 min or more per day of MVPA for children’s health maintenance (Biddle et al., 1998; National Association for Sport and Physical Education, 2002, 2004; Strong et al., 2005). In the present study, 92.4% of the children spent $\geq$60 min/day in MVPA, and 51.6% of the children spent $\geq$100 min/day in MVPA. The average amount of MVPA was 102$\pm$32 min/day. To our knowledge, this is the first report to examine Japanese children’s PA level using a triaxial accelerometer. In a previous study (Montgomery et al., 2004), direct observation of 2.6- to 6.9-year-old children showed that they spent most of their time engaged in sedentary activities (girls: 79%, boys: 73%) and only small amounts of time in MVPA (3% and 4%, respectively) as measured by a CSA/MTI uniaxial accelerometer. Reilly et al. (2004) also observed that the median time spent in MVPA was only 4% at 5 years of age as measured by a CSA/MTI uniaxial accelerometer. Alhassan et al. (2007), using an ActiGraph uniaxial accelerometer, showed that the average total daily time spent in MVPA at age 3.6$\pm$0.5 years was 2.0$\pm$1.6% in the intervention group and 1.4$\pm$0.9% in the control group. However, the results of the present study coincided closely with results in other previous studies of youth activity level measured by heart-rate monitor or accelerometer (Andersen et al., 2006; Epstein et al., 2001). Andersen et al. (2006), using an ActiGraph uniaxial accelerometer, showed that the average time spent at levels above 4 km/h at age 9 years was 116 min and at 15 years 88 min. On the other hand, Epstein et al. (2001), using a heart rate monitor, found that youths aged 3 to 17 years engaged in MVPA for 60–120 min. However, it should be noted that the present data were recorded at 1-min epochs, which may not be sensitive enough to pick up short bursts of vigorous activity (Nilsson et al., 2002). As Freedson et al. (2005) pointed out, a major and as yet unresolved problem of comparing studies is the lack of a consensus on how the activity intensity cutoff points are defined.

Our previous study showed that linear and nonlinear regression equations using vertical acceleration counts overestimated PAR for very low-intensity activities and underestimated PAR for nonlocomotive activities (such as ball tossing and stair climbing) more than the other models for preschool-aged children (Tanaka et al., 2007a). However, all models underestimated PAR while ball tossing and stair climbing to the same degree. Therefore, an additional analysis was applied in the present study to distinguish these activities from walking. The results show that the present subjects were engaged in walking-type activities for 74$\pm$41 min/day and in nonlocomotive-type activities for 167$\pm$47 min/day. Thus, adjustment of the values predicted by the regression equations using the vertical/horizontal counts ratio improved the underestimation of PAR for nonlocomotive activities such as ball tossing. The obtained average percentage difference was improved from $-32.1\pm18.9\%$ to $-4.7\pm15.5\%$. The results also suggest that the previous algorithms for evaluation of PA intensity using accelerometers may lead to erroneous estimations of PA intensities. In addition, some of the previous studies (Montgomery et al., 2004, Reilly et al., 2004) were based on cutoff values applied to accelerometer output that was validated against direct observation in 3- to 5-year-olds (Reilly et al., 2003; Sirard et al., 2005). Therefore, the difference in daily time spent in MVPA between our data and previous studies might be explained by different cutoff points and algorithms.

Relationship between period of engagement in moderate-to-vigorous physical activity and daily step counts

The average daily step count in the present study was 13,037$\pm$2,846 steps/day in 4- to 6-year-old children. On the other hand, Cardon and De Bourdeaudhuij (2007) reported that the average daily step count in 4- to 5-year-olds was 9,980$\pm$2,605 steps/day, and concluded that daily step counts in preschool-aged children were low. There are two recommendations regarding the number of steps per day for elementary school children (Tudor-Locke et al., 2004; Vincent and Pangrazi, 2002). Vincent and Pangrazi (2002) recommended 11,000 steps/day for girls and 13,000 steps/day for boys. Tudor-Locke et al. (2004) recommended 12,000 and 15,000 steps/day, respectively. The average values of the present study were similar to all recommended values, except the value for boys recommended by Tudor-Locke. Nakae et al. (2008) recently reported that a spring-levered pedometer underestimates step counts at the slow and normal paces of young children by more than 20%, whereas piezo-electric pedometers are much more accurate. Cardon and De Bourdeaudhuij (2007) used a spring-levered pedometer (Yamax Digiwalker) while we used a piezo-electric pedometer.
(Lifecorder EX), which may be the main reason for the considerably different average step counts. Thus, the average step counts for preschool-aged children might be higher than that measured by the previous study (Cardon and De Bourdeaudhuij, 2007).

Locomotion comprises one of the important parts of physical activity in free-living conditions, and daily step counts have been used as an index of physical activity in many studies. However, the relationship between daily step counts and MVPA engagement time has not been examined except by Cardon and De Bourdeaudhuij (2007). In the present study, a strong and significant correlation was observed between minutes of MVPA and step counts ($r=0.833$, $p<0.001$). The daily step counts in 60 min, 100 min, and 120 min of moderate-to-vigorous physical activity were 9,934, 12,893, and 14,373 steps, respectively, and 92.4%, 51.6%, and 27.4% of the children attained these step count levels, respectively. The relationship between minutes of MVPA and step counts was in agreement with the results reported by Cardon and De Bourdeaudhuij (2007) ($r=0.73$, $p<0.001$). However, only 8% of their subjects reached the daily step count level corresponding to 60 min of MVPA per day. Thus, the percentage of children achieving this level was higher in the present study than in their study. Though differences in categorization of moderate-intensity activities might influence the results, both studies categorized, as similar, activities with the same intensity level; namely, they also categorized brisk walking as a moderate-intensity activity. The present study categorized brisk walking as a moderate-intensity activity because our previous study revealed that the PAR for normal-speed walking in 6-year-olds was $2.60\pm0.49$ (Tanaka et al., 2007a). However, other differences in cutoff points might help explain the disparate results.

A significant correlation was also observed between minutes of PAR $\geq4$ and step counts ($r=0.604$, $p<0.001$), and 12.7% of the children engaged in 30 min or more of PAR $\geq4$ activity. The correlation coefficient was slightly lower than that for PAR $\geq3$. Because the PAR for normal walking is $2.60\pm0.49$ (Tanaka et al., 2007a), it is estimated that PAR $\geq4$ activities such as very brisk walking and running comprised a small percentage of overall locomotion, which may be the main reason for the weaker correlation. Thus, total number of steps may be a good index for moderate-intensity PA, though not for relatively high-intensity PA.

The estimated average time engaged in locomotion was 106 min, as calculated by average daily step counts in the present study (13,037 steps) and by the average step rate (122.7 steps/min) in our calibration study (Tanaka et al., 2007b). However, the percentage of time in nonlocomotive type activities was much larger than that spent in walking type activities, in the range of synthetic activity counts corresponding to medium-intensity activity. In addition, only brisk (but not normal) walking and running are included in MVPA, judging from the average PAR for normal walking in the calibration study (Tanaka et al., 2007a). Therefore, it should be noted that less than half of the 106 min was spent in MVPA in the present study. Nevertheless, the average amount of time engaged in MVPA as measured by triaxial accelerometry was almost 100 min and was strongly correlated with total daily number of steps. These results indicate that young children who engage in a substantial amount of MVPA have high daily step counts, even though prolonged locomotion does not comprise a large part of total MVPA.

In conclusion, this study suggests that daily step counts give valid information on daily physical activity for preschool-aged children. These children need to take 12,893 steps/day to attain the recommended 100 min/day of MVPA or 14,758 steps/day to attain 30 min/day of PAR $\geq4$ activity.

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References


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