Relation between physical activity and energy expenditure in a representative sample of young children

Colette Montgomery, John J Reilly, Diane M Jackson, Louise A Kelly, Christine Slater, James Y Paton, and Stan Grant

ABSTRACT
Background: Strategies for the prevention and treatment of childhood obesity require a better understanding of the relation between the pattern of free-living physical activity and total energy expenditure (TEE).
Objective: We assessed the relations between TEE and physical activity level (PAL) during engagement in different intensities of physical activity.
Design: We used a cross-sectional study of 104 children (median age: 5.4 y) in Scotland. TEE was measured with use of doubly labeled water (DLW), and resting energy expenditure was predicted to determine PAL. Time spent sedentary and in light-intensity activity and in moderate- and vigorous-intensity physical activity (MVPA) was assessed by accelerometry concurrent with DLW measurements. Correlation and regression were used to assess the relations between measures of sedentary behavior, intensities of activity, and PAL as the dependent variable.
Results: Time spent sedentary was negatively correlated with PAL ($r = -0.33, P < 0.01$), and time spent in light-intensity activity was positively correlated with PAL ($r = 0.31, P < 0.01$). In multiple regression analyses, both time spent sedentary and in light-intensity activities were significantly associated with PAL. Time spent in MVPA was not associated with PAL; engagement in MVPA was limited in this sample (median: 3% of waking hours; range: 0–14%). PAL was significantly higher in boys than in girls.
Conclusion: In this sample and setting, PAL was not influenced by engagement in MVPA but was influenced by time spent sedentary and in light-intensity activities. This study suggests that in young children, MVPA could make only a minor contribution to free-living TEE and PAL.

KEY WORDS Doubly labeled water method, preschool children, obesity, physical activity, accelerometry

INTRODUCTION
In recent years, a global epidemic of pediatric obesity (1–3) has affected both preschool and older children (4). Reduced total energy expenditure (TEE) secondary to a decline in physical activity could be a contributing factor (2, 5). Many observers believe that increased population physical activity could alleviate the obesity epidemic either by directly increasing TEE (6) or because coupling of intake and expenditure could be poor at low levels of TEE (6). However, the relation between free-living TEE and physical activity is currently unclear for all populations (7, 8), particularly children, in part because of practical difficulties associated with the measurement of free-living TEE and physical activity.

A study of 29 Dutch adults (8) made an important contribution to the field by measuring physical activity (by accelerometry) and TEE [by doubly labeled water (DLW)]. By combining these methods, Westerterp (8) was able, for the first time, to quantitatively assess the contribution of different intensities of physical activity to TEE in adults. He concluded that, in his specific sample and setting, variations in TEE and physical activity level (PAL) were largely the result of variations in moderate-intensity physical activities. This observation is important because, if it is generally applicable, it suggests that clinical and public health recommendations to increase light- and moderate-intensity activity (rather than vigorous-intensity activity) should be made both to prevent and treat obesity. However, the relations between PAL and TEE reported by Westerterp (8) for Dutch adults may not apply to other populations. A recent meta-analysis (9) suggested that greater engagement in intense physical activities might be necessary to alter TEE and energy balance significantly. Both points of view currently lack empirical evidence. Consequently, clinical and public health recommendations have not yet been made, and future recommendations require an improved understanding of the relations between physical activity and TEE.

Now that accelerometry is available for the accurate measurement of physical activity (10, 11) and sedentary behavior (12) in free-living young children (13, 14), the combination of DLW measurement of TEE with accelerometry-derived measures of behavior can provide important insights into the relation between physical activity and TEE in pediatric populations. Using such methods, we recently described low levels of TEE and physical activity and high levels of sedentary behavior in a socioeconomically representative sample of young Scottish children (5). The relations between physical activity, TEE, and PAL are not readily predictable and require empirical investigation. The aim of the present study was to assess relations between TEE and PAL.
measured with use of DLW during engagement in different intensities of physical activity measured by accelerometry.

SUBJECTS AND METHODS

Subjects

We recruited a socioeconomically representative group of children in their preschool year (n = 36) and first school year (n = 68) by recruiting from selected postal sectors in the Glasgow area, as previously described (13). We attempted to measure simultaneously TEE (by DLW), physical activity, and sedentary behavior (by accelerometry). All parents gave informed written consent to participation, and the study had the approval of the Yorkhill Hospital Research Ethics Committee.

Measurement of energy expenditure

We measured TEE with use of the DLW method as previously described (5, 15, 16). In brief, after collection of a baseline (predose) urine sample all children received a sterilized, weighed dose of 1.6 mL/kg body weight 18O-labeled water (10% enriched; Cortec, Paris) mixed with 0.24 mL/kg 99.9% enriched deuterium oxide (Aldrich Chemicals, Dorset, United Kingdom). The larger body size of the school-aged children compared with the preschool children meant that the older children had a lower rate of mass specific isotope turnover. To achieve a similar number of isotope half-lives and, therefore, a metabolically equivalent period in the 2 age groups, a longer measurement period was required for the older children. Urine samples were obtained from the preschool children on days 1 and 7 after dosing and from the school-aged children on days 1 and 10 after dosing. Isotopic enrichments of urine samples were measured by isotope ratio mass spectrometry as previously described (15). We estimated carbon dioxide production from the differential disappearance of the 2 isotopes with use of equation A6 of Schoeller et al (17). We converted estimated carbon dioxide production to heat production with use of the constant 23.8 kJ/L on the basis of the mean food quotient from dietary intake data (15).

Resting energy expenditure (REE) was not measurable for practical reasons in most of the children studied because of inadequate compliance with the protocol for measurement of REE (18). The younger children in particular were unable to fulfill the requirements of fasting for ≥4 h and lying still for up to 30 min. In 32 of the school-aged children, adequate compliance was achieved, which meant that REE was measured by ventilated indirect calorimetry with use of a short reproducible protocol described previously (18). In these 32 children we found no significant difference between measured REE and that predicted from the Schofield equation (19), as previously reported (5). We, therefore, used predicted REE (pREE) as an outcome measure. We also carried out multiple regressions with all explanatory variables focused the reporting of the current study on PAL. We then conducted multiple regressions with all explanatory variables (age, sex, BMI SDS, and sedentary behavior or physical activity measures) as the outcome (8). Separate regression analyses were performed for sedentary behavior, light-intensity activity (1100–3200 cpm), moderate- and vigorous-intensity physical activity (MVPA; >3200 cpm) (10).

Other measurements

For descriptive purposes, we measured weight (to 0.1 kg) and height (to 0.1 cm) of children to calculate body mass index (BMI). We expressed BMI as a SD score (SDS) relative to UK 1990 population reference data (24). Overweight was defined as BMI ≥ 85th centile and obesity as BMI ≥ 95th centile, relative to UK 1990 reference data (24).

Statistical analysis and power

We initially carried out simple linear correlations between our explanatory variables (sex, various measures of body size, physical activity, and sedentary behavior measures) and our outcome measure, PAL. We also carried out an analysis with energy expended on physical activity (AEE; calculated as TEE – pREE) as an outcome, but the results of both analyses were similar, and we focused the reporting of the current study on PAL. We then carried out multiple regressions with all explanatory variables (age, sex, BMI SDS, and sedentary behavior or physical activity measures) and PAL or AEE as the outcome (8). Separate regression analyses were performed for sedentary behavior, light-intensity activity, and MVPA as their reciprocal nature precludes more than one of these percentage values from being included in the same regression. Regression analyses were also performed for boys (n = 52) and girls (n = 52) separately and for children of normal weight (n = 82) and excess weight (n = 22) separately.
TABLE 1
Characteristics of subjects

<table>
<thead>
<tr>
<th></th>
<th>Boys (n = 52)</th>
<th>Girls (n = 52)</th>
<th>P²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (y)</td>
<td>5.6 (3.1–6.7)</td>
<td>5.4 (2.6–6.9)</td>
<td>0.51</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>16.2 (13.5–21.5)</td>
<td>15.6 (12.7–22.8)</td>
<td>0.34</td>
</tr>
<tr>
<td>BMI SD score</td>
<td>0.4 (–1.8–4.1)</td>
<td>0.0 (–2.3–3.4)</td>
<td>0.39</td>
</tr>
<tr>
<td>TEE (MJ/d)</td>
<td>6.7 (3.0–11.4)</td>
<td>5.7 (3.5–7.5)</td>
<td>0.0003</td>
</tr>
<tr>
<td>pREE (MJ/d)</td>
<td>3.9 (3.3–5.4)</td>
<td>3.9 (3.1–4.8)</td>
<td>0.53</td>
</tr>
<tr>
<td>AEE (MJ/d)</td>
<td>2.7 (0.0–7.4)</td>
<td>1.8 (0.0–4.4)</td>
<td>0.0002</td>
</tr>
<tr>
<td>PAL (MJ/d)</td>
<td>1.66 (0.88–2.84)</td>
<td>1.48 (0.98–2.40)</td>
<td>0.0001</td>
</tr>
<tr>
<td>Total activity (cpm)</td>
<td>848 (398–1328)</td>
<td>719 (332–1154)</td>
<td>0.001</td>
</tr>
<tr>
<td>Percentage of time spent in (% of working hours)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sedentary behavior</td>
<td>73 (61–90)</td>
<td>79 (63–93)</td>
<td>0.0002</td>
</tr>
<tr>
<td>Light activity</td>
<td>23 (9–33)</td>
<td>18 (6–34)</td>
<td>0.001</td>
</tr>
<tr>
<td>MVPA</td>
<td>4 (1–14)</td>
<td>3 (0–8)</td>
<td>0.0068</td>
</tr>
</tbody>
</table>

¹ Values are medians; ranges in parentheses. TEE, total energy expenditure; pREE, predicted resting energy expenditure; AEE, activity-related energy expenditure; PAL, physical activity level; cpm, counts per minute; MVPA, moderate- and vigorous-intensity physical activity.

² Obtained by performing Mann-Whitney U tests for difference between the sexes.

to further account for the influence of sex and BMI SDS, respectively.

Power of the analysis was difficult to assess at the outset, but we noted that with a sample of 29 adults Westerterp (8) found significant associations between similar accelerometry-derived measures of physical activity and PAL. We aimed for a sample of around 100 children from participants in a large mixed longitudinal study (total n = 209) of changes in physical activity and TEE with age (5, 13). Kolmogorov-Smirnov tests were used to assess normality of distribution for each variable.

RESULTS
Characteristics of subjects

Satisfactory adherence to the simultaneous measurement protocols for both physical activity and TEE was achieved for 104 children. Of those children, 82 (79%) were of normal weight, 11 (10.5%) were classified as overweight, and 11 (10.5%) were classified as obese. Variables were not normally distributed (Kolmogorov-Smirnov tests, all P < 0.05). The median accelerometry measurement period was 30.3 waking h (range: 18.2–38.3 waking h) in the preschool children (n = 36) and 78.3 waking h (range: 46.3–119.2 waking h) in the school children. At both ages, children wore the accelerometer between 6 and 13 waking h/d. Characteristics of subjects, including time spent in sedentary behavior and activities of different intensity, are shown in Table 1. Participants were representative of Glasgow in terms of socioeconomic status.

Relations between physical activity and physical activity level

Simple linear correlations

The accelerometry-derived measures of physical activity (total physical activity: r = 0.33, P < 0.01; percent time spent in light intensity activity: r = 0.31, P < 0.01; and percent time spent in MVPA: r = 0.22, P < 0.01) were all positively correlated with PAL. The measure of sedentary behavior (percent monitored time spent sedentary) was negatively correlated with PAL (r = −0.33, P < 0.01). Plots of time spent in the different intensities of activity and PAL are shown in Figure 1.

Regression analyses

Sex (boys significantly higher than girls, Table 1), percent of time spent in sedentary behavior, and percent of time spent in light activity (Table 2) were all found to be significantly associated with PAL. Percentage of time spent in MVPA was not associated with PAL or AEE in our sample, and a small percentage of waking hours was spent in MVPA (Table 1): median, 3%; range, 0–14%. Separate regression analyses for boys (n = 52) and girls (n = 52) and for children of normal weight (n = 82) and excess weight (n = 22) produced similar results but were limited by sample size (data not shown).

DISCUSSION

Context and implications

The current paradigm is that variation in engagement in moderate-intensity physical activity may be the principal determinant of variation in PAL in free-living subjects (8). Acceptance of this paradigm has led to suggestions that future clinical and public health initiatives should promote physical activities of light–moderate intensity to influence energy balance. Although this paradigm and its subsequent recommendations could seem uncontroversial, they are based on limited empirical evidence at present (8) and require testing in different settings or populations. A recent meta-analysis of adult data (9) suggested that more vigorous physical activity is required to significantly raise TEE and so prevent positive energy balance. Consequently, we need clear evidence on whether more light- or moderate-intensity activity is adequate for this purpose. An understanding of how patterns of physical activity influence TEE and hence energy balance is, therefore, necessary to inform public health strategies for prevention of unhealthy weight gain appropriately (8, 25).

The current paradigm also assumes wide variation in activity levels, with a high proportion of individuals who are moderately active and a sizable minority of individuals who engage in vigorous activity to some biologically significant degree. Westerterp (8) found that time spent in “vigorous” activity by his adult subjects was small (approximate range: 1–10%), which could have contributed to the observation that it had little influence on PAL. In the present study, children engaged in the highest intensity of activity (MVPA) for a similarly low proportion of time (<15%). Our own recent evidence suggests that contemporary Scottish children are sedentary (5) and engage in little MVPA. Preliminary evidence from accelerometer-based studies suggests that this level of physical activity is also true of other contemporary pediatric populations (26). In these circumstances it might be inevitable that the influence of vigorous physical activity on TEE and PAL is reduced.

The present study in young children suggests that engagement in MVPA makes a relatively minor contribution to PAL, TEE, or AEE. That is not to say that it could not do so in the future. However, in our predominantly sedentary sample, variation in activity was limited, and the main determinant of variation in...
PAL was the “split” between sedentary behavior (12) and light-intensity activity (10).

In the present study we observed an inverse association between PAL and time spent sedentary, as well as a positive association between PAL and time spent in light-intensity activities. This observation, combined with the high engagement in sedentary behavior, suggests that a shift from time spent in sedentary behavior toward light-intensity activities might be a realistic and promising strategy for increasing TEE in young children.

Comparisons with other evidence

The values for PAL and AEE observed in this study are broadly similar to those observed elsewhere (27). Our observation that sedentary behavior and light-intensity activity could be of greater importance to PAL than MVPA and that these behaviors themselves explain relatively little (≈10%) of the total variation in PAL is consistent with evidence on the prevention and treatment of pediatric obesity. Reducing sedentary behavior (television viewing) in pediatric interventions seems to be essential almost irrespective of what behaviors replace them (28–30). Some evidence suggests that childhood physical activity has a “qualitative” dimension (independent of AEE) which could contribute to energy imbalance (7). For example, sedentary behavior can influence energy balance independent of AEE by ways of associations between television viewing and snacking on energy-dense foods and drinks (28–30). In addition, greater engagement in MVPA might be beneficial not only for energy balance (9) but also for other health outcomes (31). It is not yet clear whether it is increased engagement in vigorous activity per se or its corresponding reduction in sedentary behavior which is most effective in obesity prevention and treatment.

A casual comparison of the results of the present study and those of Westerterp (8) could suggest differences in conclusions: it would appear from our study that MVPA contributes little to PAL in children, whereas Westerterp suggests that moderate activity is the main determinant of PAL in adults. However, we believe that the 2 studies are consistent and that the apparent differences are the result of differences in the terminology used to describe activities of various intensitites. In the present study we categorized activity as sedentary, light intensity, or MVPA. Westerterp (8) described activity as being of low, moderate, and high intensities. These categories of activity are actually similar: our categories of sedentary behavior, light activity, and MVPA are effectively equivalent to the activities described by Westerterp (8) as low, moderate, and vigorous intensity, respectively. In both the present study and that of Westerterp (8) the amount of time spent in each category of behavior declined sharply with increasing intensity of the behavior. Future research should assess whether the observations reported here and by Westerterp (8) are applicable in other samples and settings, although care will be required to avoid confusion arising from differences in terminology.

Limitations

The present study has several limitations. First, the extent to which the results observed are generalizable to other settings or populations is unclear and must be investigated. For our sedentary sample we observed that MVPA contributed little to PAL, but in more active populations this contribution might not be the case. Second, the use of PAL and AEE without adjustment for body size could raise questions. Adjustment for body size is a controversial and currently unresolved issue (20–22). Third, the
The present study suggests that, in a contemporary pediatric sample from the United Kingdom, MVPA contributed relatively little to PAL or AEE. This finding was probably a consequence of the limited engagement in MVPA in our sample. This observation is consistent with a widely cited earlier study performed in a small sample of Dutch adults. Given the importance of our observation for public health interventions, it should be replicated in other samples and settings.

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JR was the principal investigator. The concept for the study originated from JJJR, JYP, and SG. CM, DMI, LAK, and CS designed the study protocols and collected the data. CM performed the data analysis. All authors participated in the data interpretation and writing of the paper. None of the authors had any financial or personal interest in the organizations supporting this research.

REFERENCES


