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The effect of physical activity on body fatness in children and adolescents

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With the increasing prevalence of childhood obesity, there is an urgent need to identify risk factors that are amenable to preventative action. However, there is a remarkable lack of consistency between studies that have investigated the relationships between measurements of physical activity and energy expenditure and body fatness in children. This disparity could be because energy intake is a more important determinant in preventing obesity. Alternatively, some of the conflicting results could be related to methodological limitations in assessing activity and body composition. Erroneous conclusions may be drawn if physical activity energy expenditure is not adjusted for differences in body composition, or body fat is not appropriately adjusted for body size. For public health purposes it may be more informative to evaluate the amount and intensity of physical activity required to prevent fat-mass gain than to assess energy expended in physical activity. The lack of consensus in the cut-off points applied to define intensity levels is severely hindering comparisons between studies using accelerometers that have examined relationships between activity intensity and body fatness. Thus, it is not currently possible to develop a firm evidence base on which to establish physical activity recommendations until the limitations are addressed and more prospective studies undertaken. In order to turn research into effective prevention strategies a clearer understanding of the psycho-social, behavioural and environmental factors that influence activity is needed, including the interactions between physical activity and other behaviours such as time spent sedentary, sleeping and eating.

Childhood obesity: Physical activity: Energy expenditure: Body fatness

The prevalence of childhood obesity continues to rise (Lobstein *et al*. 2004) and there is an urgent need to identify risk factors that are amenable to intervention and preventative action. Over the medium to long term, at least, it is clear that to prevent excessive positive energy balance over and above the needs for growth, and thus excess fat-mass gain, energy intake must equal total energy expenditure (TEE). On the TEE side of the energy balance equation, physical activity is the most variable and amenable component for intervention efforts.

At present there is no compelling empirical evidence on which to base physical activity recommendations in children and adolescents in order to prevent excess weight gain. From the limited information available for children, combined with extrapolation of evidence for adults, the current general consensus is that children should undertake at least 60 min of at least moderate-intensity activity each day for general health (Department of Health, 2004). There are no objective historical data on levels of physical activity from which to compare past and present activity in

Abbreviations: AEE, activity energy expenditure; DLW, doubly-labelled water; FFM, fat-free mass; HR, heart rate; HRM, HR monitoring; PAL, physical activity level; TEE, total energy expenditure.
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children and adolescents, and thus pinpoint changes in the type and amount of activity that may be contributing to the rise in the prevalence of overweight at a population level. The evidence that children and adolescents are becoming less active has principally been based on circumstantial evidence, such as increases in the number of televisions in a household, reduced time in schools spent in physical education and increasing car use, particularly getting to and from school (Fox, 2003).

Undoubtedly, a major constraint has been the difficulty in measuring such a complex and multi-dimensional behaviour as physical activity. Physical activity is defined as ‘any bodily movement produced by the contraction of skeletal muscles resulting in caloric expenditure’ (Caspersen *et al*. 1985) and therefore incorporates all daily activities. In children movement is often more sporadic and multi-dimensional, and daily activity patterns are commonly more varied than in adults. This factor, together with children’s cognitive limitations on recalling their activities and evaluating time spent in such activities, means that it is virtually impossible to obtain valid self-reports of daily activity in younger age-groups (Livingstone *et al*. 2003). Subjective observation of activities may be viable in infants and very young children (Puhl *et al*. 1990; Li *et al*. 1995), but feasibility is limited. Overall, doubly-labelled water (DLW), heart-rate (HR) monitoring (HRM) and accelerometry are more feasible and are objective measurements of physical activity and/or energy expenditure for use in children and adolescents (Livingstone *et al*. 2003).

Physical activity energy expenditure and body fatness

In the last two decades the DLW method has been invaluable in providing the first objective and valid measure of TEE in children and adolescents. The method is based on measuring the disappearance of two naturally-occurring stable isotopes (^{2}H and ^{18}O) from the body and calculating CO_2 production, and thus deriving a measure of TEE (Coward & Prentice, 1985). Despite the expense and technical complexity of the method, its major advantage is the relatively low participant burden and the opportunity to assess TEE continuously over periods of 7–10 d in which the disappearance of the isotopes is measured from urine samples. However, the DLW method provides only an integral (average) measure of TEE and not a day-by-day measure of TEE. Also, it does not give a direct measure of energy expended in physical activity or information on the forms, frequency or intensity of physical activity undertaken. Additionally, measures of physical activity energy expenditure are derived on the basis of information known, or estimated from the other components of TEE. The two measures that are most commonly calculated are activity energy expenditure (AEE; TEE − (RMR + thermogenesis)) and physical activity level (PAL; TEE/RMR).

Intuitively, the energy expended in physical activity is pivotal in reducing the risk of excess fat-mass gain, but surprisingly there is a remarkable lack of consistency between studies that have assessed relationships between measurements of physical activity energy expenditure and body fatness. Thus, while some cross-sectional studies have reported an inverse association between measures of energy expended in physical activity (PAL and AEE) and measures of body fatness (Davies *et al*. 1995; Ball *et al*. 2001; DeLany *et al*. 2002; Ekelund *et al*. 2002; Tennefors *et al*. 2003; Abbott & Davies, 2004; Rennie *et al*. 2005*b*), just as many have observed a null association (Bandini *et al*. 1990; DeLany *et al*. 1995, 2004; Goran *et al*. 1995, 1997; Maffeis *et al*. 1995, 1996; Salbe *et al*. 1997; Treuth *et al*. 1998). In the limited number of prospective studies assessing the same issue, the majority have reported null associations (Goran *et al*. 1998; Wells & Ritz, 2001; Treuth *et al*. 2003; Bandini *et al*. 2004), with only one study observing an inverse relationship (Salbe *et al*. 2002). However, in this latter study the energy expended in physical activity explained only 1–5 % of the variance observed in body fatness.

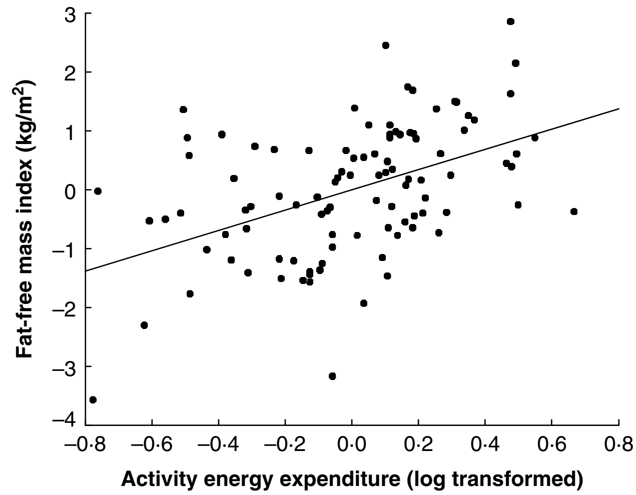

Fig. 1. Association between fat-free mass index (fat-free mass : height^{2}; kg/m^{2}) and log-transformed activity energy expenditure (AEE) adjusted for gender (in 100 subjects). B coefficient 1·72 (SE 0·34); $P<0·001$.

On the one hand, the lack of consistent cross-sectional and prospective associations between DLW-derived measures of physical activity energy expenditure and measures of body fatness could be, and has been, interpreted as evidence that energy intake is a more critical determinant of excess fat-mass gain. On the other hand, the inconsistency of study results could be explained by the way in which the data have commonly been analysed.

AEE tends to be expressed in analyses in absolute terms (kJ/d) and as such is highly related to the body weight of the subject, in particular the level of fat-free mass (FFM), as illustrated in Fig. 1. The assumption underlying the use of PAL is that by adjusting for RMR and expressing the data as a ratio the potential influence of body weight and composition is removed, thus allowing comparisons of the relative energy cost of physical activities between individuals and populations. Although this assumption may be valid for sedentary or low-intensity activities, PAL is not necessarily independent of body weight or FFM (Spadano *et al*. 2003, 2005), particularly in weight-bearing activities of moderate–vigorous intensity, such as walking

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Table 1. Comparison of body composition measurements from three hypothetical 7-year-old children

	Child A	Child B	Child C
Gender	Male	Male	Female
Weight (kg)	26	34	26
Height (m)	1·25	1·27	1·25
Body fat (kg)	4	10·2	6
Percentage body fat	15	30	23
Fat mass index (kg/m^2)	2·6	6·3	3·8
Percentage fat-free mass	85	70	77
Fat-free mass index (kg/m^2)	14·1	14·8	12·8

and running. In such instances a heavier individual may have a higher PAL as a result of their larger weight (Spadano *et al*. 2003). Thus, if a child spends the majority of the time in low-intensity activity, the effect of body size may be less than if more weight-bearing moderate–vigorous activities are undertaken. Thus, it is hardly surprising that comparisons of PAL between lean and obese children have shown very inconsistent results, with many reporting no difference between the two groups (Maffeis *et al*. 1996; Treuth *et al*. 1998; DeLany *et al*. 2004).

Measuring body fatness in children, particularly comparing adiposity levels between children, is also fraught with difficulty given the differences in the stage of maturation. From a young age, before the onset of puberty, gender differences are present (Taylor *et al*. 1997; Wells *et al*. 1999). As well as the issue of measurement error (Wells *et al*. 1999), there is also the problem of how to appropriately adjust for body size. The most common expression of body fatness used when evaluating data from DLW studies has been relative (percentage) body fat (fat mass/body weight). The rationale for dividing fat mass by body weight has been to normalise body fatness for body size. However, the conceptual difficulty of this approach has recently been highlighted (Wells *et al*. 2002*a*; Wells & Victora, 2005). Similar to PAL, when body fatness is expressed relative to weight, it remains highly correlated with body weight. Consequently, comparing the body fatness of individuals remains highly influenced by their body weight, and thus by their FFM. It may be more appropriate to adjust for body size by height, either as an index (fat mass/height^2; Van Itallie *et al*. 1990) or raise height to an appropriate power to remove the effect of height (Wells *et al*. 2002*a*).

Table 1 illustrates three hypothetical 7-year-old children and the problem in interpreting the differences in body composition between them. First, comparing genders, child A (boy), although identical in weight and height to child C (girl), has 50% more body fat in absolute terms (kg). Expressing body fat as a percentage underestimates the gender differences in body fatness (15% *v*. 23%) in contrast to evaluating body fatness by the fat mass index (50% higher in child C). A similar scenario occurs in relation to FFM. For the same body weight boys have a higher FFM than girls (Wells, 2000) and therefore higher TEE in absolute terms (kJ/d; Torun *et al*. 1996). Since the effect of FFM is not removed from the derived measures of AEE and PAL, boys will tend to have higher AEE and PAL than girls. Thus, it is inevitable that associations would be biased towards the null, given the underestimation of gender differences in body fat by using percentage body fat and the overestimation of gender differences in energy expended in physical activity. There are also implications for analyses in which data from boys and girls are combined without taking into account differences in body composition.

The same issues are observed when comparing lean and overweight children. In Table 1 child B is heavier and taller and has 255% more body fat in absolute terms (kg) than child A, who is leaner. Similar to evaluating gender differences, using percentage body fat rather than the fat mass index will also underestimate the differences in body fat between the lean and obese child. The difference in interpretation is even more pronounced in the FFM measures. In evaluating the difference between child A and B percentage FFM would erroneously suggest that child A has more FFM, but the opposite conclusion is reached when adjusted body size for height in the FFM index is used. In fact, for a given body weight obese children tend to have more FFM than non-obese children (Wells *et al*. 2006), resulting in higher TEE in absolute terms (kJ/d). Thus, obese children and adolescents have higher AEE and often PAL than non-obese children. When studies evaluate associations between AEE or PAL and percentage body fat the differences between energy expended in physical activity are likely to be overestimated between leaner and fatter children and the differences in body fatness underestimated, resulting again in associations being biased towards the null. These inaccuracies may partially explain why so many studies have concluded that there were no associations between energy expended in physical activity and body fatness.

As shown in Fig. 2, this imprecision could lead to entirely different conclusions being drawn from the same dataset, depending on whether adjustment is made for differences in body composition in DLW-derived energy expenditure measures. Fig. 2(a) shows a significant positive association ($P = 0·01$), with greater amounts of time spent being inactive or at low-intensity activity being associated with higher energy expended in physical activity. However, when this energy expenditure is normalised for FFM (Fig. 2(b)), the association is no longer apparent.

Heavier children generally have higher TEE, RMR and AEE compared with their lighter counterparts (DeLany, 1998; Ekelund *et al*. 2002). However, when normalised for body composition, these differences in energy expenditure are removed (Treuth *et al*. 1998; Ekelund *et al*. 2002; DeLany *et al*. 2004). It has frequently been concluded that the similar AEE between obese and non-obese children after adjustment for body composition reflects the lower energy efficiency in movement and/or the higher energy cost of moving a larger body mass in obese children, which results in higher overall energy expenditure in the obese children despite possibly lower physical activity (Ekelund *et al*. 2002; Spadano *et al*. 2003). However, adjustment for body size and/or body composition is not as straightforward as it first appears. The association with AEE is not

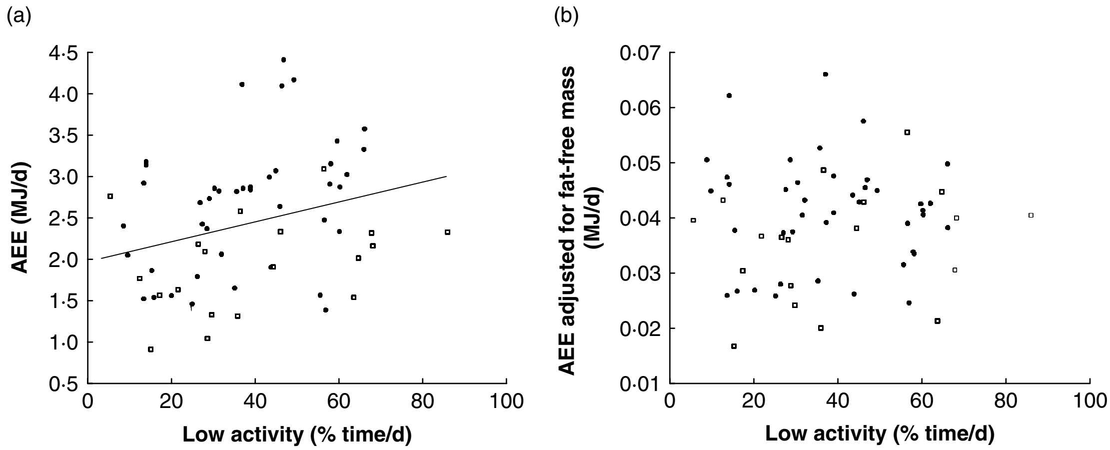

Fig. 2. (a) Activity energy expenditure (AEE) calculated from doubly-labelled water and time spent in low-intensity activity measured by heart-rate monitoring in 100 prepubertal boys (•) and girls (□; r 0·32, $P = 0·01$) and (b) AEE adjusted for fat-free mass (kg; r 0·09, NS). AEE was normalised for fat-free mass (AEE/fat-free mass$^{1·3}$; Rennie *et al.* 2005*b*).

consistent but dependent on the amount of weight-bearing and non-weight-bearing activities a child undertakes. The different approaches that attempt to deal with these issues and appropriately adjust for body size in children have been described elsewhere (Lazzer *et al.* 2003; Ekelund *et al.* 2004*b*).

Measuring energy expended in physical activity is very informative if the purpose is to determine how much energy intake is required to keep individuals in energy balance. However, if the aim is to identify how much physical activity is necessary to prevent obesity, it is considerably more complicated. Measures of physical activity energy expenditure are not easy to interpret. Even if they can be appropriately adjusted for body composition, comparisons between populations are difficult. The level of accuracy required to determine energy imbalance that may ultimately lead to excess fat-mass gain is unattainable from the measurement instruments currently employed for both intake and expenditure and with the level of variability in both intake and expenditure from day-to-day. It is also important to note that energy expended in activity is not the same as the amount of physical activity required to prevent excess fat-mass gain. Thus, other measurement instruments are required to examine physical activity *per se*.

Physical activity and body fatness

Advances in technology in recent decades have resulted in objective user-friendly instruments for the measurement of physical activity that are feasible for use in studies of childhood obesity. Techniques such as HRM and accelerometry provide minute-by-minute data, making it possible to obtain not only information on the total levels of physical activity, but also the patterning of daily activity, including intensity, duration and frequency. This additional information is central to determining what aspects of physical activity in children may be important in preventing excess fat gain and for making public health recommendations.

Heart-rate monitoring

HRM has been widely used as a proxy measure of physical activity, with minute-by-minute HR data providing information on the patterning of activity or TEE. There is considerable inter-individual variability in resting HR, and HR response to activity is influenced, for example, by body weight, age and fitness level, and therefore a calibration is required to determine an individual's HR at rest and under exertion. Similarly, because of the individualised nature of the relationship between HR and V_{O_2}, derivation of an estimate of TEE also requires an individualised calibration (Spurr *et al.* 1988). Above an empirically-derived flex HR (which distinguishes between resting and activity HR) and below maximal HR there is a good positive correlation between HR and energy expenditure, from which an estimate of AEE can be made (Spurr *et al.* 1988). However, at low levels of activity around the flex point it is difficult to differentiate between modest increases in HR around this flex point that are associated with activity and those that are associated with stress or other causes (Haskell *et al.* 1993). Given the sedentary nature of most modern lifestyles it is not surprising that this factor can introduce considerable error (Rennie *et al.* 2000), which can be particularly variable at the individual level (Livingstone *et al.* 1992). Since time spent in low- and moderate-intensity activity may be of particular interest, and important in preventing excess fat gain in children, this imprecision represents a major limitation of the HRM method in childhood obesity research. However, studies using HRM have demonstrated associations between time spent in sedentary and light-intensity activities and body fat (Maffeis *et al.* 1997; Rennie *et al.* 2005*b*), but not all studies have found such associations with HMR measures (Rowlands *et al.* 1999; Treuth *et al.* 2004*a*).

New technology that combines HRM with movement sensors enables increases in HR caused by physical activity to be distinguished from increases caused by other influences (Rennie *et al.* 2000; Brage *et al.* 2005; Johansson *et al.* 2006). This development may allow a more accurate

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determination of both daily AEE and its patterning in children and adolescents in the future.

Accelerometry

Given the multi-dimensional nature and spontaneity of their movement, the direct and objective measure of body movement by accelerometry is particularly useful in children. Movement is commonly measured in one or three planes (vertical *v.* vertical, lateral and anterior–posterior respectively).

Only a few studies have undertaken simultaneous measurements of physical activity by accelerometry and energy expended in physical activity using the DLW method (Ekelund *et al.* 2002; Abbott & Davies, 2004). These studies clearly illustrate that the two approaches to measuring physical activity provide different but complementary information on physical activity, especially in relation to body fatness. In a comparison of obese and non-obese adolescents Ekelund *et al.* (2002) have observed no difference in AEE or PAL between obese and non-obese groups after adjustment for differences in body composition. However, from concurrent accelerometer measures the non-obese group was shown to have significantly higher levels of physical activity compared with the obese group ($P<0{\cdot}001$). In younger non-obese children stronger inverse associations have been observed between accelerometer measures of activity and body fatness than with PAL (Abbott & Davies, 2004).

One prospective study in American Indian children has reported that higher activity counts at baseline in normal-weight children are related to a decrease in body fat 3 years later (Stevens *et al.* 2004). Paradoxically, in children defined as overweight at baseline higher activity counts were found to be associated with an increase in BMI, fat mass and FFM at follow-up. However, activity measured by accelerometry was assessed only for 1 d and it is not clear whether the body size of the overweight children, being heavier and taller than their lean counterparts, affected the activity counts. The impact of height and weight on movement counts clearly needs further investigation.

By applying movement count cut-off points, minute-by-minute data from accelerometers can be summated into time spent in low-, moderate- and vigorous-intensity activity, allowing an exploration of which intensity and/or frequency of activity is the most important predictor of increases in body fatness. In adults it has been proposed that inter-individual variations in energy expenditure are largely a result of variations in moderate-intensity physical activity, with the daily proportion of time spent in vigorous-intensity activities contributing very little to the variability (Westerterp, 2001). However, it is not clear whether this premise is valid in children. It has been proposed that in young children most of the variation in daily energy expenditure is associated with the proportion of time children spend in either sedentary or light-intensity activities (Montgomery *et al.* 2004). In a study of 3- and 5-year-old children that used accelerometry the majority of time (range 73–81 %) was reported to be spent in sedentary activities (Reilly *et al.* 2004), leading to the conclusion that the predominance of sedentary activity may be contributing to the rise in obesity. However, in the absence of historical data, it is not clear whether there has been a secular decrease in activities of moderate–vigorous intensity in young children or whether they inherently spend much of their time at this level of activity. Equally, another study in 4–6-year-olds has observed that boys and girls engage in activities defined as moderate–vigorous intensity for 277 and 263 min/d respectively (Janz *et al.* 2002). The possible explanations for these conflicting observations are discussed later.

Studies that have examined relationships between intensity of activity and measures of body fatness have also found conflicting results. A positive association between time spent in sedentary activity and measures of body fat has been observed in 9–16-year-old girls, with no such association in boys (Treuth *et al.* 2005). In the same study time spent in light-intensity activity was shown to be inversely associated with body fat measures, but only in girls (Treuth *et al.* 2005). Other studies that have evaluated light-intensity activity have reported a null association (Ekelund *et al.* 2002; Ekelund *et al.* 2004*a*). Some studies have found associations between moderate–vigorous- or vigorous-intensity activity and measures of body fatness (Rowlands *et al.* 1999; Ekelund *et al.* 2002; Janz *et al.* 2002; Abbott & Davies, 2004; Ekelund *et al.* 2004*a*; Gutin *et al.* 2005), but not all (Treuth *et al.* 2005), and some of these studies have observed associations with vigorous-intensity activity but not with moderate-intensity activity (Janz *et al.* 2002; Abbott & Davies, 2004). This outcome makes it difficult to draw any conclusions at present on the importance of intensity of activity on body fatness. However, two studies appear to identify an approximate threshold above which lower measures of body fatness are observed (Abbott & Davies, 2004; Ekelund *et al.* 2004*a*). In one study (Abbott & Davies, 2004) the threshold was reported to be 125 min vigorous-intensity activity/d and in the other study (Ekelund *et al.* 2004*a*) the threshold was 120 min moderate–vigorous-intensity activity/d.

The largely inconsistent results in the studies cited earlier could also reflect real differences between populations, age-groups and gender. Some studies have observed that children do not spend much time in activities that could be classed as being of vigorous intensity (Gilliam *et al.* 1981; Bailey *et al.* 1995; Reilly *et al.* 2004). Indeed, direct observation of 6–10-year-old children has demonstrated that they spend most of their time engaged in low-intensity activities (77 %) and only small amounts of time in high-intensity activity (3 %), with most of the high-intensity activity (95 %) occurring for very short bursts lasting <15 s (Bailey *et al.* 1995). However, the way in which activity data is recorded may also be contributing to this conclusion. Most data from accelerometers and HRM is recorded in 1 min epochs that may not be sensitive enough to pick up these short bursts of vigorous activity (Nilsson *et al.* 2002). It is also important that activity monitoring is of sufficient duration to adequately reflect habitual activity levels in children, including both weekdays and weekend days (Trost *et al.* 2000).

A major, and as yet unresolved, problem of comparing studies is that there is currently no consensus in how the activity intensity cut-off points applied to data are defined (Freedson *et al*. 2005). Studies may reach wholly different conclusions on the importance of vigorous-intensity activity on levels of body fatness, which are a result, at least in part, of the cut-off point used to define vigorous intensity. Cut-off points have been developed in controlled studies with children undertaking specific activities for which the intensity or energy cost of the activity is known (Ekelund *et al*. 2002; Puyau *et al*. 2002; Rowlands *et al*. 2004; Treuth *et al*. 2004*b*). These studies typically combine walking and running on a treadmill with other activities to establish cut-off points relating to metabolic equivalent levels (Eston *et al*. 1998; Puyau *et al*. 2002; Rowlands *et al*. 2004), but in young children have involved direct observation of activity (Reilly *et al*. 2003). It is questionable whether essentially laboratory-based contrived cut-off points are valid for assessing the less-structured activities typical of free-living conditions. Also, most of the studies of cut-off points have only used small samples of children (frequently twenty to thirty children) and sometimes only one gender. In addition, the study samples often cover a large age-range, which inevitably introduces considerable variability in results, particularly in relation to body size. Problems arise when these cut-off points are then applied to larger study populations that include both boys and girls and different age-ranges. This issue is also relevant in the development of equations to estimate energy expenditure from accelerometry movement counts (Eston *et al*. 1998; Puyau *et al*. 2002).

One study has found that when applying one established cut-off point for moderate–vigorous-intensity activity all children (forty-one of forty-one) achieve the current recommendations for daily physical activity (Trayers *et al*. 2006). However, when applying another established cut-off point only 7% of the children would be defined as achieving the recommendation (three of forty-one). It is hardly surprising therefore that as a result of applying different cut-off criteria studies have reported inconsistent relationships between body fatness and daily time spent in low-, moderate- and vigorous-intensity activity. At present, therefore, it is simply not possible to be confident that the existing data on the frequency and duration of different intensities of physical activity can provide a sufficiently robust evidence base on which to formulate public health recommendations for children.

Additionally, nearly all studies have been cross-sectional, with only limited prospective data available (Stevens *et al*. 2004). Thus, it impossible to draw conclusions on cause–effect relationships; whether children are fatter as a result of being less active or whether they have changed their activity behaviour in response to their body fatness and thus their fatness inhibits their physical activity. It is clear that more prospective studies are urgently needed. There is also a dearth of studies that have examined associations between physical activity and FFM or lean tissue (Janz *et al*. 2002; Stevens *et al*. 2004). Although there is some evidence that recently-measured children have less FFM than children measured 20 years earlier (Wells *et al*. 2002*b*), probably as a result of less time spent in activity, more studies are needed to examine this aspect in more detail, particularly longitudinally.

Specific physical activity behaviours

As well as evaluating the patterning and intensity of daily physical activity, objective measures of activity can be used to evaluate the impact of specific behaviours on activity levels. For example, much emphasis has been placed on the importance of schools in enhancing levels of physical activity. Although physical education has a potentially valuable role in promoting long-term participation in recreational activity, its immediate impact on children's activity is less clear. Of particular relevance is the observational study that compared total daily activity levels of children from three schools with very different levels of time-tabled physical education (Mallam *et al*. 2003). Although, average total accelerometer counts were similar between the children from all three schools, it appears that children from the schools that had less time allocated to physical education actually compensated by being more active out of school. Whether this compensatory activity is typical remains to be established.

There has also been a secular change in the mode of travel to and from school, with fewer children cycling and walking to school (Dollman *et al*. 2005). Studies that have compared daily activity levels between those who walk or cycle rather than being driven to school have observed that those who walk or cycle are more active throughout the day and not just in the period of getting to and from school (Cooper *et al*. 2003; Alexander *et al*. 2005). More work is needed in this area to assess which specific activity behaviours are amenable to intervention and can impact on activity levels sufficiently to make a long-term difference to the risk of obesity.

Objective instruments, such as accelerometers, are valuable tools not only for distinguishing the amount of activity needed to prevent obesity, but also, perhaps more importantly, for evaluating the impact of community and school-based initiatives, such as 'the walking bus', on daily levels of physical activity.

Interactions with other factors

The effect of physical activity on body fatness cannot be considered in isolation and needs to be evaluated alongside other factors such as diet, sleep and sedentary behaviour that may influence body fatness in children and adolescents.

Sedentary behaviour

Sedentary behaviour, such as television watching, has been implicated in increasing the risk of obesity. In fact, after parental obesity, television watching has been the most consistent risk factor identified for childhood obesity (Doak *et al*. 2006). One reason may be that it is relatively easier to quantify the amount of time a child spends watching television than, for example, the amount of time spent in unstructured play. Randomised controlled trials (Doak *et al*. 2006) have reported that interventions to reduce television watching can reduce fat mass gain, albeit modestly. However, it is not apparent whether reducing the time spent watching television is a direct causal factor, by decreasing the time spent inactive, or whether it is an indicator of a broader set of behaviours. For example, decreasing television viewing may reduce the risk of obesity by other mechanisms such as by removing the opportunity for more eating occasions and/or exposure to advertisements for high-fat foods (Campbell *et al*. 2006; Wiecha *et al*. 2006).

Nevertheless, sedentary behaviour, such as television viewing, is not necessarily the antithesis of being physically active. Children who spend substantial amounts of their time watching television are not necessarily less physically active than those who spend less time watching television, since they may spend the rest of their time in more vigorous-intensity activities. A meta-analytical review of the literature (Marshall *et al*. 2004) has concluded that there is only a very small inverse relationship between television viewing and physical activity. Indeed, a recent study that has examined the associations between family environment, television viewing and physical activity measured by accelerometry has observed few associations between questions about sedentary behaviours and low levels of physical activity (Salmon *et al*. 2005).

Sleep

Obesity research has principally focused on how children spend their waking hours, but recently cross-sectional inverse associations have been reported between time spent sleeping and odds of being obese (Sekine *et al*. 2002; von Kries *et al*. 2002; Chaput *et al*. 2006), with fatter children spending less time asleep. This finding has been replicated in prospective studies, with shorter sleep duration in infancy and young childhood being a predictor of becoming overweight in childhood (Agras *et al*. 2004; Reilly *et al*. 2005).

The mechanisms by which sleep could increase the risk of excess adiposity are still emerging. Shorter sleep duration has been associated with increased time spent watching television (Van den Bulck, 2004). However, the relationship between sleep duration and obesity has been observed to be independent of reported television viewing time (Locard *et al*. 1992; Sekine *et al*. 2002; Reilly *et al*. 2005; Chaput *et al*. 2006). Time spent asleep may displace other behaviours such as eating occasions in the late evening that increase the risk of positive energy balance.

Associations between sleep time and dietary intake may also have a biological mechanism. In adults short sleep duration has been related to changes in appetite-regulation hormones, with increased hunger and appetite (Spiegel *et al*. 2004). Another plausible mechanism is that those who are less active, and are thus less physically tired, may sleep less, which would suggest an interaction between low physical activity and low sleep duration with a risk of excess fat-mass gain. One study has reported a correlation between lower sleep time and lower activity levels measured by accelerometry in 3–4-year-old children (Agras *et al*. 2004), but physical activity was only measured for 24 h. More research is required in this area to determine whether interactions between sleep and physical activity are sustained over a longer time period, and to ascertain if lower sleep time is associated with time spent in moderate–vigorous-intensity activities and/or dietary intake.

Diet

Few studies have measured dietary intake and physical activity concurrently (Jago *et al*. 2005) and none have examined the daily patterning and interaction of these two potential risk factors. However, evaluation of interactions between physical activity and diet is hindered by the inaccuracy in measurements of dietary intake, particularly as a result of misreporting, which tends to be higher in older age-groups and in overweight compared with lean children and adolescents (Livingstone & Black, 2003; Rennie *et al*. 2005*a*).

Conclusions

It is only in recent years that objective measures of physical activity have become more widely available and feasible for use in large-scale studies. At the same time there is now an increased urgency to assess the impact of the duration, frequency and intensity of physical activity on the risk of obesity in children. Currently, there are major obstacles that impede the development of a firm evidence base from which physical activity recommendations can be established. First, it is essential that outcome measures of body fatness are appropriately adjusted for body size to ensure that correct conclusions are drawn from analyses. Second, a consensus is needed on intensity cut-off points from accelerometry data such that the results between studies are comparable and meaningful. Third, a real problem is how physical activity energy expenditure is appropriately adjusted for body composition differences between children so that results are not unduly biased. If these issues are addressed and applied to prospective studies, a better understanding of the role of physical activity in the prevention of obesity will be achieved. Further work is also needed to assess the impact of duration, frequency and intensity of physical activity on lean body mass and how this relationship may be a factor in reducing the risk of obesity.

Objective instruments, such as accelometers, can also be used to assess the effectiveness of interventions to change physical activity, which cannot be evaluated using self-report measures or, in the short-to-medium term, changes in body composition.

Physical activity questionnaires and diaries remain vital qualitative, if necessarily subjective, tools in studies of physical activity. Without information on the types of activity commonly undertaken and their settings it is difficult to translate findings from the objective measures of activity into public health recommendations and to find opportunities to change behaviour. For example, in changing the immediate environment to facilitate activity, such as safe routes to schools or play areas, or finding ways to encourage families to engage in more activity on a regular basis. Schools are certainly important in increasing activity in children and adolescents, but they need to be considered together with activities outside of school and the role of the family. Given the concerns of safety surrounding unsupervised travel and playing outside, implementing this change is a real challenge (Hillman, 1993). Thus, the designing of effective prevention studies must be complemented by research aimed at achieving a clearer understanding of the psycho-social, behavioural and environmental factors that influence physical activity (Livingstone *et al*. 2006). Moreover, integrated prevention strategies are needed to change not only physical activity but other related behaviours, such as eating and sleeping, if the rise in childhood obesity is to be arrested.

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