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Symposium on 'Behavioural nutrition and energy balance in the young'

Physical activity, sedentary behaviour and energy balance in the preschool child: opportunities for early obesity prevention

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Prevalence of obesity in preschool children has increased dramatically in recent years. The preschool years (age 3–6 years) have been regarded as critical for the programming of energy balance, via the concept of early 'adiposity rebound'. Children who undergo early adiposity rebound are at increased risk of later obesity. Recent evidence suggests that associations between timing of adiposity rebound and later obesity may not reflect programming, but might denote that 'obesogenic' growth trajectories are often established by the preschool period. Studies of objectively-measured physical activity and sedentary behaviour in preschool children show that levels of physical activity are typically low and sedentary behaviour high. The review of evidence presented here is supportive of the hypothesis that physical activity is protective against obesity in the preschool period, and that sedentary behaviour, particularly television viewing, is obesogenic. Definitive evidence on dose–response relationships between physical activity, sedentary behaviour and obesity remain unclear. Dose–response evidence could be obtained fairly readily by intervention and longitudinal observational studies that use accelerometry in preschool children. The generalisability of much of the evidence base is limited and there is a need for research on the influence of physical activity and sedentary behaviour in the preschool years in the aetiology of obesity in the developing world.

Physical activity: Sedentary behaviour: Child nutrition: Obesity

Prevalence of obesity among children and adolescents in the developed world and much of the developing world is high and continues to increase[(1)]. The obesity epidemic has also affected non-obese children, with secular trends to higher fat mass and more central fat distribution, even in non-obese children and adolescents, at least in the UK[(2)]. There has been interest in the contribution of environmental exposures for obesity that operate in fetal, neonatal and infant life for many years[(3)]. The preschool period has been highlighted, and in particular the possibility that risk of obesity might be 'programmed' by the timing of the 'adiposity rebound'[(4–9)], the period when BMI increases after a nadir at age 3–6 years; early adiposity rebound being associated with increased risk of later obesity. Whether or not there is a critical period for later obesity during preschool life (age 3–6 years), it is clear from recent studies that the prevalence of obesity has increased markedly among preschool children and that obesogenic lifestyles must now be prevalent among young children[(10)]. In contrast to lay perceptions of lifestyle among preschool children, there is evidence of widespread non-compliance with public health recommendations in relation to physical activity, sedentary behaviour and diet, and social patterning of both diet and obesity well before school entry in the UK[(11,12)].

The preschool period may, therefore, be important to long-term energy balance and risk of obesity by mechanisms that involve programming, by the life-course accumulation of positive energy balance that begins in early childhood and/or the early establishment of obesogenic

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lifestyles that are maintained once habits are formed[13]. The extent to which these processes are important to the obesity epidemic and the role of physical activity and sedentary behaviour in influencing energy balance during and after the preschool period are unclear. The aims of the present review are therefore to:

(a) summarise evidence on the prevalence of obesity among modern preschool children, and the extent to which lifestyles of modern preschool children are likely to be obesogenic;
(b) provide a brief critique of the evidence that the preschool period is critical for programming of energy balance;
(c) summarise recent evidence on the role of physical activity and sedentary behaviour in the development of obesity during and after the preschool period;
(d) identify major gaps in the evidence on relationships between physical activity, sedentary behaviour and energy balance in preschool children.

Importance of obesity among preschool children

Prevalence and trends in obesity in early childhood

Preschool children are widely believed to be protected from obesity by the perception that they are highly-physically-active 'supercharged dynamos'. In fact, the empirical evidence from studies or surveys of obesity prevalence is consistent in supporting the view that preschool children are actually highly susceptible to obesity and to the early adoption of obesogenic lifestyles. Across the developed world, and much of the developing world, prevalence of overweight and obesity have increased markedly among preschool children[1,14–17]. In the UK, for example, approximately 10% of children are obese (BMI ≥95th percentile relative to UK 1990 reference data[18]) by primary-school entry[2] and, at least in the past, obesity risk is socially patterned with slightly but significantly higher risk of obesity among more socio-economically-deprived families[1,14–17,19,20], although this pattern may be changing[21]. An epidemic of positive energy balance has affected much of the preschool population in the UK in approximately the last 20 years[2], and their lifestyles must have become much more obesogenic during that period.

Recent longitudinal studies of persistence of overweight and obesity have been rare, but they have tended to suggest that trajectories of excess weight gain are often established well before the preschool period[22–25], and also that overweight and obesity established by the preschool period tends to persist[26,27]. Furthermore, studies of the treatment of obesity in children in early–mid-childhood suggest that for most obese children the origin of their obesity must lie in the preschool period or earlier. Obese children in mid-childhood must have been in substantial positive energy balance for years[28,29]. For example, in a recent treatment trial[28] children by age 8 years had a median body weight of 52 kg, putting them approximately 15–20 kg above the overweight status category and >20 kg above the mean weight for the same age, gender and height in the UK reference population in 1990[18].

In summary, preschool children are highly susceptible to overweight and obesity. Recent rapid changes in body fatness, fat distribution and the prevalence of overweight and obesity among preschool children indicate that the preschool population has undergone rapid changes in lifestyle in recent years.

Rationale for study of energy balance in preschool children

The preschool period has been regarded traditionally as a critical period for the development of later obesity (the adiposity rebound) and this factor has provided a rationale for the study of energy balance in preschool children. A secular trend to earlier adiposity rebound has occurred, and reduced habitual physical activity and/or increased habitual sedentary behaviour has probably contributed to this trend[30,31].

There is increasing scepticism over the hypothesis that early adiposity rebound is a cause of obesity, and it is not clear that programming of energy balance occurs during a time-sensitive period[6,7]. There is increasing evidence that rapid early-life growth, summarised in a recent systematic review[32], is predictive of later obesity, but whether rapid growth is the cause of later obesity or simply a marker for individuals on a rapid weight trajectory (who are on an early pathway to obesity) remains unclear. Strong associations between early adiposity rebound[22] and later obesity might reflect the general influence of rapid early growth on obesity rather than any critical, time-sensitive, programming of energy balance that occurs at around the timing of adiposity rebound.

Early adiposity rebound does appear to reflect an excessive positive energy balance during the preschool period[8,9] but the precise contributions of physical activity, sedentary behaviour and dietary intake to this positive energy balance and to the timing of adiposity rebound remain unclear[3–9,30,31].

From a public health perspective the evidence that the preschool period is important (even if not 'critical' in the sense of programming) has been helpful in focusing an increasing amount of research effort at preschool children. Preschool children are particularly suitable as research participants for a variety of reasons. First, compliance with measurement methods (exposures) for dietary energy intake, physical activity and sedentary behaviour is generally very good among preschool children and their parents[33–39], and dietary energy intake methods have been shown to be unbiased in validation studies relative to doubly-labelled water, in contrast to studies in older children and adolescents[38,39]. Objective methods of measuring physical activity and sedentary behaviour are practical in preschool children[10], and accelerometry is currently the method of choice if measures of the amount of physical activity and its intensity are required[40] to characterise 'dose–response relationships' between physical activity and sedentary behaviour and obesity risk (for example, see Reilly *et al.*[41], Ness *et al.*[42] and Andersen *et al.*[43]). Many validations (against energy expenditure and/or direct observation of movement) of accelerometry have been published in preschool children[37,44–47]. These advantages

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of accelerometry for preschool children have led to its inclusion in population surveillance of physical activity in preschool children in the National Health and Nutrition Examination Surveys in the USA[48]. Accelerometry also provides a valid and practical means of measuring sedentary behaviour in preschool children[10,37]. Sedentary behaviour is now regarded as a separate construct from physical activity, it does not simply represent a lack of physical activity, and the determinants of sedentary behaviour may also differ from the determinants of physical activity[40,49,50]. In addition, in intervention studies on the prevention and treatment of child and adolescent obesity targeting a reduction in sedentary behaviour may be more effective than targeting increases in physical activity[51,52].

It is also worth noting that in many countries preschool education is common, and the existence of preschool education provides an opportunity to access the majority of the preschool population. The traditional arguments in favour of school-based obesity prevention can be made easily for preschool obesity prevention when the vast majority of the population attends formal preschool education, as in Scotland[53]. It has also been shown that preschool education can influence habitual physical activity (as measured by accelerometry) markedly[54].

One aspect of the aetiology of paediatric obesity that is becoming increasingly well-established is the concept of heterogeneity in aetiology, the existence of major differences in the behavioural pathways to obesity between groups[41]. Pathways to obesity by preschool or early school life might be different from pathways at other periods, and aetiology might differ significantly between groups defined by age, gender, ethnicity or socio-economic status[41]. Indeed, there is already some empirical evidence that physical activity and sedentary behaviour might be more important determinants of energy balance than diet during the preschool period[55].

In summary, even if the preschool period is not 'critical' in the sense of programming of energy balance, it remains an important period of life for the development of obesity. The preschool period also provides a valuable opportunity for population-based obesity prevention.

Habitual physical activity, sedentary behaviour and energy balance among preschool children

Mechanisms relating physical activity and sedentary behaviour to excessive positive energy balance

Physical activity levels are most likely to influence risk of obesity via their effect on physical-activity energy expenditure, with low levels of energy expended likely to predispose individuals and groups to obesity. There is surprisingly little convincing evidence for this hypothesis among healthy preschool children at present, but this situation reflects an absence of evidence rather than evidence of absence[41]. Secular trends identified from national surveys of energy intake in preschool children (which are not subject to biases in reporting) suggest that levels have remained stable or declined during the course of the childhood obesity epidemic in the UK[56], implying that reductions in physical-activity energy expenditure must have made a major contribution to the epidemic. Evidence on secular trends in amounts of physical activity of young children over the same period is not available because national surveys of physical activity have used subjective methods that are unlikely to be valid and are also very imprecise[40,41,57]. Low levels of habitual physical activity may increase obesity risk by more indirect methods; for example, the possibility that at low levels of activity the regulation of energy balance (or 'coupling' of intake and expenditure) might become impaired[41].

Sedentary behaviour presumably makes a direct contribution to increasing obesity risk by lowering habitual physical-activity energy expenditure[41], by displacing physically-active behaviour[10] and possibly via effects on energy intake. Some forms of sedentary behaviour, particularly television viewing, promote energy intake via exposure to food advertising, although most of the evidence on this possible mechanism comes from older children and adolescents[58]. Television viewing might also become linked to the consumption of highly-energy-dense foods or drinks and so promote obesity via effects on energy intake[51,52].

In summary, plausible biological mechanisms link variation in habitual levels of sedentary behaviour and physical activity to variation in the extent of energy imbalance in young children, but evidence confirming such a link is lacking at present. This lack of evidence relates to both a lack of research effort and to the historical dependence on crude methods of measuring the 'exposures' of physical activity and sedentary behaviour that do not measure amounts of these behaviours with sufficient accuracy and precision[40,41,57,59]. The lack of evidence means that there is currently no conclusive evidence of dose–response effects between activity and obesity in preschool children, and there is only very limited evidence of relationships between free-living physical-activity behaviour and physical-activity energy expenditure[60].

Levels of objectively-measured habitual physical activity and sedentary behaviour

Since objective and quantitative methods are required to quantify amounts of free-living physical activity and sedentary behaviour[40] and since levels of habitual physical activity and sedentary behaviour of preschool children have probably changed in recent years, the present section will focus on the body of evidence from recent studies that have used objective measures. The body of evidence on physical activity is small but fairly consistent, based on observational studies using a variety of objective methods: accelerometry; doubly-labelled water; heart-rate monitoring; direct observation of movement; pedometers[3,10,35,61,62]; all of which suggest that levels of habitual physical activity are typically much lower than current recommendations of 60 min moderate–vigorous intensity physical activity daily (activity at an intensity at least three times the individual's resting energy expenditure).

One methodological point to note is that accelerometry measures of physical activity require that 'cut-points' are applied to accelerometry output in order to determine time spent in different intensities of physical activity[40]. A consistent body of high-quality evidence shows that when evidence-based cut-points are applied to accelerometry data the habitual moderate–vigorous-intensity physical activity of preschool children appears typically to be low, although older studies that have used inappropriately-low cut-points have suggested that artefactually-high levels of physical activity are typical[40].

Studies of objectively-measured habitual sedentary behaviour in preschool children are more scarce (the author is only aware of the accelerometry and direct observation studies referred to earlier, which suggest that habitual sedentary behaviour is very high[10,35,37,61,62]). There is a larger body of evidence from studies that have used subjective measures of habitual sedentary behaviour, typically US studies using parent-proxy reports of television viewing obtained using questionnaires. With the caveat that subjective measures may not provide accurate estimates of the amount of sedentary behaviour[40], levels of exposure to television viewing that are harmful (by being obesogenic or harmful for other aspects of child health and development) are probably common among preschool children in the developed world[63–69]. Systematic reviews have concluded repeatedly that reductions in screen time are beneficial as a strategy in childhood and adolescent obesity prevention and treatment, and a target (maximum) of 2 h/d non-academic screen time has been recommended widely for some time for older children and adolescents[70–75]. The empirical evidence is fairly consistent in suggesting that levels of television viewing are >2 h/d in large minorities or majorities of the samples of preschool children in most studies[22,65,66,69,76,77]. Furthermore, there is some evidence that levels of television viewing might 'track' from the preschool period; individuals with highest exposure at one time point tend also to have highest exposure later in childhood[76]. An additional concern is the suggestion that amounts of screen time and television viewing might be socially patterned[55,66,76]. In the UK there is no marked social patterning of the amount of habitual sedentary behaviour in the preschool period when measured objectively[40], although objective measures such as accelerometry do not capture information on the types of sedentary behaviour or on associations between sedentary behaviour and energy intake.

In summary, objectively-measured habitual physical activity is low and objectively-measured sedentary behaviour high in preschool children. Levels of physical activity and sedentary behaviour are strikingly different from levels currently recommended. Low levels of physical activity and high levels of sedentary behaviour are likely to be contributing to the epidemic of positive energy balance in preschool children.

Evidence from recent epidemiological studies

In the absence of definitive evidence from physiological (energy balance) studies on the precise role of physical activity and sedentary behaviour in the development of obesity in children[41], alternative study designs are helpful; in particular, intervention studies in which physical activity or sedentary behaviour are changed and the impact of the intervention is assessed and epidemiological studies in which measures or estimates of physical activity and sedentary behaviour are related to weight outcomes[41]. Several reviews of relevant evidence have been published[57,59,78,79]. These reviews have concluded consistently that the evidence base in children is somewhat limited in quantity and quality[41,80]. Many studies have been limited by small sample size, use of crude measures of exposure, inadequate adjustment for social factors and cross-sectional design[41]. In some larger studies that have avoided these problems exposures such as objectively-measured physical activity were not available or not measured during the preschool period. In the large and comprehensive Avon Longitudinal Study of Parents and Children, for example, an objective survey of lifestyle at age 3 years did not include measures of physical activity, as these measures were not available and not practical at the time (mid-1990s)[22]. However, the addition of accelerometry to the measurement protocols from age 11 years has been successful in identifying associations between physical activity and body fatness, as well as indicating possible 'dose–response' relationships[42]; the experience of this study illustrates the importance of measuring physical activity and sedentary behaviour objectively from early childhood in future cohort studies.

Despite limitations in the evidence base, the balance of evidence from preschool children is supportive of the hypothesis that higher levels of physical activity protect against obesity and high levels of sedentary behaviour promote obesity[79]. While there may be an extent of publication bias, with 'positive' findings being more likely to succeed in editorial and peer review than 'negative' findings, the serious limitations in design and methods make it less likely that any significant associations would be observed[57,59,81] and should offset publication bias to some extent.

The aim of this section of the present review is to update the searches of previous reviews[57,59,78,79] (from end 2005 to end 2007) with the focus exclusively on preschool studies, in order to provide a summary of recent epidemiological evidence. An updated search was indicated because it seemed likely that greatly improved evidence (from accelerometry studies) might have come to light in the past 2 years.

Evidence from recent intervention studies

Eligibility for inclusion here was restricted to randomised controlled trials in preschool children that had a weight-based primary outcome and followed participants to ≥12 months after the start of the intervention. Only two eligible studies, both cluster randomised controlled trials, were identified[53,82]. In one study the intervention was based on modification of physical activity and sedentary behaviour but no net increase in physical activity or decrease in sedentary behaviour, as measured by accelerometry, was found[53]. The absence of any change in physical activity and sedentary behaviour in this trial meant that it could not be used to test hypotheses in relation to these behaviours and their impact on weight status in preschool children.

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Table 1. Recent longitudinal studies of associations between physical activity, sedentary behaviour and weight status in preschool children

Study	Exposure(s)	Exposure measure	Outcome measure	Setting, sample	Conclusions
Janz *et al.*[84]	Total physical activity; MVPA	4 d accelerometry	Body fat percent by dual-energy X-ray absorptiometry	*n* 378 4–6 year-olds, USA; 3-year follow-up	Smaller increases in body fat content in more-physically-active children
Yang *et al.*[85]*	Physical education; organised sports	Parent-proxy report	Adult waist circumference and skinfold thickness	*n* 1319 at age 3 years, USA; follow-up to adult life	Greater participation in sport and physical education associated with lower adult waist circumference
Reilly *et al.*[22]	TV viewing	Parent-proxy report	BMI ≥95th percentile	*n* 8234 at age 3 years, England; follow-up to age 7 years	Significant reduction in odds of obesity at age 7 years with greater exposure to TV at 3 years
Lumeng *et al.*[86]†	TV viewing	Parent-proxy report	BMI ≥95th percentile	*n* 946 at age 3 years, USA; follow-up to age 4 years	No significant associations between TV exposure at 3 years and obesity at 4 years in final model

MVPA, moderate–vigorous-intensity physical activity; TV, television.
*Contribution of preschool measures to findings unclear in this study (measures of exposure made repeatedly during childhood and adolescence).
†This study also carried out a cross-sectional analysis (see Table 2).

In the other trial a nursery-based diet and exercise programme also failed to demonstrate benefits for weight status[82], and the inclusion of both diet and physical activity interventions makes it difficult to identify the contribution of the latter to outcome in any case[41,82].

The absence of benefits to the intervention in the latter study[82] is of particular interest since in this study the intervention targeted preschools with a largely Latino population, while essentially the same intervention had more marked benefits in the earlier study by this group when carried out in a largely African-American population[83], implying that obesity prevention interventions may have to be more population-specific in future.

Evidence from recent longitudinal observational studies

Studies were included only if they reported on associations between a measure or estimate of physical activity or sedentary behaviour and a weight-based outcome with the exposure measured in the preschool period and outcome ≥1 year later. A total of four eligible longitudinal studies were identified that were not included in the previous review of this topic[79] (Table 1).

Of the four longitudinal studies, only one measured habitual physical activity objectively using accelerometry[84], one measured physical activity subjectively[85] and the other two measured television viewing as the exposure, subjectively[22,86]. This small body of evidence identified after the last major review of this topic is supportive of the hypotheses that higher levels of physical activity in the preschool protect against excess fat gain, and higher levels of exposure to television viewing in the preschool period significantly increase risk of subsequent obesity. It may be of note that in one of these studies significant associations between physical activity and adiposity were found despite a relatively small sample size[84]; this finding may have been because of the high quality of the exposure measure (physical activity by accelerometry).

Evidence from recent cross-sectional observational studies

In view of the limitations of the evidence base from longitudinal studies it is appropriate to consider recent cross-sectional studies that have attempted to identify associations between physical activity, sedentary behaviour and obesity or body fatness. The principal caveat that applies to cross-sectional studies is doubt over causality, and the cross-sectional study design is inferior to longitudinal design[41,57,59].

For the current review, four eligible and new cross-sectional studies were identified (Table 2). The focus of three of these four studies[86–88] was parent-reported television viewing and significant associations with overweight and/or obesity, usually robust to a range of adjustments, were found. In the fourth[89], which was a small study, significantly lower risk of overweight and obesity at higher levels of physical activity was reported. Despite the use of accelerometry, no clear ‘dose response’ was identified[89] and the authors acknowledge that they used accelerometry cut-points that were inappropriately low, rendering inferences on relationships between intensity of physical activity and overweight doubtful[40,89].

In summary, the recent evidence from preschool longitudinal and cross-sectional studies is limited but consistent with previous reviews in being supportive of the view that physical activity protects against overweight and obesity, while sedentary behaviour is a risk factor for overweight and obesity[79].

Major gaps in the evidence base on relationships between physical activity, sedentary behaviour and energy balance in preschool children

The review carried out for the present study shows that improvements in the evidence base have been fairly modest over the past 2 years. Intervention studies and longitudinal studies have been rare. There is clearly a need for greater emphasis on both types of study focused on

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Table 2. Recent cross-sectional studies of associations between physical activity, sedentary behaviour and weight status in preschool children

Study	Exposure(s)	Exposure measure	Outcome measure	Setting, sample size	Conclusions
Metallinos-Katsaras *et al.*[89]	Habitual physical activity	7 d accelerometry	Overweight and obesity (BMI ≥85th percentile)	*n* 36, 2–5 year olds, USA	Higher physical activity associated with lower risk of overweight and obesity
Jouret *et al.*[87]	TV viewing Participation in organised sports	Parent-proxy report	Overweight (BMI ≥90th percentile)	*n* 1780, 3–4 year olds, France	Greater exposure to TV viewing significantly positively associated with overweight
Lioret *et al.*[88]	TV viewing Physical activity	Parent-proxy report	Overweight using International Obesity Task Force cut-points	*n* 334, 3–6 year olds, France	Greater exposure to TV viewing significantly associated with overweight
Lumeng *et al.*[86]*	TV viewing	Parent-proxy report	Obesity BMI ≥95th percentile	*n* 1016, 3 year olds, USA	Exposure to TV viewing significantly associated with risk of obesity

TV, television.
*Study was both cross-sectional and longitudinal (see Table 1).

preschool children. Intervention studies would have added value in providing potential public health strategies to address the obesity epidemic as well as valuable evidence on the aetiology of obesity.

With the advent of accelerometry, measurement of the important exposures of sedentary behaviour and physical activity is now possible with high accuracy, practical utility, relatively low cost and relatively high precision[40,41,59]. Accelerometry also permits physical activity to be partitioned into the distinct constructs of total volume of physical activity, light-intensity physical activity and moderate–vigorous-intensity physical activity[42,60]. The availability of accelerometry could soon provide a greatly-improved understanding of the aetiology of obesity in preschool children. A number of new cohort studies are underway in which the focus is the role of the preschool environment in the aetiology of childhood obesity[21,90,91]. These cohort studies should improve understanding of the early aetiology of obesity, although to date few of the new cohort studies appear to have included objective measurements of physical activity and sedentary behaviour in early life, which is a missed opportunity.

One gap in the literature that is obvious is the lack of aetiological evidence from outside the USA, and the almost complete absence of evidence from the developing world. The obesity epidemic has progressed rapidly among children and adolescents across much of the developing world[1,17] and so intervention and longitudinal studies of preschool children that employ accelerometry should be a priority of future obesity research in developing countries.

Conclusions

While a complete understanding of the precise contributions of physical activity and sedentary behaviour to energy imbalance in early childhood remains elusive, it is clear that preschool children, at least in the developed world, lead highly sedentary lives that must predispose to overweight and obesity in the modern food environment. Other influences on energy imbalance are likely to be important in the preschool period, including potentially-important contributions of parental feeding style on food intake and genetic predispositions, but discussion of these issues is beyond the scope of the current review.

The preschool years may not be a critical period for the regulation of long-term energy imbalance, but establishment of obesogenic behaviours by or during the preschool period appears to be common in the developed world. These lifestyles commonly cause the establishment of obesogenic growth trajectories by the preschool years. The preschool period is likely to be critical in the public health sense because future efforts at obesity prevention will need to focus on ensuring that many fewer preschool children establish obesogenic lifestyles and develop obesogenic growth trajectories.

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