

## Energy expenditure and physical activity in relation to fitness in children

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Physical activity is accepted as one of the major prerequisites for normal growth and development of children and adolescents. Other desired outcomes include psychological well-being and the potential development of positive attitudes and habits as a foundation for an active lifestyle in adulthood. In addition the increasing evidence for the physiological health benefits of physical activity in adulthood, particularly in relation to coronary heart disease (CHD) has stimulated interest in investigating the childhood antecedents of adult health.

However, rigorous evaluation of the role of childhood physical activity and fitness has been hampered by a combination of methodological and conceptual constraints. First, there is a discernible feeling that children are less active and fit today than in the past. While intuitively plausible, this assumption has been difficult to validate because of difficulties in obtaining detailed, accurate and objective information on habitual patterns of energy expenditure and physical activity. Second, there has been a lack of consensus about how fitness and its components should be defined and tested. For example, major emphasis has been placed on cardiorespiratory fitness in children while the potential health and fitness benefits of regular low-to-moderate intensity physical activity have been largely overshadowed. Therefore, while physical activity and physical fitness are obviously related, their relative importance to short- and long-term health status remains to be established.

### MEASUREMENT OF HABITUAL PHYSICAL ACTIVITY AND ENERGY EXPENDITURE IN CHILDREN AND ADOLESCENTS

The measurement of total energy expenditure (TEE) and patterns of physical activity in adults is difficult. It is even more problematic in children since many of the methods are of low subject appeal and are likely to induce behavioural changes in their spontaneous and natural activity patterns. An additional consideration in large-scale studies is the need to apply methodology which is simple, low cost, robust and time-efficient such that large samples can be surveyed.

The most commonly used methods for assessing physical activity and/or energy expenditure are diaries (Thorland & Gilliam, 1981; Bouchard *et al.* 1982), activity recalls (Blair *et al.* 1985; Ross *et al.* 1987), observation (direct, video, film; Baranowski *et al.* 1984; O'Hara *et al.* 1989), electronic motion sensors (Klesges *et al.* 1985; La Porte *et al.* 1985; Klesges & Klesges, 1987; Sallis *et al.* 1990), indirect calorimetry (Saris, 1982), heart rate (HR) monitoring (Armstrong *et al.* 1990; Riddoch *et al.* 1991; Durant *et al.* 1992; Livingstone *et al.* 1992) and the doubly-labelled-water (DLW) method (Saris *et al.* 1989; Davies *et al.* 1991; Emons *et al.* 1992; Goran *et al.* 1993). Each of these methods has its strengths and limitations and these have been reviewed elsewhere (La Porte *et al.* 1985; Saris, 1986; Goran, 1993). Not surprisingly, all the reviews have concluded that there is a

need to improve the methodology for the assessment of physical activity, particularly among children.

Observational procedures are suitable for small and moderate sample sizes when information on the specific types and duration of activity in a variety of physical and social settings is the primary focus of concern. Because they are not biased by recall or self-reporting ability these procedures are particularly suitable for young children. However, the methodology can be time consuming, labour intensive and interfere with spontaneous activity patterns and to be effective it requires extreme diligence and control of observer reliability.

Most large-scale studies of habitual physical activity of adolescents and adults have used standardized self-report questionnaires or diaries. However, diaries and recalls rely on memory, are subject to misrepresentation and do not have well documented reliability and validity (La Porte *et al.* 1985; Washburn & Montoye, 1986). For obvious reasons, the utility of these instruments is especially problematic in younger children due to cognitive limitations and because their activity patterns tend to be sporadic in terms of time and intensity (Simons-Morton *et al.* 1987).

A considerable number of motion sensors, for example pedometers, actometers and accelerometers, have been developed to provide more objective measures of physical activity in terms of body movement. They have only recently been applied to children and a limited number of studies suggest that accelerometers are superior to pedometers because of their ability to assess both the quantity and intensity of movement. To date, few validation studies have been performed. Moreover, since acceleration in the vertical plane is measured, accelerometers will reflect walking and running very well, but are relatively insensitive to other common children's activities such as cycling.

Currently the most socially acceptable and powerful technique for providing an objective measure of TEE is the DLW method. Because the technique is non-intrusive and since measurements are performed over more extensive periods than with other techniques, typically 1–2 weeks, it is more likely to provide a representative estimate of TEE. The ability of the DLW method, in combination with indirect calorimetry, to assess the energy cost of activity is of particular importance given that the accurate measurement of this component of TEE has traditionally been elusive under free-living conditions. However, its application in large-scale studies is limited by its cost and technical complexity. Furthermore, in epidemiological studies it may not even be the most appropriate method to apply since it provides no assessment of the patterns of physical activity (frequency, duration, intensity) which are important functional indicators of children's health status.

Conversely, minute-by-minute HR recording fulfils many of the criteria for indirect and objective measures of both energy expenditure and physical activity in children. However, at low levels of physical activity the interpretation of HR data is confounded by the fact that HR responses reflect not only physical activity but also the site, kind and intensity of muscle activity and the metabolic status, posture, temperature and emotional status. The relationship between HR and physical activity is more secure at higher levels of physical activity and it is possible to identify and quantify from individually derived HR *v.* O<sub>2</sub> uptake ( $\dot{V}O_2$ ) regression equations, bouts of exercise that might be considered to confer a health benefit. Consequently, at moderate- to high-intensity activity HR monitoring provides a good general index of physical activity. Moreover, when cross-validated against measurements of DLW TEE, estimates of TEE from HR data

provide a close estimation of the TEE of population groups even though individual estimates lack precision (Livingstone *et al.* 1992). Provided these errors in TEE can be tolerated, HR monitoring is one of the best available techniques for objective assessment of physical activity levels.

The measurement of such a highly complex and variable characteristic as physical activity of children is difficult, but feasible. Unfortunately definitive reliability and validity studies for many of these methods are lacking. Inevitably the choice of the most appropriate method to use (aside from considerations of reliability and validity) will be dictated largely by practical, financial and logistical considerations. Since each of these methods is deficient in at least one respect, a combination of different techniques should be considered within the context of the available resources, the numbers to be surveyed and the focus of concern of the study.

#### ENERGY EXPENDITURE OF CHILDREN AND ADOLESCENTS

Until recently, there have been virtually no data on TEE of children and adolescents because of methodological constraints in measuring TEE in these age-groups. The only feasible alternative has been to base estimates of energy requirements of children on the observed energy intakes of healthy well-nourished children. Based on the tacit assumption that these energy intakes are representative of habitual intake, a major conclusion of recent studies of food intake in children is that energy requirements have declined in response to a secular trend towards hypoactivity (Darke *et al.* 1980; Darke & Disselduff, 1981; Committee on Medical Aspects of Food Policy, 1984; Hackett *et al.* 1984). In 10–18-year-old children and adolescents, recommendations for energy requirements are based on a factorial approach that sums the energy costs of different hypothetical activity patterns. Obviously both of these approaches have a number of acknowledged disadvantages and the Food and Agriculture Organization/World Health Organization/United Nations University (FAO/WHO/UNU) (1985) stressed that, in future, recommendations for energy requirements should be based on measured TEE at all ages.

Since 1989, independent laboratories in US, UK and the Netherlands have reported new data on DLW TEE of children and adolescents aged 4–18 years. These data provide, for the first time, a direct means of addressing many outstanding issues regarding total energy requirements and patterns of activity-related energy expenditure (Table 1). One of the most striking results of the studies in children is the good agreement between the TEE data for 8–9-year-old children studied in the Netherlands (Saris *et al.* 1989) with that for children of similar age in the UK (Davies *et al.* 1991). Furthermore, both sets of data concur with FAO/WHO/UNU (1985) recommendations for these age-groups. However, in marked contrast there are large differences between the energy expended by a group of 4–6-year-old children in the US (Goran *et al.* 1993) and by the 5-year-old children observed by Davies *et al.* (1991). The TEE (kJ/kg per d) for girls and boys in the UK sample were 90 and 95% respectively of current FAO/WHO/UNU (1985) recommendations; the corresponding values for the US children were only 70 and 76%.

Part of the explanation for the fact that recommendations exceed observed expenditure in both these groups may be the fact that when formulating the FAO/WHO/UNU (1985) recommendations, the FAO/WHO/UNU Committee was concerned about the perceived secular trends towards a sedentary lifestyle at all ages. Consequently, the

Table 1. Total energy expenditure (TEE) measured by the doubly-labelled-water method  
(Mean values and standard deviations)

Study	Age (years)	n	Wt (kg)	TEE				FAO/WHO/UNU (1985) estimated requirements (kJ/kg per d)
				MJ/d		kJ/kg per d		
				Mean	SD	Mean	SD	
Girls								
Saris <i>et al.</i> (1989)	8	10	28.2	8.06	—	286	—	268
Bandini <i>et al.</i> (1990)	14	14	55.7	9.94	1.86	178	8	176
Davies <i>et al.</i> (1991)	5	16	18.5	6.18	1.03	333	44	368
	7	15	26.0	8.17	1.47	320	74	318
	9	15	29.1	7.57	1.27	261	44	259
	12	10	49.3	10.53	1.89	218	33	195
	15	11	58.0	10.12	1.65	177	25	169
Goran <i>et al.</i> (1993)	18	11	62.4	11.09	1.87	170	32	165
	4	4	16.7	4.38	0.36	262	28	385
	5	4	22.3	5.67	0.64	255	31	368
	6	6	23.4	6.03	1.57	258	26	347
Boys								
Saris <i>et al.</i> (1989)	9	9	30.9	9.00	—	291	—	301
Bandini <i>et al.</i> (1990)	14	14	56.4	12.95	2.11	230	37	206
Davies <i>et al.</i> (1991)	5	12	18.9	6.88	0.75	366	42	385
	7	10	24.6	8.15	1.64	333	38	347
	9	14	29.5	8.95	1.21	309	51	301
	12	8	39.7	10.48	1.47	246	41	236
	15	12	60.1	13.47	3.03	225	32	195
Goran <i>et al.</i> (1993)	18	12	71.6	15.05	2.88	201	18	185
	4	5	19.4	5.62	1.37	295	33	397
	5	8	20.3	6.23	1.16	309	30	385
	6	3	22.0	6.00	0.72	274	40	368

FAO/WHO/UNU, Food and Agriculture Organization/World Health Organization/United Nations University.

committee inflated observed energy intakes by 5% to accommodate 'a desirable level of physical activity'. However, the wisdom of this prescriptive component is questionable since recommendations directed only at energy intakes will favour adiposity if this is not offset by a real increase in activity and energy expenditure.

A number of possible explanations may be proposed to account for the fact that the 5-year-old US boys were expending nearly one-third less energy in physical activity than their UK counterparts (107 *v.* 157 kJ/kg per d) while the US girls, relative to UK girls, were expending only about half the energy in physical activity (77 *v.* 139 kJ/kg per d). First, there may be real lifestyle differences with regard to patterns of physical activity, but this is unlikely to explain fully the differences. Another reason may be a sampling bias favouring either unusually active children in the UK or inactive children in the US. However, close scrutiny of the data by Goran *et al.* (1993) suggests that there is a methodological bias towards underestimation of TEE. In several cases measured resting

energy expenditure (REE), which includes the energy cost of meal-induced thermogenesis and spontaneous physical activity while supine, exceeded corresponding TEE values. Expressed as a multiple of REE the TEE values (TEE/REE) work out to be 1.27 and 1.20 for boys and girls respectively suggesting unrepresentatively low TEE.

In contrast to the common perception that aspects of current lifestyles, such as TV viewing (Dietz & Stransburger, 1991), are favouring more sedentary lifestyles, the available TEE data for adolescents are higher (relative to recommendations) than might be expected. Whether these are representative or not remains to be verified. However, the remarkable consistency in TEE values for 15-year-old subjects living in markedly different geographical areas (Boston, Cambridge and Belfast) suggest that biased sampling is unlikely to be the major reason for the unexpectedly high value of TEE. Evidently the reasonable inputs of leisure activity reported by the subjects (Davies *et al.* 1991) are compatible with their lifestyle and can have a significant impact on TEE values.

Unfortunately, DLW TEE data do not provide an assessment of patterns of physical activity in terms of frequency, intensity and duration. Ideally, energy expenditure and associated patterns of physical activity should be assessed simultaneously. A number of recent studies have used HR monitoring as an indirect indicator of physical activity patterns in UK children and adolescents (Armstrong *et al.* 1990; Riddoch *et al.* 1991) but only one study to date (Livingstone *et al.* 1992) has simultaneously assessed TEE by DLW and evaluated associated patterns of physical activity by HR monitoring. These studies are reviewed in the next section but, overall, they suggest low levels of moderate-to-vigorous activity (MVPA) in children and adolescents. The levels of MVPA observed by Livingstone *et al.* (1992) were higher, but when HR data on patterns of physical activities and TEE data are combined they show a decline with increasing age in physical activity level (TEE/BMR) values and in the time spent in total activity and in MVPA. Girls, in general, were less inclined to exercise than boys. It is not clear how the more representative estimates of DLW TEE over several days would relate to HR assessments of short-term periods of high-intensity physical activity. Therefore, while children, and particularly adolescents, may not voluntarily engage in much MVPA, prolonged activity at lower intensity can significantly influence TEE values.

Definitive conclusions about these limited data on TEE of children and adolescents are obviously not merited. Clearly more longitudinal, multicentre studies, which include simultaneous measurements of TEE and objective assessments of physical activity, on larger samples, are required. Only then will it be possible to confirm or refute the hypothesis that children are not as active or as fit as they should be relative to their short- and long-term health status.

#### CURRENT LEVELS OF PHYSICAL ACTIVITY IN UK CHILDREN AND ADOLESCENTS

In addition to a paucity of energy expenditure data only a limited number of studies have reported on the patterns of physical activity of UK children and adolescents. To date, the only national study in the UK has been the Northern Ireland Health and Fitness Survey (NIHFS; Riddoch *et al.* 1990). The survey was conducted during the 1988–9 school year on a representative sample of 3211 schoolchildren aged 11–18 years in Northern Ireland. The research was prompted by growing concerns that unhealthy lifestyles, including low levels of physical activity in childhood, are likely to carry over into adulthood and

increase the risk of CHD and other chronic diseases. Using a 7 d activity recall, the survey showed that younger (11–14 years) children were considerably more active than older (15–18 years) subjects. The most marked diminution in activity took place after 13–14 years, the rate being similar for both sexes. At all ages, boys were considerably more active than girls, particularly in vigorous activity (subjectively defined as exercise/activity that causes considerable breathlessness) and by the age of 17–18 years the time spent in vigorous activity by the boys was similar to that of the total exercise of the girls. Overall, younger boys were the most active and older girls the least active. The findings of this study are in accord with other national studies conducted in the USA (National and Technical Information Service, 1985), Canada (Fitness Canada, 1981) and Australia (Australian Council for Health, Physical Education and Recreation, 1985). However, while the NIHFS was unique, the data were self-reported and were, therefore, vulnerable to misrepresentation through errors in simplification or exaggeration. Also, the survey, while providing useful baseline information on activity profiles, did not objectively measure absolute levels of physical activity in terms of frequency, intensity and duration.

Only three recent studies in the UK have investigated the relationship between children's peak  $\dot{V}O_2$  ( $P\dot{V}O_2$ ), as an index of cardiorespiratory fitness, and the intensity and duration of habitual physical activity recorded over periods of 2–4 d by minute-by-minute monitoring of HR (Armstrong *et al.* 1990; Riddoch *et al.* 1991; Livingstone *et al.* 1992). As a measurement of the functional load on the subject rather than a direct measure of physical activity, HR monitoring has acknowledged disadvantages which were discussed previously (p. 208). Another limitation is that methods used for interpreting HR data are inconsistent between studies. This is largely because the threshold criteria for exercise in children are based more on intuition than fact. For example, Armstrong *et al.* (1990) took as their primary consideration the number of sustained 5, 10 and 20 min periods spent at HR above threshold values of 139 and 159 beats/min (bpm). On the other hand, Riddoch *et al.* (1991) were concerned with both sustained and intermittent activity and analysed their data in terms of the time spent above two individually determined HR thresholds (thresholds were determined for each individual child under laboratory conditions using  $P\dot{V}O_2$  testing (standardized protocol)), equivalent to 50%  $P\dot{V}O_2$  (representing MVPA) and 70%  $P\dot{V}O_2$  (representing vigorous physical activity (VPA)). Similar HR threshold criteria were also applied by Livingstone *et al.* (1992) but, in addition, the time spent in total activity was assessed from individually determined HR (FLEX HR) derived from calibration of  $\dot{V}O_2$  HR which is used to discriminate between HR which were representative of resting activities (i.e. sitting, standing) and those which represent physical activity (walking, running etc.). In this latter study TEE was also estimated from the HR data.

In spite of the lack of standardization in interpreting HR data, a number of clear trends in the frequency, intensity and duration of physical activity emerged. In terms of total activity (HR > FLEX HR; total time spent with the minute-by-minute HR above FLEX HR) young children (7–9 years) were found to be significantly more active than the older children (12–15 years); (Livingstone *et al.* 1992). In addition boys spent approximately one-third more time in activity than girls (7.7 (SD 1.8) v. 5.3 (SD 2.0) h/d,  $P < 0.01$ ). In this study an inverse relationship was also observed between age and the intensity of activity experienced. Younger children engaged in twice as much MVPA as older children (66 (SD 36) v. 36 (SD 24) min/d,  $P < 0.001$ ) and within each age-category



boys had significantly greater levels of MVPA than girls. Similar trends were also reported by Riddoch *et al.* (1991) but it was evident that older boys in the study by Livingstone *et al.* (1992) were much more active, spending 7.2% of daytime minute-by-minute HR (52 (SD 21) min/d) in MVPA compared with only 4.8% of daytime HR (24 (SD 5) min/d) in the latter study. The reasons for the greater levels of MVPA are not clear but could be due to selection bias; although the subjects in the study by Livingstone *et al.* (1992) were randomly selected, they were chosen from a group which initially volunteered for a study of fitness and, therefore, may have represented more highly fit and motivated youngsters. However, the adolescent girls in both studies undertook similar levels of MVPA (2.4% of daytime HR, 17 (SD 3) min/d (Riddoch *et al.* 1991) *v.* 2.1% daytime HR, 18 (SD 12) min/d (Livingstone *et al.* 1992)).

Using different analytical criteria, Armstrong *et al.* (1990) also observed broadly similar patterns of physical activity. In their study, 13-year-old boys and girls spent 6.2 and 4.3% respectively of daytime HR >139 bpm. Given that, for most children, 50%  $\dot{V}O_2$  probably represents a slightly higher level of activity than a HR threshold of 139 bpm, it seems likely that the MVPA of the adolescent girls in all three studies is broadly similar. However, the primary focus of the Armstrong *et al.* (1990) study was concerned with the number of sustained 5, 10 and 20 min periods when HR was >139 bpm and >159 bpm. Using this criterion, it was shown that while boys were more active than girls, over half the girls and one-third of the boys failed to sustain a single 10 min period with their HR at or >139 bpm during weekday monitoring, while during Saturdays over 90% of the girls and 75% of the boys failed to sustain a single 10 min period at or above the same threshold. Moreover, values >159 bpm were observed only 1.8% of the time in girls and 2.6% in boys; over 85% of girls and 70% of boys showed no single 20 min period of the day when they were exercising at HR >159 bpm.

#### COMPARISON WITH OTHER STUDIES

Comparisons of activity levels between studies are necessarily tenuous because of differences in focus, methodology and definitions of MVPA. Therefore, only HR monitoring studies will be considered to preserve consistency, at least with regard to methodology.

Gilliam *et al.* (1981) reported 12 h HR data recorded in 6–7-year-old children and showed that the average daily period (min) the children exhibited HR >150 bpm was 39 and 20 for boys and girls respectively. HR >160 bpm (60% of predicted maximum HR) were observed for an average of 15 min. In a comparable group of 6-year-old children in the Netherlands, boys and girls exercised at HR >150 bpm for 39 and 34 min respectively during a normal school day (Saris, 1982) while McConnie *et al.* (1982) applied a similar cut-off and reported that only 29 min/d were spent above this threshold by 7-year-old children. In contrast, Verschuur & Kemper (1985) reported that Dutch boys and girls aged 12–13 years spent 80 and 70 min/d respectively with their  $\dot{V}O_2$  above 50% of the maximum  $\dot{V}O_2$  ( $\dot{V}O_{2max}$ ) indicating that this group was probably more active. More recently, however, Janz *et al.* (1992) endorsed the lower levels of activity found in earlier studies. Physical activity patterns of seventy children aged 6–17 years were assessed for 1 d by HR monitoring. On average only 15 min/d (2.3% of total time monitored) was spent at or above the threshold for achieving an aerobic training effect.

Clearly, any conclusions drawn from a small number of studies with limited sample

sizes and applying inconsistent definitions and threshold criteria for activity must be speculative at best. Overall, it appears that children engage primarily in low-intensity activity and when high-intensity activity is experienced it is typically not sustained (Armstrong *et al.* 1990). However, while these activity levels may not be deemed desirable, at least with regard to promoting cardiorespiratory fitness, prolonged activity at a lower intensity can clearly generate high levels of TEE (Livingstone *et al.* 1992) and may be associated with other health benefits, for example maintenance of muscle strength and flexibility. Finally, while these data were cross-sectional, potentially the most serious health issue they highlight is that childhood activity patterns may not persist into adolescence, much less into adulthood. Thus, sedentary lifestyles with their associated health risks can be anticipated during the adult years.

#### PHYSICAL ACTIVITY PATTERNS AND THEIR RELATIONSHIP TO PHYSICAL FITNESS

Unfortunately, clarification of the relationship between habitual physical activity in childhood and physical fitness has been hampered by lack of a clear definition of fitness or a consensus on which assessments should be applied to determine whether or not children have attained suitable levels of fitness. In adults,  $\dot{V}_{O_2max}$  is widely accepted as a major indicator of cardiorespiratory fitness and level of habitual physical activity. Although the validity of this index has not been established in children it has also been usual to use aerobic power ( $\dot{V}_{O_2max}$ ) as a physiological marker of physical activity. (Since obtaining a maximal effort from children is difficult, strictly speaking peak aerobic power ( $P\dot{V}_{O_2}$ ) is assessed rather than  $\dot{V}_{O_2max}$  although the terms are often used interchangeably.)

Pate & Blair (1978) and Krahenbuhl *et al.* (1985) have reviewed cross-sectional and longitudinal studies of children's cardiorespiratory fitness over the past 40 years and found that nearly all values of  $\dot{V}_{O_2max}$  are consistently in the range 45–60 ml/min per kg, values which are considerably higher than those for adults. In normal children  $\dot{V}_{O_2max}$  (l/min) increases approximately in proportion to body size. Relative to body weight  $\dot{V}_{O_2max}$  remains relatively stable in boys aged 6–17 years whereas in females there is a decline after 11–12 years. At all ages the values for females are lower.

There are limited data on  $P\dot{V}_{O_2}$  values for British children. Nevertheless the results of the most recent studies (Armstrong *et al.* 1990; Riddoch *et al.* 1991; Livingstone *et al.* 1992) are consistent with earlier reports for UK children (Brooke *et al.* 1975; Thomason & Hardman, 1977; Bale, 1978, 1981; Armstrong *et al.* 1983) and are in general agreement with values cited by Pate & Blair (1978) and Krahenbuhl *et al.* (1985). Thus, contrary to the common perception of a secular decline in cardiorespiratory fitness due to sedentary lifestyle habits, the evidence suggests that fitness levels (as defined by  $P\dot{V}_{O_2}$ ) have remained remarkably stable over several decades. On this basis, therefore, it could be concluded that the level of daily exercise in children is still sufficient to maintain cardiorespiratory fitness. It is hardly surprising that it has been difficult to validate the assumption that children with higher levels of habitual physical activity have superior aerobic capacity. While positive associations between these two variables have been observed by Mirwald *et al.* (1981), Sunnegardh & Bratteby (1987), Atomi *et al.* (1986) and Fenster *et al.* (1989) a lack of correlation has been noted by La Porte *et al.* (1982), Cunningham *et al.* (1981), Anderson *et al.* (1984), Saris (1982), and Armstrong *et al.*



(1990). Indeed, it is not unusual to observe that sedentary children exhibit good aerobic capacity while many physically active children demonstrate low levels of maximum aerobic power (Anderson *et al.* 1984).

These conflicting results are due to a combination of methodological constraints and biological factors. First, obtaining a maximal effort from children is difficult and this has resulted in a lack of standardized protocols and assessment criteria for defining  $P\dot{V}O_2$ . Moreover, many of these protocols have been derived from standard methods used in adult populations and in many cases have never been validated in children. Second, comparisons between  $P\dot{V}O_2$  and habitual physical activity are confounded by the influence of growth, developmental and maturational status on  $P\dot{V}O_2$  together with an unquantifiable genetic component. Finally, lack of reliable and objective measures of physical activity levels may also have further compromised a truly valid comparison of these two variables. These factors argue against the use of aerobic power as a sensitive index for evaluating cardiorespiratory fitness and associated patterns of physical activity. What is apparent is that current levels of habitual physical activity are unlikely to lead to an increase in cardiorespiratory fitness and any improvement in  $P\dot{V}O_2$  is only likely to be stimulated by endurance exercise training programmes.

#### EFFECT OF TRAINING ON AEROBIC CAPACITY

Early studies generally concluded that children were not aerobically responsive to endurance training either because of intrinsically high levels of physical activity or because of some unexplained immaturity of the biological system. This led to the concept of a critical developmental stage when trainability might be expected (Bar-Or, 1983). However, the hypothesis that children are not aerobically responsive is largely negated by more objective assessments of daily physical activity patterns. These show that children's activity is generally sporadic in nature, consisting of quick bursts of activity followed by periods of rest. Thus, even moderately active children seldom exercise at the duration and intensity where an aerobic training response might be expected (Gilliam & MacConnie, 1984; Armstrong *et al.* 1990; Riddoch *et al.* 1991; Janz *et al.* 1992). However, it appears that aerobic mechanisms are sufficiently well developed to elicit a response to endurance training by the age of 6 years. Thus, while children may be aerobically unresponsive to deliberate increases in physical activity, an increase in aerobic capacity is evident in children who are trained for endurance sports (Vaccaro & Mahon, 1987). Close scrutiny of the early studies suggests that the results are more likely to have been biased by potentially serious flaws in experimental design. These deficiencies have centred around inadequate sample sizes, heterogeneity of the individuals selected, inadequate selection or even lack of control subjects, application of a training stimulus that was inappropriate to the initial fitness of the subjects and, finally, to sample attrition. Moreover, the interpretation of the results may have been compromised because several variables, such as body size and development, and aerobic capacity are changing simultaneously.

In contrast, more recent experimentally robust studies have demonstrated that after regular high-intensity training for periods of at least 12 weeks the  $\dot{V}O_{2max}$  levels of pre-adolescent children are increased by about 15%, of much the same order as expected in adults (Rowland, 1985; Kranhenbuhl *et al.* 1985). An increase in cardiac stroke volume appears to be the main mechanism for this gain. While the optimum intensity,

frequency and duration of the training stimulus remains to be firmly established it is generally recommended that exercise programmes designed to improve cardiorespiratory fitness in children should be similar to those which promote aerobic conditioning in adults (Rowland, 1985; Sady, 1986). In adults this involves endurance activity of large muscle groups, undertaken for three to five sessions weekly, each lasting 15–60 min, of an intensity which will elicit 60–90% of maximal HR (American College of Sports Medicine, 1978). However, it is highly improbable that these training criteria are compatible with the habitual activity patterns of most children. This is only likely to be achieved by vigorous and intensive endurance training, but whether this is feasible or even desirable is debatable. In any case, the disciplined exercise demands which are implied are incompatible with the behavioural characteristics of most children and, not surprisingly, are likely to be resisted. Furthermore, a key issue which has yet to be resolved is the extent to which such training effects persist into adulthood to offer protection against possible future cardiac events. Thus, while it is clearly possible to modify physical activity patterns in favour of more MVPA (Krahenbuhl *et al.* 1985; Rowland, 1985) there is little evidence to suggest that this stimulates long-term volitional changes in children's activity patterns (Shasby & Hagerman, 1975; Coutes *et al.* 1981; Duncan *et al.* 1983). On this basis there is little to recommend such training protocols as the primary focus of physical activity programmes for children.

#### HOW SHOULD FITNESS BE DEFINED?

Undoubtedly the usual assumption that children's physical fitness is synonymous with cardiorespiratory endurance as assessed by  $P\dot{V}O_2$  has been overly restrictive and, moreover, has presented a paradox. Empirically defined cardiorespiratory fitness is the capacity to perform MVPA for a prolonged time. Concern has been expressed at the low levels of engagement in MVPA by children but with only scant attention to the fact that MVPA is something which children are not strongly motivated to undertake. At the same time, given their inherently high  $P\dot{V}O_2$  levels they could legitimately be regarded as the fittest group in the population! This apparent paradox would not exist if physical fitness was viewed as a multi-dimensional concept comprising health-related components (cardiorespiratory function, muscular-skeletal function, body composition) and performance or skill-related components (agility, balance, coordination, speed, power, reaction time; Casperson *et al.* 1985). The adoption of a more holistic view of fitness has resulted in the development of a number of battery tests for field use (American Alliance for Health, Physical Education, Recreation and Dance, 1980; Council of Europe, 1987). However, to date, the interpretation of the fitness levels of children using these tests has been severely impeded by the lack of reference standards based on expected health outcomes and functional capacity.

Considerable caution must be exercised, therefore, when interpreting the results, particularly when comparing individual results with population scores since fitness outcomes at this age are, to a large extent, genetically determined. It is also noteworthy that in the NIHFS (Riddoch *et al.* 1990), levels of fitness improved with age, the greatest increases, at least in boys, being observed at 14–16 years, coinciding with a marked decline in self-reported physical activity. Hence, the need for informed evaluation of fitness test results, particularly in the health context. In addition a number of factors may easily mask or amplify relatively small but real changes in children's fitness. These

include motivation, previous experience, motor efficiency, prevailing test conditions, accuracy of the test equipment and methods of test administration. However, these caveats should not preclude fitness testing since its administration serves as a useful learning experience for children with the added intrinsic exercise value of testing.

A number of national surveys using these field test batteries have been conducted over the past decade using statistically-based representative samples of children. Broadly similar tests and protocols have been used and the results have been reported in a form which makes comparisons possible, if tenuous. The only UK-based study of this type is the NIHFS (Riddoch *et al.* 1990). When the results of this study are compared with national surveys conducted in Australia (Australian Council for Health, Physical Education and Recreation, 1985), Canada (Fitness Canada, 1981) and the USA (National and Technical Information Service, 1985) the fitness levels of children in the four countries are remarkably similar. This is not an unexpected outcome for two reasons. First, fitness of children at this age is predominantly genetically determined and second, these countries share broadly similar lifestyle patterns.

However, while the results of the NIHFS (Riddoch *et al.* 1990) and other national studies have provided invaluable benchmark data they cannot yet address two key issues. First, due to lack of reference standards it is not possible to state if children are 'fit enough'. Second, in the absence of longitudinal data it is not known if children are getting less fit or more fit. Finally it must be emphasized that fitness levels are not necessarily a true reflection of the activity patterns of children. Ultimately it is a lifestyle with a pattern of regular physical activity but with expected carryover benefits for physical fitness which should be promoted.

#### PROMOTION OF A PHYSICALLY ACTIVE LIFESTYLE IN CHILDHOOD

The rationale for developing recommendations for physical activity in children is not as well advanced as with adults. The immediate health value of children's physical activity is in its potential to help regulate adiposity and promote physical fitness and functional capacity. The long-term benefits are less clear. For example, despite low levels of MVPA, the cardiorespiratory fitness of children is high relative to adults. In principle aerobic power may be improved by following adult standards for duration, intensity and frequency of activity, but in practice, even if this was desirable, it is likely to be resisted by most children. In any case it is not known if such training effects would persist into adulthood to offer protection against future cardiac disease. Moreover, limiting the definition of fitness to cardiorespiratory fitness has ignored the potential benefits of more incessant but low-to-moderate intensity forms of activity, for example maintenance of muscle strength and flexibility, optimization of bone density.

At the outset it must be recognized that children's dispositions towards exercise and physical activity are different from those of adults. The notion that short- and long-term health status is related to activity is too abstract a concept to have personal meaning to children. However, they can deal with the concrete reality of enjoyment and personal competence and this should be the fundamental basis of all exercise prescriptions and programmes for children. Therefore, the key issue which needs to be addressed is how youngsters can be encouraged to appreciate and carryover regular participation in physical activity of varying intensities into adulthood where there are demonstrable effects of regular and vigorous activity on health status.

Unfortunately, the current emphasis on motor skills and sports in physical education classes is unlikely to foster the physical, psychological and social events which combine to promote the concept of total fitness. Since even the most inactive of pupils have a high fitness ( $P\dot{V}O_2$ ) level the primary focus on vigorous training programmes does not seem meaningful. Indeed, they may well be counterproductive and lead to an acceleration of the decline in physical activity which has been observed to occur during the transition from the school to the work environment (Ilmarinen & Ruthenfranz, 1980). By shifting the emphasis to increased participation in enjoyable and stimulating MVPA, children are more likely to want to keep participating for its own sake. However, if the emphasis on short-term gains in physical fitness is such that children learn to dislike exercise the gains will sow the seeds of its demise.

Nevertheless, it must be acknowledged that the participation in regular sport and physical activity is a particularly difficult habit to promote. The evidence suggests that while innovative and stimulating exercise programmes may result in active participation in the short term, ultimately they suffer high rates of attrition (Coutes *et al.* 1981). Carryover into adulthood can only be anticipated when children have reached the stage of being able to self-regulate their own exercise habits and are motivated to physical activity for its perceived benefits. How to facilitate this self-motivation is a complex problem.

#### CONCLUSION

The favourable influence of a physically active lifestyle during childhood on health status in adulthood particularly in relation to its preventive role in disease processes remains to be unequivocally established. Before these questions can be answered it is evident that the behavioural and health carryover effects of physical activity and fitness into adulthood need to be clarified by controlled longitudinal studies. In addition the relative importance of the different components of fitness to future health needs to be ascertained. This in turn depends on the development of valid and reliable field and laboratory tests for assessing patterns of physical activity and fitness so that longitudinal studies of larger groups of children in the general population and in specific subgroupings can be undertaken. When such data become available only then can the importance of childhood physical activity and fitness be assessed relative to short- and long-term health status.

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