Aerobic Fitness and Physical Activity in Children

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In Volume 1 of *Pediatric Exercise Science (PES)*, a paper by Fenster et al. (25) investigated the relationship between peak oxygen uptake (peak VO\(_2\)) and physical activity (PA) in 6- to 8-year-old children. They used both questionnaires and large-scale integrated activity monitors (LSIs) to estimate daily PA and determined peak VO\(_2\) using an incremental treadmill test to volitional exhaustion. They concluded that peak VO\(_2\) correlated well with PA as measured by LSIs but commented that questionnaire data were only weakly and nonsignificantly associated with LSI and peak VO\(_2\) data. Peak VO\(_2\) and PA are the most researched and reported variables in the 25-year history of *PES*. Yet, the assessment and interpretation of young people’s aerobic fitness and PA remain problematic and any meaningful relationship between them during childhood and adolescence is shrouded with controversy. The present paper uses Fenster et al.’s (25) report as an indicator of where we were 25 years ago, outlines how far we have advanced since then, and suggests future directions of research in the study of aerobic fitness and PA.

In the first volume of *PES*, Fenster et al. (25) investigated the relationship between 6- to 8-year-old children’s peak oxygen uptake (peak VO\(_2\)) and physical activity (PA). Five boys and 13 girls participated in the study and their data were pooled for analysis. Peak VO\(_2\) was determined during an incremental treadmill test to voluntary exhaustion and PA was estimated using both questionnaires and large-scale integrated activity monitors (LSIs). On the basis of a significant interclass correlation coefficient of \(r = .59\) between peak VO\(_2\) and the log of LSI average counts per hour Fenster et al. (25) concluded that “aerobic capacity, as measured by peak VO\(_2\) correlated well with physical activity as measured by LSI” (p.134). They also commented that questionnaire data were only weakly and nonsignificantly associated with LSI and peak VO\(_2\) data.

Young people’s peak VO\(_2\) and PA are the most researched and reported variables in the 25-year history of *PES* and yet the assessment and interpretation of peak VO\(_2\) and PA and any meaningful relationship between them during growth and maturation are still shrouded with controversy. The present paper uses Fenster et al.’s (25) work as an indicator of our understanding of young people’s peak VO\(_2\) and PA in 1989, briefly reviews what we know in 2013, and suggests future directions of research.

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Peak VO₂

The term *aerobic capacity* is now seldom used to refer to peak VO₂, as *capacity* has no time base. Peak VO₂ is usually described as a measure of maximal aerobic power or, more generally, aerobic fitness. Peak VO₂, the highest rate at which oxygen can be consumed during exercise, is widely recognized as the best single measure of young people’s aerobic fitness. Aerobic performance is limited by peak VO₂ and a high peak VO₂ is a prerequisite of elite performance in many sports but it does not describe all aspects of aerobic fitness (10). Other components of aerobic fitness during youth are less well documented and there are few data on normal values or time trends so this paper will initially reflect on the variables measured by Fenster et al. (25) and focus on peak VO₂.

Peak or Maximal VO₂?

Over 60 years ago, Astrand (15) documented that the majority of young people completed an exercise test to volitional exhaustion without demonstrating the plateau in VO₂ conventionally associated with the achievement of maximal oxygen uptake in adults. Fenster et al. (25) acknowledged this by using the term peak VO₂ (which was becoming increasingly popular in the pediatric literature at that time) to describe the children’s ‘aerobic capacity’ whether they achieved a VO₂ plateau or not. They used an incremental treadmill test and exercised the children until they could no longer continue despite constant verbal encouragement. It was concluded that ‘while reaching maximal oxygen uptake (VO₂max), as evidenced by HR > 200 bpm, RER > 1, and plateauing in VO₂, is difficult in 6- to 8-year-old children, peak VO₂ measurements can be obtained’ (25, p.134). This conclusion has subsequently been supported by studies which exercised children at treadmill gradients 2.5–7.5% greater than those achieved in an initial incremental test to exhaustion. No differences in the peak VO₂ attained across the two protocols was observed, suggesting that a maximal value of VO₂ can be achieved during an incremental test despite the absence of a VO₂ plateau (13, 40).

It is challenging to obtain genuine maximal efforts from young children and Fenster et al. (25) were one of the first to report the peak VO₂ of 6- to 8-year-olds. They investigated the test-retest reliability of peak VO₂ and noted no significant difference between the two tests and a reliability coefficient of 0.67. Support for the viability of rigorous determination of the peak VO₂ of young children has recently emerged with a report of the successful determination of the peak VO₂ of ~84% of 792 children aged 6–7 years (21). Within the study, a test-retest analysis of 20 children was undertaken and a typical error of measurement of peak VO₂ between tests 5 or 7 days apart of 0.02 L/kg was observed. The authors reported boys’ peak VO₂ to be 11% higher than that of girls confirming the importance of not pooling boys’ and girls’ values and analyzing data in relation to sex even at a young age (21). Exercise protocols have been refined over time and with the development of on-line systems capable of breath-by-breath respiratory gas analysis and sophisticated electronic cycle ergometers protocols where power output is increased linearly with time (ramp exercise) have become popular. Ramp protocols are often preferred because other parameters of aerobic function such as gas exchange thresholds and respiratory gas kinetics can be determined in the same test. Young people’s peak VO₂ determined
using a ramp test has been shown to be as reliable as that determined in tests using more traditional protocols with a typical error across three tests of ~4% (52). With a ramp test a plateau in VO₂ at exhaustion is an infrequent occurrence and commonly used secondary criteria, such as those used by Fenster et al. (25), cannot unequivocally validate a maximal effort. However, the use of a follow-up constant workload test at 105% of the maximal power output achieved during the ramp test can confirm whether a maximal effort has been elicited (16). This methodology is currently becoming widely adopted with children across a broad range of aerobic fitness (39).

**Peak VO₂ During Growth and Maturation**

Current knowledge of peak VO₂ during growth and maturation is summarized in the following paragraphs and reviewed and extensively referenced elsewhere (8).

Cross-sectional data show an almost linear increase in boys’ peak VO₂ (L/min) with age and a similar but less consistent trend in girls’ values, with some studies indicating a leveling-off in girls’ peak VO₂ from ~14 years. Longitudinal data indicate that girls’ peak VO₂ increases by ~50% from 11 to 17 years with boys’ values almost doubling over the same age range. On average, boys’ peak VO₂ values are ~10% higher than those of girls at age 10 years and the sex difference reaches ~35% by age 16 years. Muscle mass is the dominant influence in the increase in peak VO₂ through adolescence and this probably accounts for much of the sex difference during the late teens, perhaps supplemented by boys’ greater blood hemoglobin concentration. Why boys’ peak VO₂ is higher than girls’ peak VO₂ before puberty is still not clear. There appear to be no significant sex differences in maximal heart rate (HR) but evidence from studies using Doppler echocardiography suggests that maximal stroke index is higher in boys than in girls although whether this is due to differences in cardiac size and/or cardiac function remains to be proven (8).

Peak VO₂ is correlated with body mass and this is conventionally controlled for during growth by dividing peak VO₂ by body mass and expressing it as the ratio ml/kg/min as in Fenster et al.’s (25) paper. Tanner (46) pointed out the statistical limitations of this methodology in 1949 and subsequent papers in the early 1970s corroborated his concerns (e.g., 31) but inappropriate use of this ratio in reporting and analyzing young people’s peak VO₂ has persisted (50). When peak VO₂ is reported in ratio with body mass, boys’ peak VO₂ is essentially unchanged from age 8–18 years at ~48 ml/kg/min and girls’ peak VO₂ progressively declines from ~45–35 ml/kg/min over the same age span. Expressing peak VO₂ in ratio with body mass is of interest in the context of health and well-being and sports where body mass is moved but it has clouded physiological understanding of peak VO₂ during growth and maturation. With body mass appropriately controlled for using allometry boys’ peak VO₂ increases through childhood and adolescence into young adulthood. Girls’ peak VO₂ increases at least into puberty and possibly into young adulthood. Longitudinal studies using multilevel modeling have shown that, in conflict with the conventional (ratio scaling) interpretation, in addition to age both growth and maturation independently and positively influence peak VO₂ (e.g., 11).

**Are Today’s Young People Fit?**

The case for a relationship between aerobic fitness and health and well-being during youth is well documented (e.g., 19) but how fit should children be? Health-related
threshold levels of peak $\text{VO}_2$ have been proposed (e.g., 17). There is, however, little compelling evidence to support the existence of a threshold level of peak $\text{VO}_2$ which is associated with either youth health or future adult health.

Few studies have reported data in sufficient detail to estimate the prevalence of young people who fall below proposed thresholds and there is no compelling evidence to suggest that the current generation of young people have low levels of peak $\text{VO}_2$. A reanalysis of large data sets from my laboratory in relation to the health thresholds proposed by an expert group from the European Group of Pediatric Work Physiology [35 ml/kg/min for boys and 30 ml/kg/min for girls] (17) revealed that of 164 untrained prepubertal children none fell below the threshold (7). Of 220 untrained 11- to 16-year-olds, 3% of the boys and 3% of the girls fell below the threshold (14).

**Are Today’s Young People Less Fit Than Previous Generations?**

An analysis of studies which have assessed young people’s peak $\text{VO}_2$ over the last 50 years shows a consistency over time which is quite remarkable considering that these studies have been performed in different laboratories using different equipment, testing protocols and staff. A review of the peak $\text{VO}_2$ data of American boys from the 1930s through the 1990s and girls from the 1960s through the 1990s noted that peak $\text{VO}_2$ had remained relatively stable among boys of all ages and in young girls. In girls in the 15–19 years age group, peak $\text{VO}_2$ was observed to increase from the 1960s–1970s and then fall back toward 1960s values over the next two decades (22). Similarly, a systematic review of data of more than 4,000 9- to 17-year-olds from five countries over the period 1962–1994 reported a small mean change in peak $\text{VO}_2$ (ml/kg/min) of ~0.1% per decade (10). More recent large studies of both children (21) and adolescents (11) support these reviews and show no apparent reductions in peak $\text{VO}_2$. These reports are revealing and consistent but they are not epidemiological studies and only provide a series of local snapshots of volunteer participants into temporal trends of peak $\text{VO}_2$. There are wide variations within studies of healthy young volunteers, with typical coefficients of variation of ~15%, and elite young athletes present peak $\text{VO}_2$ values ~50% higher than their untrained peers. Nevertheless, as a population young people’s peak $\text{VO}_2$ seems to have remained stable over several decades.

In contrast to peak $\text{VO}_2$ data, there are large sets of data on 20m shuttle run (20mSRT) performance which indicate a temporal decline of ~4% per decade since 1975 in young people’s maximal aerobic performance. 20mSRT performance is strongly influenced by the body mass the participant carries over the distance run and it has been shown that increases in body fat over time explain ~50–70% of the temporal decline in 20mSRT performance (10).

**Physical Activity**

Fenster et al.’s (25) study used both subjective and objective techniques of estimating PA and noted only a weak, nonsignificant relationship between the two methods. They hypothesized that the weak association between LSI and questionnaire data may be due to the questionnaire data reflecting a whole year whereas LSI data were collected for only 1 day. For a true picture of PA some account must be taken of day-to-day variation and most recent studies have monitored PA for at least
3 days. It has, however, been recommended that 4–9 days of monitoring, including 2 weekend days might be the minimum period required for a reliable estimate (47).

Fenster et al. (25) did not comment on the (in)activity of the children in relation to health and well-being, probably because evidence-based PA guidelines were not well-established at the time. Since the publication of Volume 1 of *PES* numerous critical reviews comparing and contrasting methods of measuring PA during youth have been published (e.g., 1). Expert committees have developed guidelines with which to interpret PA in relation to health and well-being (e.g., 45) and the PA patterns of young people across the world have been extensively documented using both subjective (e.g., 28) and objective methodology (e.g., 27). Current knowledge is briefly summarized in the following sections and reviewed and extensively referenced elsewhere (24)

**Measurement of Young People’s Physical Activity**

Even before the publication of Volume 1 of *PES* more than 30 different methods of measuring PA had been described (33). Measurement tools and techniques have been further developed but all current instruments have deficiencies and no single method can capture all aspects of PA. Some studies have attempted to overcome this by simultaneously employing more than one method but, as noted by Fenster et al. (25), correlations between subjective and objective methods are at best low to moderate.

Subjective measures of estimating PA are subject to recall bias and are influenced by the ability of the respondent to accurately recall relevant activities retrospectively. This limitation is particularly pertinent with children who tend to be less time conscious than adults are and less able to provide details of specific events from the past. Nevertheless, although there are substantial errors in estimating an individual’s PA several large, well-designed multinational surveys have provided insights into young people’s PA at a population level (e.g., 28).

Physiological sensors such as HR monitors have been used to estimate PA since the early 1970s and were used extensively in the 1980s and 1990s (e.g., 3) until generally replaced by motion sensors as the monitor of choice. Physiological sensors do not directly measure PA but they can provide clinically relevant data with which to evaluate relationships between PA and health-related behavior.

Pedometers have been used to monitor PA since the 1920s although Leonardo da Vinci is reported to have designed a pedometer to measure distance by counting steps somewhat earlier (43). In recent years accelerometers have become the motion sensor of choice. Data from accelerometers are normally collected over a specific time period (epoch) and reported as counts per minute (cpm) which are then converted into estimates of the intensity of PA. The optimum epoch and appropriate cut-off point with which to describe PA are; however, currently subjects of intensive research programs. Despite a lack of consensus over interpretation of data, the ongoing development and application of accelerometers has provided real advances in understanding young people’s PA (e.g., 27).

**Are Today’s Young People Active?**

The benefits of regular PA on the health and well-being of youth are well-established (45) but the precise amount of PA appropriate to optimize beneficial health outcomes is less clear. The earliest PA guidelines for young people were published by the
American College of Sports Medicine and based on recommendations for adults (2). But the first evidence-based PA guidelines, complete with supporting reviews, were published in a 1994 special issue of *PES* (41). Subsequently, a number of public health authorities have endorsed PA guidelines for youth and despite criticism of the interpretation of the underlying evidence base (48) there is general support that “school-age youth should participate daily in 60 min or more of moderate-to-vigorous physical activity that is developmentally appropriate, enjoyable, and involves a variety of activities” (45, p.732).

Several large, multinational surveys of young people’s PA have been supported by the World Health Organization and, although the subjective data collected must be viewed with caution, the general population trends in relation to PA guidelines are consistent. More boys participate in moderate-to-vigorous PA (MVPA) than girls do, with the sex difference being more marked in comparisons of participation in vigorous PA. The amount of PA experienced by both sexes declines as they move through adolescence. Data from a survey of more than 72,000 13- to 15-year-olds from 34 countries indicate that self-reported levels of PA from developing countries are lower than levels from North America and Europe (28). Taken together, recent data on self-reported PA indicate that between 60% and 70% of youth do not satisfy current PA guidelines (35).

Objective measurement and observation of behavior has established that the majority of bouts of children’s PA last between 3 and 22 s which makes it difficult to assess and interpret health-related PA. Using accelerometry the inconsistent use of cut-off points and epoch lengths confound the quantification of the prevalence of young people who satisfy PA guidelines. The proportion of young people reported to meet PA recommendations ranges from 1 to 100% depending on the cut-off points used to define the intensity of PA. A review of 35 studies of European young people’s PA illustrates the issue (27). The authors commented that all of the data reviewed were collected using the same type of accelerometer and that this may enhance comparability of the findings. They reported 78–100% of participants to meet PA guidelines with a cut-off point of more than 1,000 cpm applied, 36–87% to meet recommendations with a cut-off point of more than 2,000 cpm, 3–9% to comply with a cut-off point of more than 3,000 cpm, and 1% to meet PA guidelines with a cut-off of more than 4,000 cpm applied. The selection of epoch length also influences the interpretation of data. A difference of 62% has been reported in the time preschool children spent in MVPA when a 5-s epoch was compared with a 60-s epoch (49).

Despite the difficulties in interpreting data across studies a consistent trend is that more boys meet recommendations defined by cut-off points more than 2,000 cpm, more than 3,000 cpm, or more than 4,000 cpm than girls although a decline in the amount of PA with age is not as readily apparent as with subjective data. The review underpinning the International Olympic Committee (IOC) consensus statement on the health and fitness of young people through physical activity and sport concluded that less than 25% of young people satisfy current PA guidelines using a cut-off point of 3,000 cpm (equivalent to brisk walking; 35).

**Are Today’s Young People Less Active Than Previous Generations?**

Large surveys from the US (34), Australia (37) and Europe (42) have concluded that there is no clear evidence of young people becoming less active from ~mid-1980s to
Armstrong ~mid-2000s. These data are supported by studies using pedometers (38), accelerometers (36), and HR monitors (51), which have reported no change or an increase in PA over time. Following their critical review of the literature the IOC expert group concluded that although data on temporal trends in PA should be interpreted cautiously young people’s PA levels seem to have stabilized at least over the last two decades (35).

**Peak VO₂ and Physical Activity**

Seliger et al. (44) were probably first to objectively estimate PA and compare it to directly determined peak VO₂. They estimated the PA of 11 12-year-old boys using 1 day HR monitoring and found no significant relationships with peak VO₂. More comprehensive studies, including at least 3 days of PA monitoring, have consistently supported this finding and observed weak or no significant relationships between peak VO₂ and PA.

HR monitoring studies of 10–16 year olds from the UK ($n = 325$) reported no significant correlations between either moderate or vigorous PA and peak VO₂ (4, 9). A similar study of 82 Swedish 14–15 year olds observed no significant relationships between MVPA and peak VO₂ in either boys or girls. This study observed weak but significant correlations between ‘activity-related energy expenditure’ and peak VO₂ in both boys and girls but after controlling for body fat and maturation none of the PA variables were significantly related to peak VO₂ in boys. Highly active boys were compared with the rest of the boys and no significant difference was observed in peak VO₂ (23).

A study of 248 Swedish 8- to 11-year-olds used accelerometers to estimate PA and reported that multiple forward regression analysis showed vigorous PA to explain 9% and mean daily PA 1% of the variability in peak VO₂ (20). Similarly, a study of 592 Danish 6- to 7-year-olds noted sustained periods of PA to explain 9% of the variance in peak VO₂ (21). The relationship between peak VO₂ and PA of 424 nonoverweight and 473 overweight, 4- to 19-year-old, Hispanic Americans was explored through generalized estimating equations. The strength of the relationship was observed to be generally low to moderate accounting for a small percentage of the variation in peak VO₂ (18).

A longitudinal investigation of over 200 children used multilevel modeling to examine age, sex, and maturation influences on PA, from 11 to 13 years. With the primary variables controlled for peak VO₂ was introduced as an additional variable and a nonsignificant parameter estimate was recorded (12). Kemper and Koppes (32) analyzed longitudinal data from participants in the Amsterdam Growth and Health Study. They reported a 30% increase in HPA score and a 2–5% increase in VO₂ max but noted that the functional implications were small and concluded that, ‘if we take into account that the relationship calculated with autoregression over the period of 23 years resulted in nonsignificant relationships, we must admit that in this observational study no clear relation can be proved between PA and VO₂ max in free-living males and females’ (32, p. 163).

**1989–2013**

Since 1989 we have become much better informed about the appropriate assessment and interpretation of peak VO₂ and we have a comprehensive, although not complete,
understanding of the development of peak \( \text{VO}_2 \) during growth and maturation. There is no compelling evidence to suggest that as a population young people have low levels of peak \( \text{VO}_2 \) or that they have lower levels of peak \( \text{VO}_2 \) than young people of previous generations did. Nevertheless, as most health-related and sporting activities involve moving body mass an increase in body fatness without a corresponding increase in peak \( \text{VO}_2 \) is a cause for concern in the context of young people’s health and well-being.

Huge strides have been made in the technology underpinning PA monitoring and evidence-based health-related PA guidelines have been developed and regularly refined. Consistent trends, regardless of methodology, are that more boys than girls satisfy PA guidelines and the prevalence of young people satisfying PA guidelines falls with age in both sexes. Inconsistent interpretation of intensity thresholds confounds data describing the percentage of youth who are deemed sufficiently active. Self-report data suggest 30–40% of young people meet current PA guidelines whereas accelerometry data indicate that they are achieved by less than 25%. Evidence from studies using both self-report and objective methodology suggests that PA has not declined during the last two decades.

**Future Directions**

**Aerobic Fitness**

When considering children’s PA patterns, spontaneous play, and participation in most organized games we are concerned with intermittent exercise and rapid changes in exercise intensity. Under these conditions peak \( \text{VO}_2 \) and steady-state \( \text{VO}_2 \) are variables of investigative convenience rather than factors underpinning behavior. It is the transient kinetics of pulmonary \( \text{VO}_2 \) (p\( \text{VO}_2 \)) which best describe the relevant component of aerobic fitness. Furthermore, unique insights into physiological function rest in the transient or non-steady-state response to a forcing exercise regimen. In addition, the p\( \text{VO}_2 \) kinetics time constant (\( \tau \)) can be used as a proxy measure of muscle phosphocreatine (PCr) kinetics and therefore a noninvasive window into the metabolic activity of the muscle and a means of understanding exercise metabolism during growth and maturation (6). Current knowledge of young people’s p\( \text{VO}_2 \) kinetic responses is briefly outlined in the following paragraphs and reviewed and comprehensively referenced elsewhere (5).

At the onset of a step transition from rest to moderate exercise (i.e., intensity < the lactate threshold, TLAC) there is an almost immediate increase in \( \text{VO}_2 \) measured at the mouth. This phase (Phase I) is associated with an immediate increase in cardiac output and is independent of muscle \( \text{VO}_2 \). Phase I is followed by an exponential increase in p\( \text{VO}_2 \) (Phase II or the primary component) that drives p\( \text{VO}_2 \) to a steady-state (Phase III). Phase II is described by its \( \tau \) and the shorter the \( \tau \) the smaller the anaerobic contribution to the step change in exercise intensity. During a step change to heavy exercise (i.e., intensity > TLAC but < critical power [CP]) Phases I and II are similar to those observed in the moderate exercise domain but in Phase III the oxygen cost increases over time as a slow component of p\( \text{VO}_2 \) is superimposed and the achievement of a steady state in p\( \text{VO}_2 \) is significantly delayed.
During a step change to very heavy exercise (i.e., intensity >CP but <peak VO₂) the slow component of pVO₂ rises rapidly with time and reaches peak VO₂. A step change to an exercise intensity which requires a projected pVO₂ at or above peak VO₂ is classified as severe exercise.

The pVO₂ kinetic responses of adults have been researched for over 40 years and the interactions between peak VO₂, TLAC, CP, the primary τ, and the slow component of pVO₂ in describing performance and responding to training have been well-documented (e.g., 30). Rigorously determined and appropriately analyzed data on young people’s pVO₂ kinetic response to step changes in exercise intensity in relation to specific exercise domains are sparse. Current data suggest that children are characterized by a faster Phase II τ for moderate, heavy, and very heavy exercise compared with adolescents and adults. Little is known about responses to severe exercise. Boys’ primary component τ is faster than that of girls during step changes to exercise intensities >TLAC but not during moderate exercise. During exercise of intensity >TLAC, boys show a truncated pVO₂ slow component compared with girls. During exercise intensities >TLAC, the magnitude of the pVO₂ slow component is reduced and the oxygen cost during Phase II is higher in young people than in adults but the end-exercise total oxygen cost is similar to that of adults. No relationship has been demonstrated between peak VO₂ and the τ of the primary component in either children or adolescents (5).

Future research questions include the following: Is the faster Phase II pVO₂ kinetics in children indicative of a faster muscle oxygen delivery and/or a greater potential for oxidative metabolism in children compared with adults? Why are there sex differences during the step transition to heavy intensity exercise but not moderate intensity exercise? Are observations of pVO₂ kinetic responses consistent with an age-related decline in percent of Type I muscle fibers and in accord with boys having a higher percent of Type I fibers than similarly aged girls? What are the mechanisms underlying the pVO₂ slow component? Is the lack of relationship between the τ of the pVO₂ kinetics and peak VO₂ during youth due to peak VO₂ being primarily dependent on oxygen delivery to the muscles whereas pVO₂ kinetics is more dependent on oxygen utilization by the muscles? Is the exercise domain important in the relative contribution of oxygen delivery and oxygen utilization to peak VO₂ kinetics during youth? Does maturation exert an effect on pVO₂ kinetics independent of age and body size? How close is the coupling between pVO₂ and PCR kinetic profiles in young people at the onset and offset of exercise of different intensities? Is children’s pVO₂ kinetics trainable? If so, what are the relative responses of the Phase II τ and the VO₂ slow component in relation to changes (or not) in peak VO₂? What is the optimum exercise prescription to speed up the τ and/or reduce the size of the VO₂ slow component?

These and many other questions require evidence-based answers. The recent application of technologies such as magnetic resonance spectroscopy, near-infrared spectroscopy and electromyography to studies of breath-by-breath analyses of respiratory gas kinetics provide appropriate tools. The introduction of experimental models such as priming exercise, work-to-work transitions, and manipulation of pedal rates to pediatric exercise studies (6) provide intriguing avenues for future research into aerobic fitness and developmental exercise metabolism.
Physical Activity

PA guidelines for young people have evolved over the last 25 years but are they optimum? Twisk (48) critically reviewed the literature linking PA with skeletal, cardiovascular, and psychological health seeking dose-response relationships or threshold values. He concluded that where there is evidence of a relationship between PA and health outcomes there is only limited evidence of a particular pattern of that relationship. More research is required.

There is no consensus on the interpretation of accelerometry data. The percentage of young people reported to meet PA guidelines varies from 1 to 100% according to the cut-off point used (27). It has been suggested that the use of multiple cut-off points might represent a reasonable compromise until a consensus is reached (24). But, what is the appropriate cut-off point(s) to represent MVPA? Are the same cut-off points applicable throughout growth and maturation? Consistent, rigorous methodology and calibration techniques need to be developed if we are to understand fully the interpretation of data from accelerometers and their application to PA during childhood and adolescence.

Recent advances in engineering technology have stimulated the emergence of highly sophisticated motion sensors with the potential to revolutionize PA data collection and analysis. It is envisaged that nonintrusive sensors located at multiple sites on the body and in the environment will be coordinated into a single system with the data storage and analytical capacity to enable monitoring and interpretation of PA over extended periods of time (29). The most fruitful future direction of research in PA epidemiology therefore appears to lie in the application of emerging technology but as Intille et al. (29) point out: “to maximize the effect of physical activity measurement research being conducted today, investigators must expect and plan for change so as to fully exploit the potential of the new devices on the horizon” (29, p.S31). Regardless of the inevitable change in the tools available to study PA best practices need to be researched and firmly established and it is interesting to note that one of the coauthors of Fenster et al.’s (25) paper is still at the forefront of developments (26).

Evidence suggests that PA during childhood and adolescence is at best only weakly related to peak VO2. This is not surprising as young people’s PA seldom includes exercise of the duration and intensity necessary to enhance or even maintain their peak VO2. The emergence of better methods of assessing and interpreting PA and components of aerobic fitness other than peak VO2 provides opportunities for investigating further the elusive relationship between PA and aerobic fitness during growth and maturation.

Conclusion

Fenster et al.’s (25) exploratory paper in Volume 1 of PES predicted the direction of much of the research published in the first 25 years of PES. Many of the papers published in the subsequent 24 volumes of PES have made significant contributions to the advancement of our knowledge of exercise physiology during growth and maturation. Innovative techniques and technologies have been developed and their application to the exercising child is opening up numerous opportunities for further research. Which papers published in PES Volume 25 will provide the
inspiration and platform for new discoveries in developmental exercise physiology over the next 25 years?

References


