Maximal Intensity Exercise Performance of Young People
青年人的最大強度運動能力

Michael CHIA
Physical Education and Sports Science,
National Institute of Education,
Nanyang Technological University, SINGAPORE

謝永和
新加坡南洋理工大學
國立教育學院體育與運動科學組

Abstract

Exercise data show that young people's capability to perform exercise tasks of a maximal intensity lasting between one and 90 seconds, are lower than that of adults. In general, the maximal intensity exercise performance of young people improves with age and level of biological maturity but further research that involve larger samples of boys and girls, over the entire maturity range are needed to supplement the sparse database. Data of girls are notably lacking. More research is needed to identify the specific development stage (s) where young people acquire the adult levels of maximal intensity exercise performance. Longitudinal studies, encompassing the entire maturity range (i.e. Tanner stages one to five) of young people are needed to clarify the evolution and stability of maximal intensity exercise performance with age and maturation. Multiple bouts of maximal intensity exercise can shed light on the fatigue and power recovery profile of young people and research in this area is deserving of encouragement.

摘 要

研究資料顯示，青年人進行最大強度運動的持續時間較成年人短，約為1－90秒。一般認為，隨著年齡增長及身體各器官系統發育成熟，青年人最大運動能力提高，但這有待於大量的實驗數據加以驗證，包括不同年齡階段成熟度的資料。在這方面, 女性的資料尤為缺乏。有關青年人在何一生長發育階段可達到成年人的最大運動能力的水平，這是一個需要進一步研究證實的課題。對於青年人的最大強度運動能力隨著年齡的增長及生長發育而發展以至穩定的過程，進行縱向調查是十分必要的，而以反覆多次最大強度運動的形式觀察青年人的疲勞與恢復過程是值得重視與推荐的。

Introduction

Young people's habitual physical activity has been described as that resembling Brownian Motion (particles in random motion) (Rowland, 1996) or variable in terms of exercise intensity with high intensity activity bouts of a short duration, interspersed with periods of low intensity bouts of physical activity, with the exercise intensity and duration alternating seemingly without any discernable sequence (Chia, & Quek, 2001). Researchers have argued that young people are more dependent on energy metabolism that involves oxygen, yet young people's exercise performance in long distance running, swimming, rowing, cycling and skiing is generally accepted to be inferior to those of young adults. Other researchers argue that given young people's proclivity for sudden spurts of physical activity of a brief duration, young people are more aptly described as 'anaerobic creatures' rather than 'aerobic creatures.' Part 1 of this review examines the maximal intensity exercise performance of young people.

Genetic Influence on Maximal Intensity Exercise

Exercise performance of young people is a function of environmental, genetic and interactive genetic-environmental influences (Bouchard et al, 1997). There are limited data on the genetic effect on maximal intensity exercise performance and previous reported estimates have been divergent, ranging from almost zero to almost 100% of the variance (Komi et al, 1973; Komi, & Karlson, 1979). However, the earlier heritability estimates might be flawed because of the small sample sizes involved in the studies and the differential effects of age according to twin types (Bouchard, & Malina, 1983). Malina and Bouchard (1991), reported that in 10-s supra-maximal cycle exercise performance, in a study of siblings and twins, genetic effects accounted for about 50% of the performance. However a strong heritability estimate of 97% was reported for maximal muscular power generated by the arms in 17 pairs of male twins aged between 11 and 17 years (Malina, & Bouchard, 1991). Further research attention is needed to elucidate the role played by genetics in explaining the maximal intensity exercise performance of young people.

Longitudinal versus Cross-sectional Studies

Data on the evolution of exercise performance are more secure when they are derived from longitudinal studies that encompass prepubescent, pubescent and post-pubescent periods (Kemper et al, 1989; Rutenfranz, 1986). However, as longitudinal approaches are a heavy burden on resources, cross-sectional studies are more common. Our understanding of the evolution of maximal intensity exercise performance of children is principally derived from cross-sectional studies that tend to focus on male subject cohorts (Falgairette et al, 1991; Mercier et al, 1992). Data on girls are notably lacking (Armstrong, & Welsman, 1997). Apparently, only longitudinal data on boys (Duche et al, 1992; Falk, & Bar-Or, 1993; Paterson et al, 1986) are available, and even then the periods of monitoring, as with the age span studied are limited.

Performance data on children's maximal intensity exercise performance are garnered mainly from results of the Margaria stair-running test (Margaria et al, 1966; di Prampero, & Ceretelli, 1969; Kurowski, 1977), and the Wingate Anaerobic Test (WAnT) (Armstrong, & Welsman, 1997; Blimkie et al, 1989; Chia et al, 1997; Chia 2001; Falk, & Bar-Or, 1993; Inbar, & Bar-Or, 1986;). Other performance data on children's maximal intensity exercise performance are derived from smaller subject populations and are based on results of force-velocity cycle tests (Mercier et al, 1992; Sargeant, & Dolan, 1986), a combination of force-velocity and WAnT (Falgairette et al, 1991; Van Praagh et al, 1990), an isokinetic cycling test (Sargeant, & Dolan, 1986, 1986; Sargeant, 1989), Quebec-10-second maximal intensity cycle test (Bouchard & Simoneau, unpublished data, cited by Malina & Bouchard, 1991) and on maximal knee extensions and flexions lasting 10, 30 and 90 seconds (Saavedra et al, 1991).

Maximal Intensity Exercise Performance of Young People in Relation to Adults

Children's ability to generate mechanical power at maximal intensities is lower than adults (Bar-Or, 1983; di Prampero & Ceretelli, 1969; Kurowski, 1977; Margaria et al, 1966; Saavedra et al, 1991). Children generate lower peak power and have lower local muscular endurance than adults during high intensity exercise, irrespective of whether the performance is expressed in absolute terms (Armstrong & Welsman, 1997; di Kurowski, 1977; Prampero & Cerretelli, 1969; Margaria et al, 1966;), per unit of body mass (Armstrong and Welsman, 1997; Bar-Or, 1995; Falgairette et al, 1991; Inbar & Bar-Or, 1986;), or in relation to lean body mass (Blimkie et al, 1989).

Table 1 is a summary of child-adult comparisons in maximal intensity exercise performance compiled from the extant literature.

Table 1. Child-Adult Comparisons in Maximal Intensity Exercise Performance.

Investigators	Population & Gender	Test	Performance measure	Performance measure
			* Peak power at 10 yr. (% of adult values-age unspecified)	* Peak power at 15 yr. (% of adult values-age unspecified)
Margaria et al (1966)	Total N = 131 Italian boys	Margaria stair-run	72	86
	Italian girls	Margaria stair-run	74	86
di Prampero & Ceretelli (1969)	Total N = 156 African boys	Margaria stair-run	72	95
	African girls	Margaria stair-run	104	102
Kurowski (1977)	Total N = 294 American boys	Margaria stair-run	86	98
	American girls	Margaria stair-run	85	102
Inbar & Bar-Or (1986)	Total N = 306 Israeli boys	Wingate	75	85
			Δ Optimised peak power at 13 yr. (% of adult values-age unspecified)	
Sargeant & Dolan (1986)	Total N = 55 Dutch boys	20-s isokinetic cycle	60	
			ϕ Work done in 10s at 9 yr. (% of adult values-at 19 yr.)	ϕ Work done in 10s at 15 (% of adult values-at 19 yr.)
Bouchard & Simoneau, cited by Malina & Bouchard (1991)	Total N = 220 Canadian boys	Quebec-10 s	65	82
	Canadian girls	Quebec-10s	66	94
			∅ Work done in 10-s at 10 yr. (% of adult values-at 19 yr.)	∅ Work done in 10-s at 15 yr. (% of adult values-at 19 yr.)
Saavedra et al (1991)	N = 83 French-Canadian boys	10-s supra-maximal isokinetic knee extensions	54	90
	N = 84 French-Canadian girls	10-s supra-maximal isokinetic knee extensions	67	92
	French-Canadian boys	30-s supra-maximal isokinetic knee extensions	53	85
	French-Canadian girls	30-s supra-maximal isokinetic knee extensions	54	96
	French-Canadian boys	90-s supra-maximal isokinetic knee extensions	61	96
	French-Canadian girls	90-s supra-maximal isokinetic knee extensions	57	100
			♣ Peak power at 11-12 yr-Tranner stage 1 (%of adult values-at 22 yr.)	
Gaul et al (1995)	Total N = 69 Canadian boys	90-s supra-maximal cycle	67	

Table 1. (Con't) Child-Adult Comparisons in Maximal Intensity Exercise Performance.

Investigators	Population & Gender	Test	Performance measure	Performance measure
			◊ Optimised peak power at 11 yr. (% of adult values-at 19 yr.)	◊ Optimised peak power at 15 yr. (% of adult values-at 19 yr.)
Mercier et al (1992)	Total N = 37 French boys	Force-velocity cycle	63	92

Table legend
- * Values are peak power per kg body mass
- ϕ Values are total work output per cross-sectional thigh area
- ∅ Values are total work output per kg of body mass
- ♣ Values are total work output per unit thigh volume
- ◊ Values are peak power per kg lean body mass
- Δ Values are absolute peak power

Margaria et al (1966) tested 131 healthy subjects aged between eight and 73 years, using a stair-running test that quantified peak maximal intensity exercise power. The subject pool was made up of 35 athletes and 96 sedentary subjects, and the authors reported that among the non-athletes, nine-year-old children had lower peak power in absolute terms and attained only 60 % of the peak power in $W.kg^{-1}$ BM of the 20-year-old adults. In another study, di Prampero and Cerretelli (1969), examined a subject pool of 156 African male and female tribes people of Nilo-Hamitric and Bantu origin, aged between five and 68 years. They reported that peak power expressed in absolute terms and in relation to body mass, as determined by the Margaria stair-running test, are lower in the boys than in the adult tribesmen. Interestingly, in the women studied, the power scores at age 10 years are found to be 104 % of the adult women (di Prampero & Cerretelli, 1969). However, differences in the habitual activity patterns that were not assessed in the cited study between the girls and the adults in the tribal community might have accounted for the documented differences. Cross sectional performance data of 306 active but untrained Israeli male subjects aged between eight and 45 years, assessed by a 30-second WAnT, showed that the relative peak power output of a 10-year-old boy is only 75 % of that generated by a 17-year-old (Inbar & Bar-Or, 1986).

Other investigators using tests other than the Margaria stair-running test or the WAnT have consistently reported that young children's maximal intensity exercise performance is inferior to that of adults (Bouchard & Simoneau, unpublished data, cited by Malina & Bouchard, 1991; Mercier et al, 1992: Sargeant & Dolan, 1986; Saavedra et al, 1991). For example, Mercier et al (1992), examined the maximal intensity exercise performance of 69 male subjects aged between 11 and 19 years using a force-velocity test, and reported that the optimised peak power ratio-scaled to account for differences in lean body mass in 11 year old boys is only 63 % of the adult values at 19 years old. Sargeant and Dolan (1984) used a 20-second isokinetic cycle test to assess the maximal intensity exercise performance of 30 young adults and 25 thirteen-year-old boys. They reported that children's peak power ratio scaled to upper leg volume, at four different pedalling speeds, is 40 % less than that of young adults. Saavedra et al (1991), used tests of all-out intensity knee extension and flexion over 10-, 30- and 90 seconds to assess the maximal intensity exercise performance of 84 girls and 83 boys in comparison to that of 19-year old adults. Over the three test durations, they reported that children's performance (as indicated by work done) at nine years of age range from 53-61 % of the adult values. Malina and Bouchard (1991), citing the unpublished work of Bouchard and Simoneau, that involved testing 220 boys and girls between the ages of nine and 19 years reported that work done in the 10-second test (Quebec-10-second test), ratio-scaled to body mass, at nine years old, is only 65 % of the adult values at 19 years old.

The majority of cross-sectional studies that have made child-adult comparisons in maximal intensity exercise performance have compared the subjects' respective performances at various ages between nine and 22 years. It should be noted however that the evolution of maximal intensity exercise performance continues beyond the second decade of life and like most physiological parameters appears to peak around 30 - 40 years of age (di Prampero & Ceretelli, 1969; Inbar & Bar-Or, 1986; McArdle et al, 1994). Therefore, it appears that if child-adult comparisons in maximal intensity exercise performance were to be made between children aged nine and adults aged 30-40 years, it is likely that young people's ability to generate high power outputs during maximal intensity exercise may even be comparatively lower than those documented in the previous cited studies.

The reservoir of data, albeit, generated from studies with disparate methodologies, suggests that young children's exercise performance in maximal intensity exercise tasks is not equivalent to those documented for adults, either in absolute terms, or when ratio-scaled to body mass, lean body mass, or leg volume. However, there is accumulating evidence and growing conviction that division by body mass or lean body mass by means of the ratio model may not be the best scaling approach to normalise exercise data (Armstrong & Welsman, 1997; Nevill & Holder, 1995; Welsman et al, 1996; Winter, 1992, Consequently, use of different scaling models may affect our interpretation and understanding of children's ability to perform maximal intensity exercise tasks (Chia, 2000). Further research on the use of alternative statistical procedures such as log-linear adjustment techniques, may provide further insight into child-adult differences in maximal intensity exercise performance (Armstrong & Welsman, 1997).

Young People's Maximal Intensity Exercise Performance in Relation to Chronological Age

Cross-sectional performance data from the WAnT on normal and healthy children demonstrated an age-related improvement in maximal intensity exercise performance (Bar-Or, 1995). For instance, between the ages eight and 14 years, both absolute peak and mean power outputs, improve by more than 100%. When the performance over the same time period, is ratio-scaled for body mass, mean and peak power outputs in $W\cdot kg^{-1}BM$ for boys improves by 43%. In girls, mean power in $W\cdot kg^{-1}BM$ improves by 18% and peak power in $W\cdot kg^{-1}BM$ improves by 50% (Bar-Or, 1995). A compilation of cross-sectional data of 306 active but untrained males between the ages of eight and 45 years also shows a consistent increase in lower limb peak and mean power output from age 10 to young adulthood (Inbar & Bar-Or, 1986). Beyond age 20 years, lower limb maximal intensity exercise performance continues to improve with peak and mean power increments of $35W\cdot year^{-1}$ and $30W\cdot year^{-1}$, respectively. Both measures seem to peak at nearly 40 years of age (Inbar & Bar-Or, 1986). Information is also available from a cross-sectional study of 144 boys aged between six and 15 years conducted by Falgairette et al (1991). In this study, peak power was determined by a force-velocity test and mean power (force derived from the F-V test) was determined from the WAnT. The authors noted a progressive increase for generated peak power and mean power with age. Between the ages six to eight years and 14-15 years, peak power in $W\cdot kg^{-1}BM$ increases by 74% and mean power in $W\cdot kg^{-1}BM$ increases by 62% (Falgairette et al, 1991). In a longitudinal study of 13 boys aged between nine and 11 years, and 11 boys aged between 12-14 years, that employed a similar methodology as the French team, Duche et al (1992), reported that generated peak power and mean power in $W\cdot kg^{-1}BM$ increase with age, results that were also duplicated in a mixed-cross-sectional and longitudinal study on 36 pre-, mid- and late pubescent boys who were tested at six monthly intervals on the WAnT over 18-24 months (Falk & Bar-Or, 1993). In a study conducted in China, Duan and Qiao (1987), tested 131 girls and 134 boys, aged 11-18 years (divided into four age groupings). Their results revealed generated mean power and peak power in the WAnT increase with age, both in absolute and relative terms. They also reported that the greatest increases occur in the 11-12 and 13-14 years age groupings for both sexes.

It appears that there is a spurt in maximal intensity exercise performance, particularly for boys, during or soon after the age of male puberty (Chia et al, 1997). Cross-sectional studies demonstrated that in boys the greatest improvements in peak power and mean power are about 30% and occur between 11 to 12 years old (Falgairette et al, 1991), or between 12 and 13 years old (Mercier et al, 1991). In a mixed cross-sectional and longitudinal study exclusively on boys, Falk and Bar-Or (1993), reported that over the 18-24 month study period, body mass-related peak and mean power outputs increase significantly over time, especially during the transition from pre-puberty to mid-puberty. Research reviewed by Armstrong and Welsman (1997), also supports an acceleration in peak and mean power outputs between sexual maturity, Tanner stages three and four in boys. However, the improvements in maximal intensity exercise performance in girls between the same maturity stages are more consistent. Results of studies that supported a spurt in maximal intensity exercise performance around or soon after puberty, especially in boys, collectively report power data that are superior to those attained by younger pre-pubertal children (Inbar et al, 1996). However, the values attained in the 'power spurt' are still lower than the values attained by adults (Bar-Or, 1983; Falgairette et al, 1991; Inbar & Bar-Or, 1986; Mercier et al, 1991; Saavedra et al, 1991).

Young People's Maximal Intensity Exercise Performance in Relation to Biological Maturity

Given that biological age and chronological age do not necessary parallel one another (Astrand, 1992; Rowland, 1996), several investigators have studied maximal intensity exercise performance of children in relation to distinctly different markers of biological age- skeletal (Falk & Bar-Or, 1993), secondary sex characteristics (Nindl et al, 1995; Armstrong et al, 1997), and hormonal levels of testosterone (Armstrong et al, 1997; Van Praagh et al, 1990). However, the database of children's maximal intensity exercise performance in relation to biological maturity is inadequate. Data on girls are notably sparse.

Falgairette et al (1990), reported that peak and mean power outputs increase 52- and 58%, respectively between the ages of 10 to 15 years. Additionally, the authors reported that the increase in power is associated with a 200 % increase in the levels of the hormone testosterone, over the same period. Moreover, a 30% increase in exercise performance between the groups occurred between early puberty (Tanner stage two to three for pubic hair / genitalia; mean age 13.1 years) and late puberty (Tanner stage 4; mean age 14.4 years) (Falgairette et al, 1990). Significantly, they reported moderate and significant correlations between absolute PP ($r = 0.45$), absolute MP ($r=0.47$) and levels of testosterone, suggesting that the increased concentration of testosterone may have contributed to the boys' improved capability to generate power in the WAnT. However, whether testosterone exerts an independent and significant effect upon maximal intensity exercise performance remain speculative as in the study of Falgairette et al, 1990), the influence of changes in body mass was not appropriately partitioned out (Armstrong & Welsman, 1997; Armstrong et al, 1997; Bar-Or, 1995). Armstrong and Welsman (1997) highlighted substantial increases in peak power and mean power that are observed in much younger children in the absence of notable increases in testosterone. Indeed, WAnT data generated from 100 boys and 100 girls, aged 12±0.4 years, revealed that the levels of testosterone make no significant ($p > 0.05$) additional contribution to explained variance in either peak power or mean power, once the contribution of body mass was statistically removed (Armstrong et al, 1997). Nevertheless, the observation of a spurt in maximal intensity exercise performance in boys around the age of puberty in the cited study of Falgairette et al (1990) is still valid, even though the mechanism (s) responsible for that remains speculative. More research is warranted on whether testosterone exerts an independent effect on young people's ability to generate power in maximal intensity exercise tasks. This raises the question of whether other hormonal changes, independent of testosterone, such as increases in levels of oestradiol, growth hormone and insulin-like growth factor occurring during puberty may also affect muscle metabolism during intense exercise (Cooper, 1995).

Notable increases in boys' performance in the WAnT during the time around puberty (Duche et al, 1992; Falgairette et al, 1990) suggest that sexual maturation may have an impact on children's exercise performance. Yet there have been very few studies on the subject of maturation and impact on children's maximal intensity exercise performance. Strikingly absent are data on girls. In apparently the only previously reported study on the subject, Falk and Bar-Or (1993), examined 36 boys, grouped accordingly as pre-pubertal (Tanner stage one), mid-pubertal (Tanner stages two, three and four) and late pubertal (Tanner stage five). The authors pointed out that the small sample numbers in the three groups precluded any statistical analyses but they noted that body mass-related peak power increase from Tanner stage one to two, and from Tanner stage four to five, with no apparent change in mean power with sexual maturity. Data on 100 boys and 100 girls, demonstrate a main effect for maturation (sex by maturity) in peak and mean power outputs, even when the values were statistically adjusted for body mass (Armstrong & Welsman, 1997). The results showed that at all levels of maturity, boys generate higher peak and mean power at corresponding levels of maturity. The sex difference was also magnified with increases in maturity. For instance, with body mass adjusted for, girls at Tanner stage one could only match 95 % and 97 % of the boys' PP and MP, respectively. However at Tanner stage four, the girls could only generate 87 % and 84 % of the boys' PP and MP, respectively (Armstrong & Welsman, 1997).

Repeated Bouts of Maximal Intensity Exercise Protocols versus Single Bouts of Maximal Intensity Exercise Protocols

Single bout maximal intensity exercise bouts such as those involving cycling, running, jumping and leg extensions provide useful information about young people's capability to generate power or accomplish work over a short period of time. However, such single bout test protocols do not provide a complete picture of the capability of an exercising young person. Moreover, such single bout exercise protocols are not ecologically valid as they do not reflect the true nature of young people's habitual physical activity, which tend to comprise of repeated bouts of exercise but not always necessarily of maximal intensity. Studying young people's capability to generate power over repeated bouts using test protocols described by Chia (2001) using the WAnT is an attempt to better describe the capability of young people to generate maximal power and also understand the fatigue profile and time course for the recovery of maximal power.

Conclusion

Exercise data show that children's ability to perform all-out intensity exercise tasks lasting between one and 90 seconds, are lower than those of adults. In general, the maximal intensity exercise performance of children improves with age and level of biological maturity but further research that involve larger samples of boys and girls, over the entire maturity range are needed to supplement the sparse database. More research is needed to identify the specific development stage(s) where children and adolescents acquire the adult characteristics and levels of maximal intensity exercise performance. Longitudinal studies, encompassing the entire maturity range (i.e. Tanner stages one to five) of young people are needed to clarify the evolution and stability of maximal intensity exercise performance with age and maturation. Multiple bouts of maximal intensity exercise can shed light on the fatigue and power recovery profile of young people and research in this area is deserving of encouragement.

References

Armstrong, N., & Welsman, J. (1997). *Young People and Physical Activity.* Oxford University Press.

Bar-Or, O. (1995). The child and adolescent athlete. *The Encyclopaedia of Sports Medicine.* London: Bench mark Press.

Blimkie, C.J., Roche, P., Hay, J.T., & Bar-Or, O. (1989). Anaerobic power of arms in teenage boys and girls: relationship to lean tissue. *European Journal of Applied Physiology,* 57, 677-683.

Bouchard, C., & Malina, R.M. (1983). Genetics for the sports scientist: selected methodological considerations. *Exercise and Sports Science Reviews,* 11, 275-305.

Bouchard, C., Malina, R.M., & Perusse, L. (1997). *Genetics of Fitness and Physical Performance.* Champaign, IL: Human Kinetics.

Chia, M., Armstrong, N., & Childs, D. (1997). The Assessment of Children's Anaerobic Performance using modifications of the Wingate Anaerobic Test. *Pediatric Exercise Science,* 9, 80-89.

Chia, M. (2000). Assessing young people's exercise using anaerobic performance tests. *European Journal of Physical Education,* 5, 231-258.

Chia, M. (2001). Repeated sprint performances among Girls and Women. *Journal of Physical Education and Recreation (Hong Kong),* 7, 55-60.

Chia, M., & Quek, J.J. (2001). Physical Activity, Physical Fitness and Health: Distilling Guidelines for Young People. *Journal of Physical Education and Recreation (Hong Kong),* 26-30.

Cooper, D.M. (1995). New horizons in Pediatric exercise research. In *New Horizons in Pediatric Exercise Science,* Blimkie, C.J.R. & Bar-Or, O. (Eds.). Champaign IL: Human Kinetics, pp. 1-24.

Di Prampero, P.E., & Cerretelli, P. (1969). Maximal muscular power (aerobic and anaerobic) in African natives. *Ergonomics,* 12, 51-59.

Duan, W., & Qiao, J. (1987). Age and sex characteristics of anaerobic capacity in children and adolescents. *Chinese Journal of Sports Medicine,* 6, 142-146.

Duche, P., Falgairette, G., Bedu, M., Fellman, N., Lac, G., Robert, A., & Coudert, J. (1992). Longitudinal approach of bio-energetic profile in boys before and during puberty. In *Pediatric Work Physiology,* Coudert, J.& Van Praagh, E. (Eds.), Paris, Masson. pp. 43-46.

Falgairette, G., Bedu, M., Fellmann, N., Van Praagh, E., Jarriage, J.F., & Coudert, J. (1990). Modifications of aerobic and anaerobic capacities in active boys during puberty. In *Children and Exercise XIV,* Beunen, G., Ghesquiere, J., Reybrouck, T. & Claessens, A.L. (Eds.), Stuttgart, Ferdinand Enke. pp. 42-49.

Falgairette, G., Bedu, M., Fellmann, N., Van Praagh, E., & Coudert, J. (1991). Bioenergetic profile in 144 boys aged 6-15 years with special reference to sexual maturation. *European Journal of Applied Physiology,* 62, 151-156.

Falk, B., & Bar-Or, O. (1993). Longitudinal changes in peak aerobic and anaerobic mechanical power in circumpubertal boys. *Pediatric Exercise Science,* 5, 318-331.

Gaul, C.A., Docherty, D., & Cicchinni, R. (1995). Differences in anaerobic performance between boys and men. *International Journal of Sports Medicine,* 16, 451-455.

Inbar, O., & Bar-Or, O. (1986). Anaerobic characteristics in male children and adolescents. *Medicine and Science in Sports and Exercise,* 18, 3.

Inbar, O., Bar-Or, O., & Skinner, J.S. (1996). *The Wingate Anaerobic Test.* Human Kinetics.

Kemper, H.C.G., Verschuur, R., & de Mey, L. (1989). Longitudinal changes of aerobic fitness in youth ages 12 to 23 years. *Pediatric Exercise Science,* 1, 257-270.

Komi, P.V., & Karlsson (1979). Physical performance, skeletal muscle enzyme activities and fibre types in monozygous and dizygous twins of both sexes. *Acta Physiologica Scandinavica,* 462, 1-28.

Komi, P.V., Klissouras, V., & Karvinen, E. (1973). Genetic variation in neuromuscular performance. *Internationale Zeitschrift fur Angewandte Physiologie,* 31, 289-304.

Kurowski, T.T. (1977). Anaerobic power of children from ages 9 through 15 years. *Master's Thesis,* Florida State University.

Malina, R., & Bouchard, C. (1991). *Growth, Maturation and Physical Activity.* Champaign, IL: Human Kinetics.

Margaria, R., Aghemo, P., & Rovelli, E. (1966). Measurement of muscular power (anaerobic) in man. *Journal of Applied Physiology, 21,* 1662-1664.

McArdle, W.D., Katch, F.I., & Katch, V.L. (1994). *Essentials of Exercise Physiology.* Lea & Febiger.

Mercier, B., Mercier, J., Grainer, P., Le Gallais, D., & Prefaut, C.H. (1992). Maximal anaerobic power; relationship to anthropometric characteristics during growth. *International Journal of Sports Medicine,* 13, 21-26.

Nevill, A.M., & Holder, R.L. (1995). Scaling, normalising and per ratio-standards: an allometric modelling approach. *Journal of Applied Physiology,* 79, 1027-1031.

Nindl, B.C., Mahar, M.T., Harman, E., & Pattton, J.F. (1995). Lower and upper body anaerobic performance in male and female adolescent athletes. *Medicine and Science in Sports and Exercise,* 27, 235-241.

Paterson, D.H., Cunningham, D.A., & Bumstead, L.A. (1986). Recovery O2 and blood lactic acid: longitudinal analysis in boys aged 11 to 15 years. *European Journal of Applied Physiology,* 55, 93-99.

Rowland, T.W. (1996). *Developmental Exercise Physiology.* Champaign, IL: Human Kinetics.

Rutenfranz, J. (1986). Longitudinal approach to assessing maximal aerobic power during growth: the European experience. *Medicine and Science in Sports and Exercise,* 18: 270-275.

Saavedra, C., Lagasse, P., Bouchard, C., & Simoneau, J.A. (1991). Maximal anaerobic performance of the knee extensor muscles during growth. *Medicine and Science in Sports and Exercise,* 23, 1083-1089.

Sargeant, A.J. (1989). Short-term muscle power in children and adolescents. In *Advances in Pediatric Sports Sciences, Vol. 3,* Bar-Or, O. (Ed.). Champaign, IL: Human Kinetics. pp. 41-63.

Sargeant, A.J.,& Dolan, P. (1986). Optimal velocity of muscle contraction for short term (anaerobic) power output in children and adults. In *Children and Exercise XII.* Rutenfranz, J., Mocellin, R. & Klimit, F. (Eds.). Champaign, IL: Human Kinetics. pp. 39-42.

Van Praagh, E. (1990). Anaerobic power in boys and girls. *Hermes (Leuven) XXI,* 3, 431-437.

Welsman, J.R., Armstrong, N., Nevill, A.M., Winter, E.M., & Kirby, B. (1996). Scaling peak V02 for differences in body size. *Medicine and Science in Sports and Exercise,* 4, 259-265.

Winter, E. M. (1992). Scaling: partitioning out differences in size. *Pediatric Exercise Science,* 4, 296-301.

Correspondence:

Dr Michael Chia
Physical Education and Sports Science
National Institute of Education
Nanyang Technological University
1 Nanyang Walk
Singapore 637616
SINGAPORE

Tel: 65-67903701 Fax: 65-68969260
Email: yhmchia@nie.edu.sg