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Original Article

DEVELOPMENT AND DETERMINANTS OF AND RECOVERY FROM ALL-OUT INTENSITY EXERCISE IN PAEDIATRIC SUBJECTS

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This purpose of this review is to provide a critical analysis of current literature on the development and determinants of and recovery from all-out intensity exercise in paediatric subjects. Between 8 and 21 years of age, the tempo and timing of development of power output among male and female paediatric subjects are different. Age exerts an independent effect on the evolution of maximal short-term power but sexual maturity does not appear to exert any significant effect once body mass, body fatness or thigh muscle volume are accounted for. Both quantitative and qualitative factors help to explain the 'growth curve' for maximal short-term power. Power recovery during repeated all-out intensity exercise is faster in paediatric subjects than in adult subjects. Directions for future research include the use of non-invasive technologies to study the mechanisms of all-out intensity exercise in paediatric subjects.
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Introduction

Exercise nomenclature

A surfeit of terms is used to describe all-out intensity or maximal non-steady state short term exercise in the paediatric exercise literature. Nomenclature such as alactacid, lactacid, short-term power, short-term capacity, short-term work capacity, instantaneous power, peak power, mean power and short term power are used commonly and often indiscriminately to describe non-identical aspects of maximal non-steady state short term exercise in refereed journals and physiology textbooks.

Performance during short-term all-out intensity exercise should not be confused with maximal intensity exercise in a maximal oxygen uptake test, since the mechanical power elicited during the former is 2-4 times that elicited during the latter in young people using cycle ergometer tests. In this paper, short-term all-out intensity exercise refers to the accomplishment of maximal exercise, where the predominant though not exclusive source of energy is from non-oxidative metabolism.

High intensity exercise fitness can be explained as the capability of the young person to perform short-term all-out intensity exercise. In essence, the competence to generate the highest mechanical power or peak power (PP) over a few seconds (an indicator of short-term power) and to sustain the high power over a short period of time (usually less than 60 s) or mean power (MP) (an indicator of short-term endurance) can be considered as prime indicators of high intensity exercise fitness.

Tests of all-out intensity exercise

Invasive procedures like muscle biopsies are necessary for the direct determination of energy turnover during rest and exercise but these procedures are opposed for use in healthy young people. Non-invasive estimations of energy yield such as the use of magnetic resonance spectroscopic (MRS) technologies are now available but they are very expensive, not accessible to most researchers and only limited types of exercises can be performed because of the size limitations of the apparatus.

Consequently, sports scientists are reliant on surrogate performance tests using various laboratory contraptions-cycle ergometer, treadmill, and isokinetic dynamometer. These tests usually last between 10 s and 60 s, and paediatric subjects are verbally encouraged to yield a maximal effort throughout the test. Shorter tests of up to 10 s are usually focused on the quantification of maximal power or PP, while longer tests of up to 60 s are concerned with the assessment of average power or MP, total mechanical work accomplished or some estimation of short-term capacity. Tests of 30 s usually provide data on PP, MP and a measure of fatigue or fatigue index (FI).

Inevitably, considerations for selecting the test of choice must depend on (1) The research question being addressed, (2) the characteristics of the paediatric subjects and what modifications or customisation of the test protocol are necessary and (3) the feasibility and applicability of testing.

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Comprehensive reviews of the different types of tests used in the paediatric population are available elsewhere (e.g. Inbar *et al*, 1996; Chia, 2000) and will not discussed in this paper.

Development of all-out intensity exercise in young people
Young people's all-out intensity exercise capability continues to develop from childhood through adolescence and into early to middle adulthood and is thought to peak sometime in the third decade (Inbar et al 1996). Between 10 and 21 yrs, the timing and tempo of changes in performance during short-term all-out exercise in male and female subjects are not identical. In the extant literature, the most abundant information on young people's performance during short-term all-out exercise comes from PP and MP derived from the 30 s WAnT but there is now more information on PPopt derived from Force-velocity Tests (FVTs) and Inertia-corrected Force Velocity Test (iFVT) over sprint (s) lasting less than 10 s. However, these data are not always comparable because of differences in test protocols and subject characteristics. Performance data from tests longer than 30 s are fewer as they could encompass a considerable aerobic contribution to the exercise (Chia et al 1997) and subject compliance may be lower because sustaining the motivation to give a maximum effort throughout the test in young people can be problematic.

There are more exercise data on male than female subjects and more are derived from cross-sectional than from longitudinal studies. Power data are normally expressed in absolute terms, in ratio to BM or some other estimate of muscle mass but alternative methods such as liner adjustment and log-linear methods have also come to the forefront. The choice of the body size descriptor employed in the size-normalisation procedure will also affect the results and consequently, the interpretation of the data (Chia 2004).

Typical paediatric all-out intensity exercise data such as PP and MP in the WAnT (Inbar et al 1996; Armstrong *et al*, 2001), PPopt derived from FVTs (Santos *et al* 2003) and CPP in the iFVT (Dore *et al* 2000) are available. However, caution is advised when making comparisons across different studies since the results can be complicated by different subject characteristics, different test protocols, different variables of interest, and different statistical treatments of the data. This precludes and limits direct comparisons in results across laboratories that employ dissimilar assessment tests.

Table 1 is a comparison of the competence of paediatric subjects to perform all-out intensity exercise in various cycle ergometer tests in comparison to adults. For clarity, the comparisons are made using data in the absolute only.

Table 1 presents data gleaned from different studies using maximal short-term cycling exercise. The data show that children's capability to perform all-out intensity exercise is not equivalent to that of adults, but it improves with calendar age. Cycling power in adolescence is higher than that attained in childhood but still do not match that measured in adults (Inbar *et al* 1996). The difference in exercise performance between boys and men is greater than the difference in exercise performance between girls and women. It should be noted that all-out intensity exercise capability in male and female adults peak sometime in mid-adulthood and not in early adulthood (Inbar *et al* 1996).

Longitudinal studies

All-out intensity exercise data of male and female paediatric subjects derived from longitudinal studies are rare but such data are insightful as they allow for a careful examination of the impact of physical growth and development on all-out intensity exercise competence in young people. Previous longitudinal data had been solely on boys (Falk & Bar-Or 1993) aged 11-18 yrs, grouped by pubertal status. However, because of the small number of subjects within each group, no clear outcomes based on statistical analyses were described. There is an urgent need for longitudinal data on female subjects since data garnered from paediatric male subjects cannot be generalised to pediatric female subjects.

A selected summary of a longitudinal study on the evolution of PP and MP in the 30 s WAnT is presented. Chia (unpublished work, 1998) conceived a juxtaposed study of two groups of subjects aged 10 yrs (N=21 boys, 21 girls) and 12 yrs (N=18 boys and 9 girls) at the baseline year. The first group performed a 30 s WAnT at ages 10 yrs, 10 yrs plus 8 mths and 10 yrs plus 14 mths. The second group performed a 30 s WAnTs at ages 12, 13 and 17 yrs. The applied force used in the WAnT was 0.74 N/kg BM for all the test assessments. Blood lactate concentration was also sampled 2-3 min after the WAnT.

Table 2 provides a summary of % change in PP and MP in absolute, ratio and allometrically adjusted data expressed relative to BM and post-WAnT data in the juxtaposed longitudinal data of Chia (unpublished work, 1998).

Between the time periods 10 yrs and 10 yrs+ 14 months, increases in PP were 48.5 and 77.5 %, while MP increases were 23.0% and 27.4 % for male and female subjects, for data allometrically scaled to BM. For the time period 12-17 yrs, PP increases were 119.6 and 77.7 %, while MP increases were 113.1 and 60.0 % for male and female subjects, for data allometrically scaled to BM. These increases were statistically significant at $p<0.05$. But changes in BL concentration throughout the time periods in male and female subjects were not significantly different ($p>0.05$).

The above results illustrated the following points: (1) PP and MP continued to increase in the male and female subjects from 10 to 17 yrs, independent of BM (2) Improvements in PP and MP in male and female subjects were of dissimilar magnitude and tempo and (3) Post-WAnT BL changes did not mirror the changes in PP and MP between 10 and 17 yrs. Additionally, short term

Table 1. Comparison in maximal short-term cycle ergometer exercise in young people and adults

Researchers	Sample data	Test	Performance indicator (absolute values only)	Performance indicator (absolute values only)
Inbar & Bar-Or 1986			Peak power at 10 -12 yrs % of adult value at 25-35 yrs	Mean power at 10-12 yrs % of adult value at 25-35 yrs
	Male children	30 s WAnT	42	47
			Peak power at 12-14 yrs % of adult value at 25-35 yrs	Mean power at 12-14 yrs % of adult value at 25-35 yrs
	Male adolescents	30 s WAnT	57	62
			Peak power at 10-12 yrs % of adult value at 18-25 yrs	Mean power at 10-12 yrs % of adult value at 18-25 yrs
	Female children	30 s WAnT	44	55
			Peak power at 12-14 yrs % of adult value at 18-25 yrs	Mean power at 12-14 yrs % of adult value at 18-25 yrs
	Female adolescents	30 s WAnT	66	78
Hebestriet *et al* 1994			Peak power at 10.6 yrs % of adult value at 21.6 yrs	Work done at 10.6 yrs % of adult value at 21.6 yrs
	Male children	30 s WAnT	62	68
Chia 2001			Peak power at 13.6 yrs % of adult value at 25.1 yrs	Mean power at 13.6 yrs % of adult value at 25.1 yrs
	Female adolescents	15 s WAnT	81	96
Armstrong *et al* 2001			Peak power at 12.2 yrs % of adult value at 17 yrs	Peak power at 12.2 yrs % of adult value at 17 yrs
	Male adolescents	30 s WAnT	45	47
	Female adolescents	30 s WAnT	60	63
Williams & Keen 2001				Mean power at 14.7 yrs % of adult value at 28.8 yrs
	Male adolescents	5 s ICT		66
Dore *et al* 2000			Cycling peak power at 9.5 yrs % of adult value at 18.2 yrs	Cycling peak power at 14.4 yrs % of adult value at 18.2 yrs
	Female children & adolescents	iFVT	44	81
Santos *et al*			Optimised peak power at 10.1 yrs % of adult value at 21.2 yrs	Optimised peak power at 14.8 yrs % of adult value at 21.2 yrs
	Male children & adolescents	FVT	21	66
	Female children & adolescents		33	71

WAnT = Wingate Short-term Test
ICT = Isokinetic cycle test
iFVT = Inertia-accounted force velocity cycle test
FVT = Force velocity cycle test

Table 2. % change in WAnT PP and MP in the juxtaposed longitudinal study of Chia (unpublished work, 1998)

WAnT power	10yrs to 10yrs+8mths (% change)	10yrs+8mths to 10yrs+14mths (% change)	12yrs to 13yrs (% change)	13yrs to 17yrs (% change)
PP (W)	36.4 (16.4)	9.5 (55.9)	41.2 (38.5)	58.8 (8.4)
MP (W)	20.8 (16.1)	1.7 (10.8)	23.4 (14.5)	73.8 (19.8)
Allometrically adjusted PP (W)	33.1 (18.8)	11.6 (49.4)	59.1 (42.8)	38.0 (24.4)
Allometrically adjusted MP(W)	19.3 (17.9)	3.1 (8.1)	42.1 (20.5)	50.0 (32.8)
Post WAnT BL (mmol/L)	1.7 (0)	-7.0 (1.8)	1.7 (0)	33.3 (13.1)

Numerals without brackets are data of male subjects and numerals within brackets are data of female subjects.
PP = peak power; MP = mean power; BL = blood lactate concentration sampled at 2-3 minutes post-test

stability of PP and MP (10 yrs to 10 yrs+ 14 mths) was significant ($r=0.77-0.92$, $p<0.05$) but longer term stability of PP and MP (12 yrs to 17 yrs) was not significant ($r=0.02-0.49$, $p>0.05$) in male and female subjects.

Sex differences

Data from the juxtaposed longitudinal study (Chia unpublished work, 1998) revealed that when PP and MP were allometrically adjusted for BM, (1) Male subjects had significantly higher PP and MP than female subjects at 10 yrs and 10 yrs+8 mths, but male and female subjects had similar PP and MP at 10 yrs+14 mths, (2) Male and female adolescents had similar PP and MP at 12 yrs and 13 yrs but at 17 yrs, male subjects had significantly higher PP and MP than female subjects.

In a subsequent published longitudinal study, with increased subject numbers added on to the unpublished work of Chia (1998) using multilevel modelling analyses in male and female subjects aged 12 to 17 yrs, Armstrong et al (2001) reported that BM and skinfold thickness were explanatory variables for WAnT PP and MP. Additionally, the researchers also reported significant independent effects for both age and sex, for both PP and MP derived from the 30 s WAnT.

Cross sectional studies

Many cross-sectional studies on the maximal non-steady state short term exercise of young people are available but there are less data on female than on male subjects for all age groupings. A cross-sectional study that involved 144 boys aged 6-14 yrs showed a progressive increase in PP and MP with calendar age. Between the ages 6-8 yrs and 14-15 yrs, PP in W/kg BM increased by 74 % and MP in W/kg BM increased by 62 % (Falgairette *et al*, 1991). In another study that was based in China, Duan and Qiao (1987), tested 131 girls and 134 boys, aged 11-18 yrs. PP and MP, derived from the WAnT, increased with calendar age, both in absolute (W) and relative terms (W/kg BM). They also reported that the greatest increases occurred in the 11-12 and 13-14 yrs age groupings for male and female subjects.

These earlier observations are affirmed by results of Dore et al (2000) and those of Santos *et al* (2002). The development of cycling peak power (CPP) using the iFVT was described by Dore *et al* (2001) in a cross sectional study of female subjects, which included girls (age 9.5 ± 0.7 yrs, N = 64), adolescents (age 14.4 ± 0.4 yrs, N=62) and adults (age 18.2 ± 0.9 yrs, N = 63). The linear regression approach was used to account for BM, fat-free mass (FFM) and lean leg volume (LLV). CCP adjusted for BM increased 23.6 % from age 9.5 to 18.2 yrs. For the same age span, the increase in CCP adjusted for FFM was 19.8 %. The authors stated that CPP adjusted for LLV could not be computed due to a lack of homogeneity of variances in the data on girls. Nevertheless, the increase in LLV-adjusted CCP from adolescence to adulthood in the female subjects was 13.7 %.

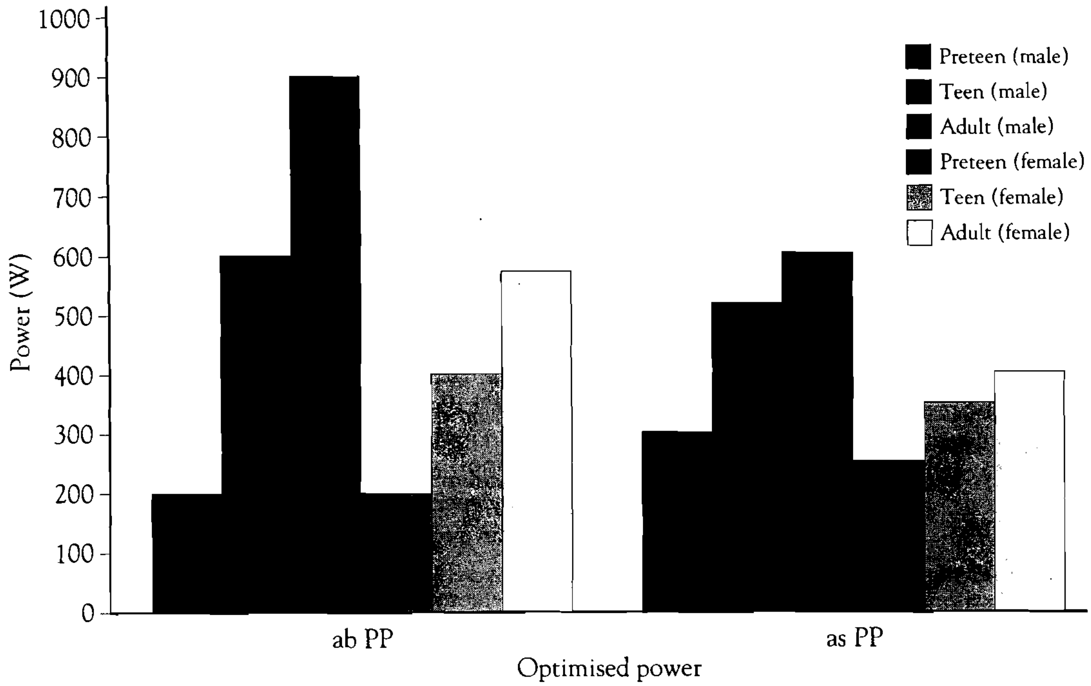
Santos *et al* (2003) compared the PPopt derived from the FVT in three groups of subjects - preteen (age 9-10 yrs, N=21 male and 20 female subjects), teenage (age 14-15 yrs, N=23 male and 22 female subjects) and adults (age 20-21 yrs, N=20 male and 21 female subjects). Selected results based on the tabulated data of Santos et al (2003) are presented in Figure 1.

The following salient points were gleaned from the study by Santos et al (2003): (1) Increases in PPopt from preteen (9-10 yrs) to adulthood (21-22 yrs) were 91.0 and 55.6 % for male and female subjects, respectively for PPopt allometrically adjusted for BM and (2) No sex differences were detected in PPopt for preteen boys and girls, but male subjects had significantly higher PPopt than female subjects in the teen and adult groups, for data allometrically scaled to BM.

Summary on the development of maximal non-steady state short term exercise

There is a compelling need for longitudinal studies that encompass male and female subjects throughout the paediatric age span and extending into mid adulthood. These studies should employ valid and reliable protocols for the assessment of all-out intensity exercise and

Fig 1. Optimised PP derived from the FVT in absolute terms and allometrically adjusted for BM. Selected results based on the tabulated results of Santos *et al* (2003) are presented.



ab PPopt = absolute optimised peak power
as PPopt = optimised peak power adjusted allometrically in relation to BM, obtained by taking the antilog of the log values derived from analysis of covariance. The increases in ab PPopt and as PPopt across the groups in male and female subjects are significant ($p<0.05$).
b exponents identified for the male subjects and female subjects across the age groups were 0.95±0.09 and 0.84±0.09, respectively.

appropriate statistical approaches should be used to interpret the results. The current understanding of young people's growth in all-out intensity exercise fitness is based principally on results gleaned from cross-sectional studies, supplemented by some data from short-term longitudinal studies. Between10 and 21 yrs and plausibly thereafter till sometime in middle adulthood, PP and MP in male and female subjects continue to improve. Though it is likely that PPopt would follow similar trends of improvement from childhood into adulthood, this has apparently not yet been verified. The tempo and magnitude of these improvements are not identical and present data suggest that the improvement in PP are more marked that the improvement in MP before 13 yrs, but thereafter improvements in MP are greater than the improvements in PP in male and female subjects. Improvements in PP, PPopt and MP are also more marked in male than in female subjects even when BM is allometrically adjusted for. Sex differences in PP, PPopt and MP, independent of BM are exacerbated in the period encompassing late childhood and early post-puberty.

Determinants of all-out intensity exercise

Genetics

Data on the genetic effect on all-out intensity exercise in young people are scarce, with previous estimates ranging from 0 to 100 % of the variance (Komi and Karlson 1979). Malina and Bouchard (1991) reported that in 10 s cycle test on siblings and twins, genetic effects accounted for about 50 % of the performance. However a heritability estimate of 97 % was reported for maximal power of the arms in 17 pairs of male twins aged between 11 and 17 yrs (Malina and Bouchard 1991).

In another study, the heritability index (HI) of 32 male twins (age 21.3 ± 2.1 yrs, N = 8 monozygotic and 8 dizygotic pairs) with similar backgrounds on a series of tests was reported (Calvo *et al* 2002). Their results revealed significant HI values for 5 s PP (HI=0.74) and MP over 30 s (HI=0.84) and for maximal post exercise BL concentration (HI=0.82). However, the HI for fatigue index (FI) was not significant (HI=0.43, $p>0.05$). The HI for the AOD test was also not significant (HI=0.22, $p>0.05$). Importantly, the genetic effect determined using different exercise tests in the same subjects were different (Calvo *et al* 2002) and therefore results must not be extrapolated to tests with dissimilar characteristics.

Age

Ample data suggest that PP, MP and PPopt increase with calendar age. For example, in 306 subjects aged 8 to 45 yrs, PP and MP in the WAnT for arms and legs, expressed in W/kg BM, increase from childhood to adulthood. Apex values for WAnT power for the legs were achieved at the end of the third decade for men and in the middle of the second decade for women. Conversely, the highest WAnT power values for the arms were attained in the middle of the second decade for men (Inbar *et al* 1996).

The typical 5 s PP of boys (age 10-12 yrs) were 83.2 % (7.98 ± 1.15 vs. 9.59 ± 0.78 W/kg BM) while 30 s MP of boys were 83.6 % (3.73 ± 0.46 vs. 4.46 ± 0.34 W) of that of male adults (25-35 yrs) for WAnT leg power. The equivalent 5 s PP of girls (age 10-12 yrs) were 74.3 % (6.34 ± 1.53 vs. 8.53 ± 1.07 W/kg BM) and 30 s MP of girls were 93.8 % (5.31 ± 1.08 vs. 5.66 ± 0.59 W/kg BM) that of women (18-25 yrs). Throughout the age span, WAnT power for the arms was 60-70 % that for WAnT power for the legs (Inbar et al 1996).

These early observations are affirmed by results of FVTs where PPopt of both male and female subjects were presented (Santos *et al* 2003). Allometrically adjusted PPopt in the preteen (9-10 yrs) group was 61.7-73.3 % that of the teen (14-15 yrs) group, while the adjusted PPopt in the teen group was 87.4-87.6 % that of the adult (21-22 yrs) group. When the preteen group was compared to the adult group, the adjusted PPopt in 9 to 10-yr-old boys and girls was 52.3-64.3 % of the 21 to 22-yr-old male and female adults.

In a separate study that utilised multilevel modelling to examine changes in short term power (inertia adjusted PP and MP, 30 s WAnT) in 10 to 12-yr-old boys (N=15) and girls (N=18), age was a significant independent predictor for PP and MP (De Ste Croix 2001) among other body size covariates. However, other data on 12 to 14-yr-old subjects that emanated from the same laboratory showed no age effect on FVT-determined PPopt (Santos et al 2003), using the same statistical treatment of longitudinal data. In another longitudinal study, which involved measurements of WAnT PP and MP at ages 12, 13 and 17 yrs, results of multilevel modelling revealed that calendar age exerted a positive but non-linear effect on PP and MP, with BM and body fatness controlled for (Armstrong et al 2001).

Body size

Indictors of body size include stature, BM, FFM, lean leg volume (LLV) and thigh muscle volume (TMV) and lower limb muscle mass (LLMM). These body size descriptors have been used to normalise maximal short-term power (PP, MP, PPop, CCP) using either simple ratio standards, linear regression adjustment of log-linear adjustment methods.

Ample data in the literature show that increases in PP and MP (Inbar & Bar-Or, 1986, Chia, 1998) in PPopt (Santos *et al* 2003) and in CPP (Dore *et al* 2000) parallel the increases in BM or other surrogate indicators of body size, but not exactly. When body size is taken into account, increases in power are still evident. For example, between the ages of 8 and 18 yrs, increases in BM in boys were approximately 160 % and in girls, about 145 %. Conversely, increases in short term power over the same age span, were about 160 % in girls and about 180 % in boys (Van Praagh & Dore 2002). In a sample of 189 prepubertal, adolescent and adult female subjects, CCP derived from iFVTs increased, as did BM, FFM and LLV but Dore et al (2000) explained that body dimensions alone did not account for all the increases in CCP across the different age groupings. These results echoed their earlier findings on 506 male subjects aged 7.5-18 yrs (Dore *et al* 2000).

Additional insights on the determinants of short term power are provided by the previously cited study of De Ste Croix *et al* (2001). According to their results, researchers explained that (1) The introduction sum of skinfolds improved the fit of the multilevel model and rendered the stature term non-significant for WAnT PP and MP and (2) Thigh muscle volume (TMV) exerted a positive influence on PP and MP and (3) Peak isokinetic strength did not exert any independent influence on PP or MP. It is noteworthy that in the cited study, peak isokinetic strength was achieved at the lower angular velocities (0.52 or 1.05 rad/s). However, it is not known if isokinetic strength measured at the higher angular velocities (1.56, 2.09 or 3.14 rad/s or higher) would have exerted an independent effect on PP or MP. A reanalysis of the data may provide some answers.

Selected results from another study that employed the multilevel modelling technique founded on 146 determinations of PPopt from FVTs (79 from boys and 67 from girls, aged 12-14 yrs) revealed that BM and stature were explanatory variables for PPopt, with sum of skinfolds exerting an additional negative effect (Santos *et al* 2003). These results are insightful and it would be useful to extend the studies to encompass the time periods from childhood to mid adulthood in male and female subjects.

Sex and maturity

Many cross-sectional studies describing sex differences in short-term test performance at different ages from 8 to 21 yrs provide inconsistent results especially between the ages of 10 and 14 yrs. Chia *et al* (1997) reported no sex differences for inertia-adjusted WAnT PP and MP expressed in ratio to BM in 50 boys and girls aged 9-10 yrs. When the same data were expressed in ratio to TMV, which was determined using magnetic resonance imaging (MRI), PP was significantly higher in boys than in girls but there was no sex difference in MP. However, when PP and MP were expressed allometrically in relation to TMV, PP and MP were similar in boys and girls (Chia *et al* 1997). These results suggested that the choice of the body size descriptor and the scaling method used to normalise the exercise data affected the outcomes of the study.

In another study, Chia (2004) reported that in 81 adolescent boys (N=45) and girls (N=36) aged 13-14 yrs, PP and MP expressed in ratio and adjusted allometrically in relation to lower limb muscle mass (LLMM), determined using dual energy X-ray absorptiometry (DXA) was not significantly different. In the cited studies of Chia (1997, 2004), age was not significantly different between the male and female subjects and it was suggested that other qualitative explanations must be sought to explain the results.

The effect of sexual maturity on all-out intensity exercise is less clear with previous studies reporting significantly greater ANCOVA-adjusted arm and leg WAnT PP and MP adjusted for BM, FFM and muscle cross-section area (CSA) in adolescent male (N=20) than adolescent female subjects (N=20). This was despite the subjects having similar sexual maturity status, assessed using Tanner indices (Nindl *et al* 1995).

Van Praagh *et al* (1990), also reported significantly higher PP and MP adjusted for lean thigh volume (LTV) using ANCOVA, in 12-13 year-old adolescent boys (N=15) than in adolescent girls (N=10). The adjusted PP and MP, in relation to LTV, were 57 and 45 % higher, respectively in the boys than in the girls. The authors speculated that these sex differences in PP and MP could be attributed to the dramatic increase in sex steroid concentrations at the onset of male puberty, but they acknowledged that there was little data on the effect of female sex hormones on muscle in early puberty.

Armstrong *et al* (1997) described the 5 s PP and MP over 30 s in the WAnT of 100 boys and 100 girls aged 12.2 yrs in relation to sexual maturity using allometric principles to scale the power data. They reported that although no sex differences were detected for PP and MP for the age group, sexual maturity exerted an influence on PP and MP that was independent of BM. Additionally, no sex or maturity effects were noted for WAnT blood lactate values, which were sampled 3 min after the test.

Contrarily, in a series of studies monitoring the changes in WAnT PP and MP in 10 to 12-yr-old children (Armstrong *et al* 2001) and FVT-derived PPopt in 12 to14-yr-old adolescents (Santos *et al* 2003), using multilevel modelling, no significant sex or maturity effect was observed for PP or MP, and no sex difference was evident for PPopt. More secure data are necessary as to whether sexual maturity exerts a significant and independent influence on young people's competence to perform maximal non-steady state short term exercise, once other confounding factors are controlled for.

Sex differences in power generation beyond the age of 14 yrs are more secure, with data showing an enlargement of sex differences, especially after puberty (Inbar *et al* 1996, Armstrong *et al*, 1997, Chia, 1997, Dore *et al* 2000). These observations are buttressed and also challenged by the 5-yr-longitudinal study (with WAnT measurements at 12, 13 and 17 yrs) of Armstrong *et al* (2001), the seminal points of which were that with BM and fatness statistically controlled for (1) Male subjects had significantly higher PP and MP (2) Age exerted a non-linear but positive effect on PP and MP at 17 yrs but not at 12 yrs and at 13 yrs, and (3) Sexual maturity did not contribute any significant additional effect on WAnT PP and MP.

Summary on determinants of all-out intensity exercise

Genetics appear to exert a strong influence on young people's maximal non-steady state short term exercise, especially PP and MP in the WAnT. The heritability index (HI) for short term power measured in the WAnT range from 0.74 to 0.82. Longer tests such as the AOD have no significant heritability index. Short term power increases with increases in body size- e.g. BM, FFM, LLMM, LTV, and TMV and with age, but these increases are of a different magnitude in paediatric male and female subjects.

Sex differences in power are enlarged after puberty even with body size controlled for, but maturity does not appear to exert any additional significant effect once age, BM and fatness are controlled for. Qualitative or body size-independent determinants of short term power in young people could plausibly include among others: alterations in muscle fibre type distributions or muscle mechanics, changes in energy metabolism, changes in neuromuscular characteristics and oxygen on-transients. However, these postulations await further research attention and confirmation in male and female subjects within the paediatric age span.

Power recovery in repeated all-out intensity exercise

There is now greater recognition that young people's habitual physical activity patterns are intermittent and pulsating. Yet, there is insufficient data about young people's capability to recover from intense bouts of exercise. Limited data in young people show that young people recover faster than adults in repeated maximal non-steady state short term exercise of a short duration. Baradi *et al* (1991) reported that heart rate after high intensity exercise was lower in children than in adults. Lending support to these observations, Hebestreit *et al* (1994) reported that prepubertal boys (N=8, age 8-12 yrs) recovered faster than adult men (N = 8, age 18-23 yrs), despite having similar BM-related peak (boys vs. men, 49.6 vs. 51.1 ml/kg BM/min, $p>0.05$). Over a series of 3 separate test sessions, the boys and men completed two 30 s WAnT (WAnT 1 and WAnT 2) separated by 1, 2 and 10-min active recovery intervals (exercise-to-recovery ratios of 1:2, 1:4 and 1:20)

The seminal points gleaned from the study were (1) PP (W/kg BM) and total mechanical work (TMW) (J/kg BM) in boys was 61.5 and 67. 8 % that of the men in WAnT 1 (2) % fatigue in WAnT 1 was 43.8 % in boys versus 52.4 % in men ($p<0.05$) (3) recovery in PP in WAnT 2 was 90.6, 112.2 and 105.1 % versus 58.8, 70.9 and 95.2 % ($p<0.05$) of PP in WAnT 1, in boys and men respectively and (4) % recovery in PP was significantly higher than recovery in TMW in WAnT 2 in boys and men. The authors explained that the faster power recovery in boys compared to men could be partially explained by their lower PP, TMW and % fatigue in WAnT 1, their lower implied post exercise BL concentration and plausibly a faster removal of post exercise metabolites.

In another study, Ratel *et al* 2002 reported that 10-yr-old boys were able to maintain cycling peak power (CPP) (0% decrement) during 10 sprints of 10 s, separated by 30 s recovery intervals (exercise-to-recovery ratio of 1:3 between sprints) compared to 15-yr-old boys and 20-yr-old male adults where the decrements in CPP were 18.5

and 28.5 %, respectively.

Chia (2001) examined the power recovery in adolescent girls (N=19, age 13.6 yrs) and women (N=21, age 25.1 yrs) using a series of three 15 s maximal cycle sprints (WAnT 1, WAnT 2 and WAnT 3) separated by a active recovery interval of 45 s between the sprints (exercise-to-recovery ratio of 1:3). The girls and women had similar BM and DXA-determined lower limb muscle mass (LLMM). Pre-and post exercise BL were obtained. The following results from the study were noteworthy: (1) PP and MP in WAnT 1 in girls were significantly ($p<0.05$) correlated with BM (r=0.79-0.83) and LLMM (r=0.88-0.93) but in women WAnT power was significantly correlated with BM (r=0.55-0.56) but not LLMM (r=0.31-0.36, $p>0.05$), (2) PP in WAnT 1 in W/ kg LLMM in girls was 81.1 % that of the women but MP in W/kg LLMM was not significantly different ($p>0.05$) between girls and women, (3) WAnT PP and MP in W/kg BM was similar in girls and women, (4) girls were able to replicate 82 and 81 % of PP and MP of WAnT 1 in WAnT 3 while the women could replicate only 70 and 63 % of PP and MP using the same mode of comparison and (5) pre-test (2.5 vs. 1.9 mmol/L) and post-test blood lactate concentrations before the WAnT 1 and taken at 3 min after WAnT 3 (9.2 vs. 8.4 mmol/L) were not significantly different ($p>0.05$) between girls and women. These data suggested that despite similar post BL values, girls demonstrated a faster recovery in WAnT PP and MP than women. Chia (2001) suggested that possibly a higher peak in girls than women, and differences in oxygen on-transients in response to intense exercise and differences in the time course of CP resynthesis between girls and women could account for the swifter power recovery in girls. However, these postulations await further research confirmation.

Summary on power recovery in repeated all-out intensity exercise

Notwithstanding the different research protocols used in the different studies, results suggest that young boys and adolescent girls demonstrate swifter power recovery than male and female adults. The reasons proposed for the faster power recovery after repeated maximal exercise in boys and girls are different and further clarity in the matter can come from an examination of power recovery in repeated sprints in pre-pubertal and adolescent boys and girls, the results of which await a research and evidence-based explanation. The patterns of power recovery in different exercise-to-recovery ratios and also different exercise and recovery times for a fixed exercise-to-recovery ratio in young people should also be elucidated.

Directions for future research

A firm understanding of the all-out intensity exercise capability of young people is important considering that daily tasks among children and adolescents involve both sub-maximal and maximal function, albeit less is documented for the latter. Researchers have to grapple with methodological and ethical constraints when dealing with young people and this has limited somewhat the proliferation of the knowledge base on the all-out intensity exercise capability of young people.

Future research directions worthy of consideration include (1) affirming the relevance of documenting short term power output for sports, exercise performance or physical health, (2) embarking on longitudinal studies and using appropriate statistical techniques to model short term power data from childhood into mid adulthood, (3) employing the use of non-invasive technologies such as magnetic resonance imaging (MRI), magnetic resonance spectroscopy (MRS), on their own, or in combination with other emergent technologies to examine mechanisms that account for the maximal non-steady state short term exercise of male and female children and adolescents and (4) studying the patterns of power recovery in male and female paediatric subjects following intermittent exercise, using different exercise-to-recovery combinations.

References

Armstrong N, Welsman J, Kirby B 1997 Performance on the Wingate Short-term Test and maturation. *Pediatr Exerc Sci* 9: 253-261.

Armstrong N, Welsman JR, Chia M 2001 Short term power output in relation to growth and maturation *Br J Sports Med* 35: 118-124.

Calvo M, Rodas G, Vallejo M *et al* 2002 Heritability of explosive power and short-term capacity in humans *Eur J Appl Physiol* 86: 218-225.

Chia M, Armstrong N, Childs D 1997 The assessment of children's short-term performance using modifications of the Wingate short-term test. *Pediatr Exerc Sci* 9:80-89.

Chia 1998 Performance during short-term all-out exercise of young people PhD theses Exeter University UK.

Chia M 2000 Assessing young people's exercise using short-term performance tests *Eur J Phys Educ* 5: 231-258.

Chia YHM 2001 Power Recovery in the Wingate Short-term Test in girls and women following prior sprints of a short duration. *Biol Sport* 18: 45-53.

Chia YHM 2004 High intensity cycle performances of adolescent boys and girls expressed in relation to muscle mass *Biol Sport* 21: 35-40.

De Ste Croix MBA, Armstrong N, Chia MYH *et al* 2001 Changes in short-term power output in 10-to-12-year-olds *J Sports Sci* 19: 141-148.

Dore E, Bedu N, Franca NM *et al* 2000 Testing peak cycling performance: effects of braking force during growth *Med Sci Sports Exerc* 32 (2): 493-498.

Duan W, Qiao J 1987 Age and sex characteristics of short-term capacity in children and adolescents *Chinese J Sports Med* 6: 142-146.

Falgairette G, Bedu M, Fellmann N *et al* 1991 Bioenergetic profile in 144 boys aged 6-15 years with special reference to sexual maturation *European J Applied Physiol* 62:151-156.

Hebestreit H, Minura K-I, Bar-Or O 1994 Recovery of muscle power after high intensity short-term exercise: comparing boys to men *J Appl Physiol* 74: 2875-2880.

Inbar O, Bar-Or O 1986 Anaerobic characteristics in male children and adolescents. *Med Sci Sports Exerc* 18: 3.

Inbar O, Bar-Or O Skinner, J S 1996 The Wingate Short-term Test Human Kinetics, USA, p 1-76.

Komi PV, Karlsson 1979 Physical performance, skeletal muscle enzyme activities and fibre types in monozygous and dizygous twins of both sexes *Acta Physiol Scand* 462:1-28.

Malina R, Bouchard C 1991Growth, Maturation and Physical Activity. Champaign IL Human Kinetics.

Ratel S, Bedu M, Hennegreave A et al 2002 Effects of age and recovery duration on peak power output during repeated cycling sprints *Int J Sports Med* 23: 397-402.

Santos AMC, Armstrong N, De Ste Croix MBA *et al* 2003 Optimal peak power in relation to age, body size, gender and thigh muscle volume *Pediatr Exerc Sci* 15: 406-418.

Van Praagh E, Dore E 2002 Short-term muscle power during growth and maturation *Sports Med* 32 (1): 701-728.

Van Praagh E, Fellmann N, Bedu M *et al* 1990 Gender difference in the relationship of short-term power output to body composition in children *Pediatr Exerc Sci* 2: 336-348.

Williams CA, Keen P 2001 Isokinetic measurement of maximal muscle power during leg cycling: a comparison of adolescent bos and adult men *Pediatr Exerc Sci* 13: 154-166.

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