A COMPARISON OF THE FORCE-VELOCITY-POWER RELATIONSHIP OF THE QUADRICEPS OF CHILDREN AND ADULTS

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This study examined the force-velocity and power-velocity relationships of the quadriceps muscles of children and adults. Measurements of muscle function were collected using the Contrex isokinetic dynamometer. Twenty adults and twenty children performed maximal effort knee extensions at nine different velocities. ANOVA revealed significant differences in the absolute values of peak torque and power between the two groups. When power values were corrected for lean muscle volume, no significant differences were found between the two groups.

KEY WORDS: force, velocity, power, cross-sectional area, lean muscle volume

INTRODUCTION: The development of ballistic type skills is limited by a variety of factors. Factors such as coordination, fibre type and muscle pre-tensing interact in complex ways with cognitive and affective development, (Gallahue and Ozmun, 1995). Performance of various ballistic skills may also be restricted by the ability of the muscle to use the stretch shortening cycle (SSC). This, in turn, may be limited by the force-velocity (F-V) relationship of the muscles (Bosco and Komi, 1980). Few studies to date have examined the F-V relationship of children compared with adults. A notable exception, Asai and Aoki (1996), found a significant difference between children and adults in the F-V relationship of the elbow flexors. This suggests that children do not use the SSC as effectively as adults. However, the F-V relationship was only corrected for muscle length, which does not take into account the influence of increasing cross-sectional area (CSA) of muscle as children develop. This would make any inferences from the results questionable.

Bosco & Komi, (1980) examined the effect of age on SSC performance and found that children could not use the SSC as effectively as adults. On closer examination of the results, however, the conclusion does not seem to be fully justified. Although the results were normalised for weight, the relative differences between counter-movement jump and squat jump performances were not examined. Calculation of the relative differences from these data revealed that children appeared to have the same ability as adults to utilize a SSC. The effects of age on performance enhancement due to SSC therefore remain unresolved.

Surprisingly, all studies of the F-V relationship have concentrated only on one component of increased muscle size (CSA or muscle length). There is a steady increase in both muscle fibre diameter and length with increasing body size and age of children and both factors have been shown to impact on the F-V relationship (Asai & Aoki, 1996). Muscle volume is a more appropriate indicator of three-dimensional muscle size. Power is the product of force and velocity, therefore, power values epitomize the F-V relationship. A study of the relationship between lean muscle volume and power would provide a truer insight into the effect of quantitative changes in muscle on the F-V relationship.

Considerable change takes place in locomotion kinetics and kinematics as a function of age (Gallahue and Ozmun, 1995). Given the importance of the F-V relationship in locomotor activities, it seems reasonable to investigate the role of quantitative development in muscle on functional ability. While isokinetic tests do not emulate the expression of F-V in a ballistic skill, they do provide the level of control required to produce a reliable estimate of this function. The primary purpose of this study was to compare the F-V relationship of adults and children by examining power corrected for muscle volume.

METHODS: Subjects and set-up: Twenty University students and twenty primary school children consented to participate in this study, which had received ethical approval from the

University Ethics Committee. The adult group consisted of 11 females of average age 22 ± 1.45 years and 9 males of average age 22 ± 1.37 years. The children's group consisted of 11 females of average age 6 ± 0.51 years and 9 males of average age 6 ± 0.47 years. The children were chosen because of their age, (approximately 6 years), as it is believed that they should be able to perform the simple movement pattern of knee extension at this point in their development, (Gallahue & Ozmun, 1995). By this age, the CNS should be able to activate the major muscles fully and produce a maximum voluntary contraction under instruction, (Asai and Aoki, 1996). No participants had any past history of nervous system or muscular dysfunction.

Data Collection: Muscle mass (plus bone) volume of the thigh was measured on the leg being assessed using the methods of Katch and Weltman (1975). This involved a series anthropometric measurements comprising of circumferences and lengths on the dominant leg. Skinfold thickness was measured at two sites with a Harpenden fat caliper and the lean thigh volumes were calculated using the method of Jones and Pearson (1969). Although this method may introduce some measurement error, it has been considered to yield a more representative index of lean muscle mass than CSA measurements (Davies, 1988).

Torque production during concentric contraction of the right quadriceps muscle group was determined during leg extension on a Contrex isokinetic dynamometer (CVH AG, Dübendorf, Switzerland). Subjects were stabilised at the thigh, pelvis, and trunk with velcro straps. The subjects arms were placed across their chest during the testing procedure. The axis of rotation of the lever arm of the dynamometer was aligned with the anatomical axis of the knee. The distal shin pad of the dynamometer was placed 3 cm proximal to the medial malleolus. Subjects were asked to relax the leg while the gravity effect torque was recorded. Each subject completed a period of familiarisation with the testing procedure before measurements were taken.

Peak torque was measured at nine different velocities. The sequence of these velocities was varied between subjects to negate any possible effect of fatigue on the results. Two minutes rest was given between each effort. This period is frequently chosen for isokinetic measurements (e.g. James et al. 1994). All subjects were encouraged verbally during the measurements. The force produced for each contraction was registered continuously as torque on the Dynamometer.

Data Analysis: Peak torque was obtained by inspection of the torque curves. The torque and velocity data for each subject were fitted to the Hill equation:

$$(P + a)(V + b) = \text{constant} \qquad \text{(Hill, 1938)}$$

Where P = force of contraction, V = velocity of shortening, and a and b are constants.

This was done by substituting measured values of torque and velocity into three simultaneous equations using the results at the mid-range velocities of 2.094, 2.618 and 3.142 rad.s^{-1}. Power was calculated as the area beneath the F-V curve. These values were then corrected for the lean muscle volume estimate.

Statistical analysis of the data was carried out in SPSS © using a general linear model (GLM) multivariate ANOVA with repeated measures. The GLM had one within-subjects factor (velocity, with 9 levels) and one between-subjects factor (age, with 2 levels). A probability of $p<0.05$ was chosen as the significance level in all analyses. The dependent variables were torque and power. This enabled an examination of all nine trials for each subject, and not simply an average of the nine trials. An independent t- test was used to determine significance between the groups for the constants *a* and *b.*

RESULTS AND DISCUSSION: The isokinetic measurements for both groups conformed to the classic F-V relationship. The absolute torque values for the adults were slightly higher than those found by Wickiewicz et al, (1984) for the quadriceps muscles. However, the adults in Wickiewicz's study were older than the group used in the present study. The difference between the adult and children groups for both torque and power was significantly different ($p<0.05$) as was found in the study by Asai and Aoki, (1996), see table 1.

It should be noted that maximum power was not found for all subjects. At the highest velocity of 5.236 rad.s^{-1}, the power curves, for most subjects, are still increasing. The maximum velocity

that can be studied using the Contrex is 5.236 rad.s^{-1}. Velocities greater than 11 rad.s^{-1} have been reported during all out knee extensions against light levers.

Table 1 Test of Within-Subjects Effects for Uncorrected Power Scores

Source	df	F	p value
Power	8	270.2	<0.001
Power $\times$ Group	8	138.4	<0.001

The difference between the adults and the children's groups for the constant *a* was found to be significant p<0.05. The parameter *a* is related to force and depends on the cross-section of the muscle, (Hill, 1938). The constant *a* when corrected for CSA still showed a significant difference between the groups. This is possibly due to the inaccuracies of the method used to estimate CSA. The difference between the groups for constant *b* was not significant. This is because the constant *b* describes velocity, which was controlled.

It has been suggested that the maximum force generating capacity of the muscle is determined by the muscle CSA (Hill, 1938). Therefore, the force for the F-V curve was normalised for the muscle CSA of each subject, assuming for convenience that the lean CSA measured at the one-third subischial height level is proportional to the CSA of the quadriceps muscle. It has also been suggested that the maximum shortening speed determined from the F-V curve is closely related to muscle length (Asai & Aoki, 1996). Accordingly, the velocity for the F-V curve was normalised by dividing by the thigh length of each subject, assuming for convenience that the thigh length is proportional to the length of the quadriceps muscles. Despite these corrections, the differences in the F-V relationship between the children and adults were still great. It is reasonable to assume that the measurements used for length and CSA are not true reflections of the muscle length and CSA or of three-dimensional muscle size. For this reason, the power-velocity (P-V) relationship, corrected for lean muscle volume was examined. Table 2 shows results of the ANOVA test of Within-Subjects Effects for corrected power scores. These data show that the interaction term power $\times$ group was no longer significant. It appears that with correction for muscle volume there was no group related difference in the P-V relationship. Figure 1 provides graphs of the corrected P-V curves for both groups and it is obvious that little difference exists.

Table 2 ANOVA Test of Within-Subjects Effects for Corrected Power Scores

Source	df	F	p value
Power	8	270.2	<0.001
Power $\times$ Group	8	138.4	0.996

Fuchimoto and Kaneko, (1981) concluded that age differences in muscle power were attributed to muscular function (i.e. qualitative development). However, this study also corrected velocity for forearm length, overlooking the influence of muscle CSA. In the present study, the result of the comparison of power between the groups when corrected for lean muscle volume was that the differences between them have become insignificant. This would suggest that the difference in muscle power between children and adults is attributable to quantitative changes in the muscle rather than qualitative as suggested by Fuchimoto and Kaneko. This is an important finding as it suggests that the functional ability of the muscle is the same, per unit of muscle, for children and adults. It is possible therefore, that muscle fibre composition and function remain consistent from age 6 to early adulthood. Regression analysis shows that the relationship between lean muscle volume and maximum torque is highly significant at each velocity (mean R-squared value of 0.842). However, when the groups are examined separately the strength of this relationship is reduced, especially for the adults. These results indicate that quantitative

differences between individuals do not account for the different values of peak torque measured i.e. lean muscle volume cannot predict the force generating capacity of the muscle. It is likely that other factors such as fibre composition have a bearing on the relationship.
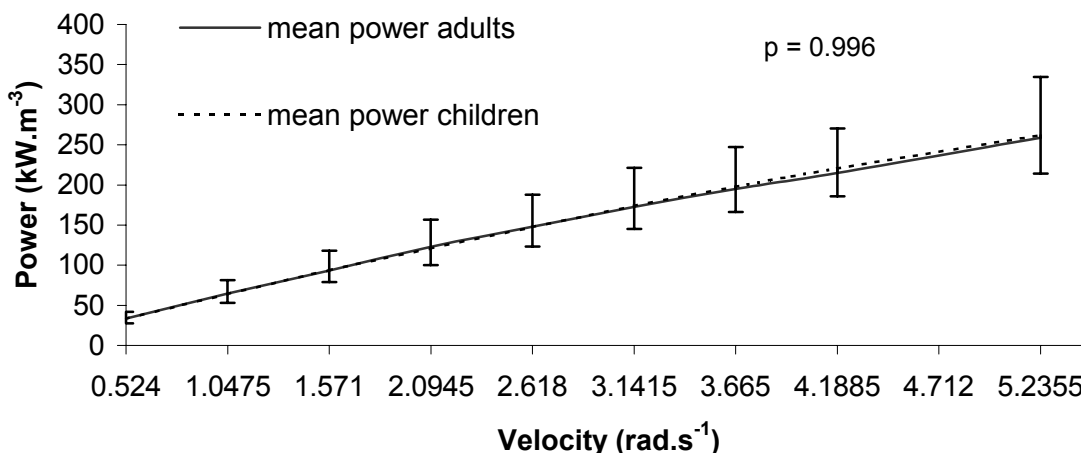

Figure 1 - The corrected power-velocity curve for both groups.

CONCLUSION: Muscle volume appears to account for the differences between power measurements of children and adults. This finding emphasises the uniformity of muscle function in children and adults and suggest that the force generating capacity remains unchanged through adolescence and early adulthood. It is likely that the F-V relationship does not limit the performance of ballistic skills for children.

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