Comparing Muscle Function of Children and Adults: Effects of Scaling for Muscle Size

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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 Con-Trex isokinetic dynamometer. Twenty adults and twenty children performed maximal effort knee extensions at nine different velocities. The mean force-velocity curves of children and adults revealed obvious differences between the groups. The curves remained different following corrections of torque for CSA and velocity for length. ANOVA revealed significant differences in the uncorrected values of power between the two groups. When power values were corrected for lean thigh muscle volume, no significant differences were found between the groups. These findings suggest that differences in muscle strength between children and adults are a function of muscle size and imply that muscle function remains relatively unchanged from childhood to early adulthood.

Introduction

Various motor skills progressively become part of the motor repertoire during childhood (7). Performance of many locomotor and ballistic skills may be limited by the force-velocity (F-V) relationship of the muscles (14). In an isolated muscle contraction, the F-V relationship can be described by the Hill equation:

\[(P + a)(V + b) = \text{constant} \] (8)

where \(P\) = force of contraction, \(V\) = velocity of shortening, and \(a\) and \(b\) are constants.

The constants \(a\) and \(b\) define the relationship between force and velocity. The constant \(a\), describes force and depends largely on the cross-sectional area (CSA) of the muscle. The constant \(b\) relates to velocity and should be proportional to the length of the muscle (8). The F-V relationship therefore, is determined at least in part, by the size of the muscle.

Few studies to date have examined the F-V relationship of children compared with adults. One notable exception found a significant difference between the F-V relationship in children and adults (1). This is not surprising considering the significant increases in muscle size accompanying growth in children.

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Numerous studies have focused on measuring isometric and isokinetic strength and the increases in both associated with growth and maturation are well documented (2, 4, 5). What remains unknown is how much of the increase in strength is attributable to increases in muscle size. Appropriate scaling for differences in muscle size is a fundamental requirement for clarifying how strength changes with respect to normal growth and maturation. The objective of scaling is to produce a “size free” variable. In an attempt to negate the influence of muscle size, and to determine if muscle develops qualitatively, a variety of scaling techniques have been employed. Ratio standards, such as strength per kg body mass, and corrections for body height squared, have been used extensively (5, 18, 9, 17). Corrections for whole body dimensions are controversial since they are based on an assumption of geometric similarities being retained from childhood to adulthood. This may lead to false correlations and incorrect conclusions (20). Evidence suggests, that as children grow, their leg volume increases in a greater proportion to their body mass (15). This indicates the ineffectiveness of corrections based on total body size. Allometric scaling based on whole body dimensions offers a more plausible solution as it may introduce other growth components such as height (15). Allometric scaling of strength accommodates the non-linear but proportional changes with body mass by using log-linear regression. However, because measures of strength are specific to a localised muscle group, using the entire body to control for developmental increases in muscle size is unlikely to be the most appropriate covariate. Isometric and isokinetic tests isolate particular muscle groups for investigation. It is logical, therefore, to correct for the size of the specific muscle group involved rather than correcting for some covariate based on whole body size.

A number of previous studies have implemented single correction on torque for CSA (2, 4, 16), or velocity for length (1, 6). Since, there is a steady increase in both muscle fibre diameter and length with increasing body size and age, a single correction for either local muscle CSA or length is not adequate. This is because the Hill equation demonstrates that both factors will have an impact on muscle function. Therefore, an appropriately corrected F-V curve should include correction of the torque for CSA and velocity for length. Some studies have corrected force for CSA × muscle length (12) and limited research has found the isometric force of a muscle to be directly proportional to lean limb volume (3). Muscle volume is a more appropriate indicator of muscle size as it combines aspects of CSA and length, however, the Hill equation demonstrates that force should not be corrected for volume. Power is the product of force and velocity; therefore, power as a single measurement of muscle function lends itself to convenient correction for volume and subsequent comparison across groups. A single correction of the power-velocity (P-V) relationship for lean muscle volume should provide a truer insight into the effect of muscle size on muscle function.

In order to gain a greater understanding of development, it is important that research concentrates on the effect of maturation on the mechanisms of motor control. Given the importance of the F-V relationship in locomotor activities, it seems reasonable to investigate the role of muscle size on muscle function. Comparative studies of children and adults provide the opportunity to maximise the period of development and therefore identify the greatest changes in the dependent variables. Consequently, we have selected the youngest children (age 6) reported to be able to perform maximum voluntary knee extension under instruction (2, 7, 10).
It is not clear whether the F-V or P-V relationships of muscle in pre-adolescent children are different from that of adults when expressed per unit muscle size. Many of the scaling techniques used in research to date have been inappropriate for the measurements taken. The overall aim of this study was to examine whether growth related changes in muscle size fully account for the changes in muscle function from childhood to adulthood. There were two objectives. Firstly, to compare the knee extension torque-velocity curves of children and adults with appropriate correction for CSA and length. Secondly, to compare the P-V curves of children and adults with correction of power for lean thigh volume.

Methods

Forty subjects participated in this study. Group 1 consisted of twenty young adults, 11 females of average age 22 –1.45 years and 9 males of average age 22 –1.37 years. Group 2 consisted of 20 year 2 primary school children, 11 females of average age 6 –0.51 years and 9 males of average age 6 –0.47 years. The study had received ethical approval from the University ethics committee and written informed consent was obtained from all adult subjects and from the parents of the children. No participants had any past histories related to the nervous system or muscular dysfunction.

Thigh volume was measured on the subjects’ dominant leg (i.e., preferred kicking leg). Anthropometric measurements comprising of a series of circumference and length measurements were made using a flexible steel tape. Skinfold thicknesses were measured at the anterior and posterior thigh in the midline at the one-third subischial height with a Harpenden fat calliper. The circumference measurement was corrected for skinfold thickness using the methods of Jones and Pearson (11). The lean thigh volume was calculated as the sum of two truncated cones using the method of Katch and Weltman (13). Thigh CSA was calculated from the lean circumference measurements at the one-third subischial height level. While these methods were devised with and for adults, they have been used extensively with children (3, 4).

Isokinetic knee extension torque was determined on a Con-Trex isokinetic dynamometer (CVH AG, Dübendorf, Switzerland Switzerland). Before each test, the dynamometer was calibrated using the manufacturers instructions. All subjects completed a short habituation session and practice with the apparatus. A warm up which included 8 to 10 minutes of intermittent running and jumping activities preceded each test. In accord with the extant literature, the adult subjects undertook an additional warm up (5), which consisted of a 5-minute cycle on a Monarch 814E cycle ergometer (Varberg, Sweden). During the tests, subjects were stabilised at the thigh, pelvis, and trunk with velcro straps. 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 instructed to place their arms across their chest during the testing procedure. All torque measurements were corrected for gravity effect on each subject.

Maximum concentric knee extension torque was measured at nine different velocities (ranging 0.524 to 5.236 rad · s⁻¹). Each maximal effort trial was immediately preceded by a sub-maximal extension-flexion movement. This ensured the muscle contracted maximally throughout the measured concentric knee extension
exercise. The sequence of the velocities was randomised for each subject to negate any possible effect of fatigue on the results. Two minutes rest was given between each effort. Each subject was given the same level of encouragement during trials. The force produced for each contraction was registered continuously as torque on the computer and the contraction that produced the highest peak torque at each test velocity was used for subsequent analysis. To ensure an accurate reading of maximum torque, it was necessary to monitor if the leg extension was performed at a constant velocity when the peak torque value was recorded. This was done by visual inspection of the angle–time graph for the exercise. Trials were rejected if the angle–time graph was non-linear at the instant of peak torque.

Maximal torque values were corrected for thigh CSA. Angular velocity values were corrected by dividing them by thigh length. Power was calculated as the area beneath the F-V curve at each velocity. The power values were then corrected for lean thigh volume.

The mean and standard deviation of uncorrected and corrected torque was plotted against uncorrected and corrected velocity respectively for both children and adults. Comparisons were made between these corrected and uncorrected F-V curves. Statistical analysis of the P-V data was carried out using a general linear model (GLM) multivariate ANOVA with repeated measures in SPSS. The GLM had one within-subjects factor (velocity, with 9 levels) and one between-subjects factor (age, with 2 levels). A probability of $p \leq 0.05$ was chosen as the significance level in all analyses. The dependent variables were: uncorrected and corrected power.

**Results**

The isokinetic measurements for both groups conformed to the classic F-V relationship. Figure 1 shows the uncorrected F-V curves for children and adults. Figure 2 shows the same curves with corrections for lean thigh CSA on torque and length corrections on velocity. Despite these corrections, the differences in the F-V relationship between the children and adults were still obvious.

Figure 3 shows the uncorrected P-V curves for the children and adults. Figure 4 shows the effect of correcting the power measurements for lean thigh volume. The corrected P-V curves for children and adults appear almost identical.

![Figure 1 — Uncorrected F-V curves.](image-url)
Figure 2 — F-V curves corrected for lean thigh CSA and length.

Figure 3 — Uncorrected P-V curves.

Figure 4 — P-V curves corrected for lean thigh volume.
Discussion

The uncorrected torque values of the children were clearly lower than the adults, see figure 1, this is consistent with other studies (1, 6). When simultaneous corrections for both CSA and length where made, the F-V curve of the children remained lower, yet the overall shape curves for the two groups were very similar, see figure 2. It is possible that some further proportional correction would bring the curves even closer together. Whilst the estimates of length and CSA used in this study were reliable, they would not be truly representative of muscle size. It is probable that a more sophisticated and precise measure of muscle size may fully account for the differences observed in the F-V curves.

The uncorrected P-V curves for children and adults (Figure 3) show large differences in power values at all velocities. When these data were corrected for lean thigh volume, the resulting curves appeared almost identical, see Figure 4. The results of the ANOVA confirm that the differences in the P-V curves between children and adults were almost entirely due to differences in volume. This shows that the difference in muscle power between children and adults was almost entirely due to quantitative rather than qualitative changes in the muscle as suggested previously by Fuchimoto and Kaneko (6). This is an important finding as it suggests that the functional ability of the muscle is the same, per unit of muscle volume, for children and adults.

These findings underlie the uniformity of muscle function in children and adults and suggest that the relative force generating capacity may remain unchanged through adolescence and early adulthood. More research is needed on the F-V and P-V relationships, of children and its applications for sport and exercise. A longitudinal study could trace the F-V and P-V relationships through adolescence to examine if power per unit of muscle changes linearly with growth and age.

The maximum power was not determined for the subjects. At the highest velocity the corresponding power values were still rising. The maximum velocity that could be studied using the Con-Trex isokinetic dynamometer was 5.236 rad · s⁻¹ and this is a common limitation of most isokinetic dynamometers. Velocities greater
than 11 rad · s\(^{-1}\) have been reported during all out knee extensions against light levers (19). The inclusion of bone in the lean volume could also influence results if the proportion of bone in the limbs of adults and children is different. Inactive muscle is also included in the lean volumes, but it is likely that this would represent a constant proportion of the total lean volume (3).

Previous studies comparing the F-V and P-V relationships of children and adults have concluded that the muscle of each group was functionally different. This was probably due to the inappropriate scaling techniques used in these studies. The present study used a more specific and appropriate scaling technique and found that muscle volume accounted for the differences between power measurements of children and adults. The results suggest that correction of the P-V relationship for lean thigh volume is entirely appropriate and may be superior to other scaling techniques. Other aspects of muscle function with respect to growth and development need to be reviewed, employing similar corrections where appropriate.

While this study included equal numbers of male and female subjects in each group, it did not examine gender differences in muscle function. Since the differences in muscle volume between males and females of the same age would be relatively small, more sensitive measures of muscle volume would probably be required to make an accurate gender comparison. An implication of this study would be that future studies of gender effects on muscle function should take proper account of differences in local lean muscle volume. This could also be true of any group or treatment comparison that may be subject to an influence of muscle size.

**References**


