The development of muscle function from childhood to adulthood

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The Development of Muscle Function from Childhood to Adulthood.

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Declaration

I declare that this thesis is entirely my own work and has not been submitted in full or part for any other academic award, or to any other academic establishment.

Signed: ____________________________

Ursula Barrett

Date: 20th May 2011

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Abstract

The quality of movement is determined in part by the force velocity relationship of the muscle involved. Conflicting results have been reported in studies comparing this relationship in adults and children due mainly to the variety of scaling techniques employed. These two studies examined the force-velocity and power-velocity relationships of the quadriceps muscles of children and adults using results scaled for local muscle size. Measurements of muscle function were collected using the Con-Trex isokinetic dynamometer. In study one twenty adults and twenty children performed maximal effort knee extensions at nine different velocities. Study two repeated the methodology of study one with three groups of equal gender distribution: children aged 6 years (n=20), 10 years (n=20) and young adults (n=20). Both studies scaled power values for lean thigh volume which was calculated using previously validated anthropometric measurements. The mean force-velocity curves showed a predictable shift upwards in the curves with each ascending age group in both studies. No gender difference was observed in the children's groups but adult males achieved superior scores than female adults. 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 in study one and three groups in study two. When power values were corrected for lean thigh muscle volume, no significant differences were found between the groups in study one however this correction only yielded no differences between six year old boys and girls and 10 year old males. Despite these corrections for muscle size 10 year old females and, male and female adults all exhibited significantly higher power values at all ten velocities. Results in study two also revealed a significant mechanical advantage in the angle of peak torque for females' age 10 years. The findings for study one 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. However the results of study two are not consistent with this assertion. Results of this study suggest that quantitative differences do not entirely account for the differences in the power velocity curves. The question as to whether there are qualitative differences in the muscle of children and adults remains open. Future studies should preferably be longitudinal in nature and examine known covariates while simultaneously using appropriate scaling techniques.

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Chapter 1

Introduction

1.1 Motor Development

Motor Development has been defined as “the progressive change in motor behaviour throughout the life cycle, brought about by interaction among the requirements of the task, the biology of the individual and the conditions of the environment” (Gallahue and Ozmun, 1995, p.3). The changes in motor behaviour indicate learning and an understanding of these learning processes can provide valuable insights that can shape future educational techniques. Motor development is a lifelong process however the majority of research in this field has been on the acquisition of motor skills throughout childhood.

1.2 History of Motor Development Research

The majority of early observational studies were mainly descriptive in nature and provided a great deal of information about the sequential progression of normal development from the acquisition of early rudimentary movements to mature patterns of behaviour. Since 1960 the knowledge base in the study of motor development has grown steadily. Work on the acquisition of mature fundamental movement patterns concentrated on identifying the mechanisms behind the acquisition of skill rather than on the final skill itself. During the 1980s and 1990s the emphasis of study in motor development shifted to understanding the underlying processes involved in motor development. Researchers led by the work of Kugler, Kelso and Turvey (1982), formulated new theoretical frameworks for the control and development of motor behaviour. Since then the work of Thelen and her colleagues (1987, 1991), Clark et al (1988, 1989) and others led to the formulation of a dynamical systems theory of motor development which is guiding much of the research being conducted at the present time.

According to Gallahue and Ozmun (1995) there are 4 main theories of motor development:

Phase - Stage Theories.
Developmental Task Theories.
Developmental Milestone Theories.
Dynamic Systems Theories.

The Phase-Stage Theories proposes that human development is characterised by universal age periods or stages during which certain types of behaviour occur. The stages may follow an ordered sequence but the sequence need not follow a smooth continuous pattern; instead, development may be characterised by a series of abrupt starts and stops. The Phase-Stage Theories are characterised by the idea that human development unfolds logically in an established pattern that is described by discontinuous stage related behaviours.

The Developmental Task Theories maintain that each individual must accomplish certain tasks within a certain time if they are to function effectively and meet the demands placed on them by society. These theories assert that learning is the primary factor involved in development unlike the Phase-Stage Theories that propose maturation as the predominant force driving development. In further contrast to the Phase-Stage Theories, the Developmental Task Theories are predictive of future success or failure. Human development is described as unfolding logically but there can be no deviation from the set pattern, and development may be halted or retarded if a particular task is not accomplished. The notion of critical periods of development is conceptually linked to the developmental task approach.

The Developmental Milestone Theories are similar in many respects to both the Developmental Task and the Phase-Stage Theories. Instead of referring to tasks that the individual must accomplish, certain behaviours are seen as strategic indicators or milestones of development; i.e. when a child can perform certain tasks this indicates that he or she has developed to the level indicated by the milestone behaviour. The accomplishment of developmental milestones may or may not, be crucial to effective functioning in the world. Milestones are merely convenient guidelines by which the rate and extent of development can be gauged. Like the Phase-Stage Theories, Developmental Milestones are descriptive rather than predictive; but unlike Phase-Stage Theories, they view development as a continual unfolding and intertwining of developmental processes rather than a neat transition from one stage to the next.

Although the previous three conceptual frameworks help to describe the products of development by describing behaviour during a particular phase or stage they offer little explanation of why change may, or may not occur. All theories acknowledge that the developmental sequence of change varies from one individual to another but provide minimal explanations for such variation. The Dynamic Systems Theories that are based largely on the work of Bernstein (1967) aim to provide explanatory models in an attempt to understand more about the underlying processes that govern development. Bernstein was the first to define movement in terms of coordination and as a product of not only a developing central nervous system but also biomechanical and energetic properties of the body and environmental support (Thelen 1995). Rather than being one cohesive theory, the dynamic systems perspective has several strands that continue to evolve. Central to this perspective is the idea that motor behaviour arises from co-operation amongst many subsystems within a task specific context. One of the issues addressed by dynamic systems theories is the question of how common complex patterns of behaviour arise out of so many possibilities (degrees of freedom). Transition from one pattern to another is called a phase shift and phase shifts can be retarded or accelerated by factors called rate limiters or affordances.

Recent advances in the study of motor development include not only the shift from description to explanation of the dynamic systems theories but also the emergence of multidisciplinary approaches to gaining insights into the underlying processes limiting or offering affordances to motor development. Many recent reviews have welcomed this approach (Thelen 1995; Van Ingen Schenau 1989) as it offers an opportunity to study the various subsystems that contribute to overall human development.

1.3 Factors influencing motor development

Human development spans the life cycle and spans the cognitive, affective and psychomotor domains. The development of motor skills is influenced in complex ways by a variety of factors. The main influencing factors across time and each of the domains include task factors, environmental factors and individual factors (Gallahue and Ozmun 1995).

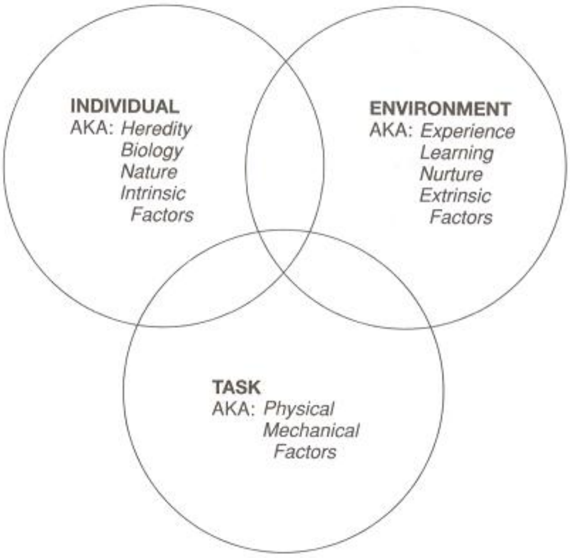


Figure 1.1 Causation in motor development (reprinted from Gallahue and Ozmun 1995)

Figure 2.1 illustrates the concept that the specific demands of a task transact with the individual and the environment. This model implies that factors within the task, the individual and the environment are not only influenced by one another but may also be modified by one another.

One of the important factors in improving motor skills at a certain stage in development is assumed to be the ability to exert necessary force in a precise and timely manner (Asai and Aoki 1996). The combination of strength and speed is exhibited in children's activities that require jumping, striking and throwing for distance etc. (Gallahue and Ozmun 1995). Performances of such tasks may be limited by the muscular strength of the individual or more specifically dynamic muscular strength. Strength measurements are influenced by variables within the task, the environment and the individual and these will be discussed in more detail as part of the literature review in chapter 2.

1.4 Future research in motor development

The development of the human body from infancy through adulthood and into old age has been studied with interest for many centuries by researchers and practitioners in specialist areas including psychology, physiology, neurology, and biomechanics. The research conducted on the developmental aspects of movement behaviour has until recently been more limited in scope and magnitude than that conducted on cognitive and affective processes of development. Since the primary thrust of motor development research has come from the many branches of psychology, it is natural that motor development has frequently been viewed in terms of its potential influences on other areas of behaviour, or a means of studying behaviour rather than a phenomenon worthy of study in its own sake.

While the research on motor development has broadened beyond the psychology field the majority of avenues of exploration into the processes and contributors to motor development tends to be isolated to singular disciplines rather than using the collective strengths and knowledge of each area to look at the overall process of motor development and behaviour. The collective findings have often overlapped in many areas and have added to our overall understanding of motor development. Van Ingen Schenau (1989) highlighted the previously expressed need for both bottom-up studies of isolated component properties and top-down studies at various levels of observation. Future studies in the area of motor development need to explore the possible advantages of cross disciplinary or multifaceted studies that look at both the bottom-up approach as well as the top-down approach to investigation.

One area where a gap in knowledge remains in relation to motor development is how the body and mind combine to learn to master new skills and what neural, biomechanical and physiological limitations to that development exist. Differences in the neuromuscular structure and function of adults and children have been found to include a slower rate of isometric force development and longer electromechanical delay in children; their muscles generate less force and show slower relaxation times; the force and frequency of muscle twitches increases from childhood to adulthood; children have a greater predominance of slow twitch muscle than adults; the threshold stimulus intensity for evoking muscle responses is greater in children and myelination within the brain appears to continue through childhood (Deutsch and Newel 2005). While the aforementioned authors highlighted many physiological functional differences between children and adults they also acknowledged that the failure of many studies to body scale appropriately may have incorrectly led to the conclusion that differences in performance were due to age related differences in neural control (Deutsch and Newel 2005). Harrison and Gaffney (2001) in a study examining changes in the stretch shortening cycle with respect to maturation, highlighted the relative absence of investigation on the maturation of the mechanisms of motor function from the vast body of motor development research. A comparison of relative variables, scaled for body size, revealed that no statistical differences existed between adults and children in the utilisation of the stretch shortening cycle to enhance jumping performance. This finding contrasted with previous conclusions and shows the need to re-examine the maturation of muscle function using appropriate scaling techniques. It appears logical that future studies of motor development must fill the void in understanding of how the mechanisms that control movement develop and mature as this basic understanding is essential to improve any recommendations in the areas of assessment, learning, training and rehabilitation.

Few studies have looked at the contribution of basic physiological systems to the overall acquirement of motor skills. Since the development of ballistic type skills is limited by a variety of physiological factors we need to understand the parallel development of these factors and motor skills. Motor skills are skills associated with muscle activity therefore when studying the development of motor skills the obvious starting point is to examine developments in muscle associated with growth and maturation. This study proposes to look at the subsystem of muscle function using developmental scaling techniques so that the qualitative characteristics of muscle can be examined as a potential limiting factor in developing fundamental movement skills. A skilled movement has been defined as a product of four different elements: force, velocity, accuracy and purposefulness (Kent 2001). Since performance of various ballistic skills may be limited by the force-velocity (F-V) relationship of the muscles, this possible limitation to motor development will be examined across different age groups.

1.5 Aims of study 1

- To compare the F-V relationship of children aged 6 years (the youngest reliable age possible) and young adults.
- To examine the effects of scaling for muscle size on the divergence between the 2 groups.

1.6 Aims of study 2

- To compare the F-V relationship of children aged 6 years (the youngest reliable age possible), 10 year olds (prepubescent) and young adults (post pubescent) using suitable scaling for muscle size.
- To examine gender differences in the F-V relationship of each group.

Chapter 2

Literature Review

2.1 Motor skill development

Various motor skills progressively become part of the motor repertoire during childhood (Gallahue and Ozmun 1995). This progressive change in motor behaviour throughout the life cycle is referred to as motor development. The term ‘motor’ refers to the underlying biological and mechanical factors that influence movement. One of the important factors in improving motor skills at a certain stage in the development is assumed to be the ability to exert necessary force in a precise and timely manner (Asai and Aoki 1996). The combination of strength and speed is exhibited in children’s activities that require jumping, striking, and throwing for distance etc. (Gallahue and Ozmun, 1995). Performances of such tasks may be limited by the force-velocity relationship of the muscles (Kreighbaum and Barthels, 1996). Multidisciplinary approaches are affording new insights into the processes by which children learn to control their bodies and the limiting factors to that learning and development. Advances in the disciplines of biomechanics and physiology allow the subsystem of muscle contractile properties to be examined in isolation so that’s its influence on motor development can be explored. The following sections review the research on the underlying mechanics of muscular strength and the factors responsible for improvements in muscular contraction from childhood to adulthood.

2. 2 The mechanics of muscular strength

Muscle fibres, the cells of skeletal muscles, have but one function: to generate force. They are large single cells filled by cylindrical contractile organelles, the myofibrils. These myofibrils are built on a series of sarcomeres, the contractile units, which consist of overlapping protein filaments, actin and myosin (Noth 1996). The sarcomeres contract by sliding the thick and thin filaments against each other through interdigitating cross-bridges. This process is triggered by electrical impulses from neurological innervation of the muscle. The electrical depolarisation of the muscle fibre frees calcium ions, which are responsible for initiating contraction of the myofibrils. The result of this entire process is the production of muscle tension, expressed as strength (Rowland 1996). During the production of tension, the whole muscle can shorten (concentric contraction), lengthen (eccentric contraction) or remain unchanged (isometric contraction). These different types of contraction vary in their ability to produce strength.

A large number of variables influence the development of tension in the muscle. These include age, gender, the force-velocity relationship, muscle size, neural, temperature, muscle fibre type and composition, measurement of torque, joint leverage, joint angle and connective tissue. Each of these variables will be discussed in detail in the following sections.

2.2.1 Age

The picture of evolution of strength during childhood is, in general, remarkably consistent: substantial improvements are made throughout childhood. These improvements are shown in figure 2.1, which show grip strength improvements with age.

Only a few studies have provided information on changes in strength as measured by isokinetic dynamometry across a broad range of pediatric years. These show the same improvements in force generation with age. The factors influencing inter-subject variability in strength gains however, remain unresolved. Malina and Bouchard (cited in Rowland 1996) suggested that changes in both size and function of the muscle contribute to the process of biological maturation, which culminates in the mature adult state, but the exact contribution of each is still unclear and is being much debated in current research in the field.

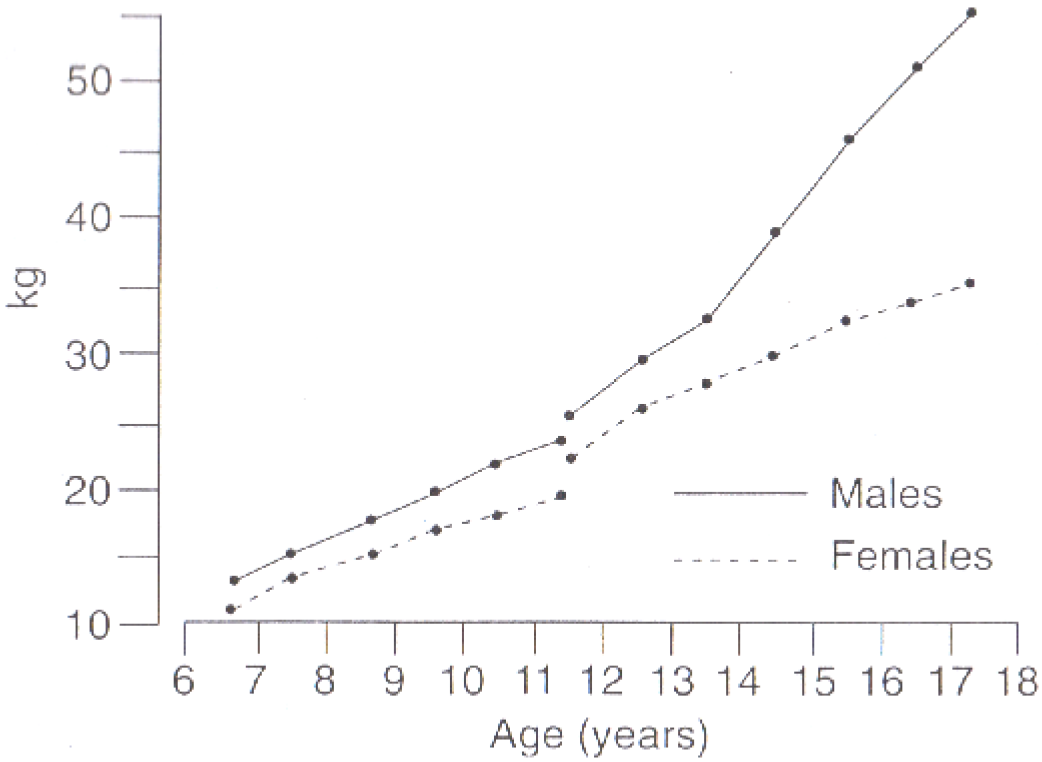


Figure 2.1 Handgrip strength in boys and girls. (Reprinted from Rowland 1996).

Limited research suggests that maturational differences in muscle contractile properties do not exist in humans, at least in older children. Davies, C.T.M., et al, (1983), compared the contractile properties of the triceps surae muscle of children aged 11-14 years and young adult subjects. No age related differences were observed in muscle force generating capacity (per CSA), fatigability, or speed of contraction and relaxation. Similar results were found by Belanger and McComas (1989) for boys aged 6-18 years. These findings imply that muscle fibre composition and function are consistent during mid-to-late childhood through adult years. That is, changes in muscle strength as children grow do not appear to be explained by developmental alterations in the contractile mechanism.

2.2.2 Gender

Figure 2.2 shows differences between the strength improvements of males and females. In general little difference has been found between the sexes below age 6 after which males tend to gain more strength than their female counterparts. This divergence becomes more obvious during puberty. During adolescence when the strength curve deviates upward in males, the curve for females either continues to rise in a linear fashion or in some studies, actually plateaus, showing no improvement throughout adolescence (Beunen and Thomis 2000).

The majority of studies have shown the trend for males to be stronger than females, however the reasons for these differences remain unexplained. It has been suggested that sex differences in strength might relate to the size advantage in boys as sex differences in lower body strength have been found to be negligible when controlled for body size (Beunen and Thomis 2000). Many studies have made allowances for the differences in body size (Seger and Thorstensson 1994; De Ste Croix et al 1999; Pääsuke et al 2001) however only a few have made allowances for the well documented increase in females body fat/muscle mass ratio as they move from the early teen years into adulthood. Studies comparing strength in males and females at different ages that have corrected for lean muscle volume have found less of a difference between the genders in particular at the younger ages (Davies, C.T.M. et al 1984; Davies, B.N. et al 1988; Davies, B.N. 1990). These results support the authors' conclusion that differences in strength between boys and girls are related to differences in body composition and hormonal stimulation rather than to gender-related influences on the contractile properties.

It is possible that differences in hormone levels between males and females may contribute to observed strength differences. The divergence of testosterone levels in males and females from the onset of puberty is well documented. Testosterone is thought to not only influence muscle growth but also affect the various cellular mechanisms and enhance the development of the muscles protein contractile unit thereby providing for improved force production. Testosterone may also play a role in influencing neural factors and the possible muscle fibre transition of type II fibres to more glycolytic profiles (Kraemer 1996).

There remains a need to examine the differences between males and females under isokinetic conditions taking account for body composition and hormone level differences to understand more about the influence of each to the generation of force by the muscle.

2.2.3 Force-velocity relationship

There exists a given relationship between active force and velocity of shortening known more commonly as the force-velocity (F-V) relationship. This relationship as illustrated in figure 2.2 is characterised by a decrease in maximum force development as the velocity increases during concentric contractions, (Fenn and Marsh 1935; Hill 1938; Wilkie 1950; Gulch 1994). At zero velocity the maximum amount of force that can be developed, without lengthening, occurs (Edman 1992). During eccentric contractions, force increases further with lengthening velocity (Gulch 1994).

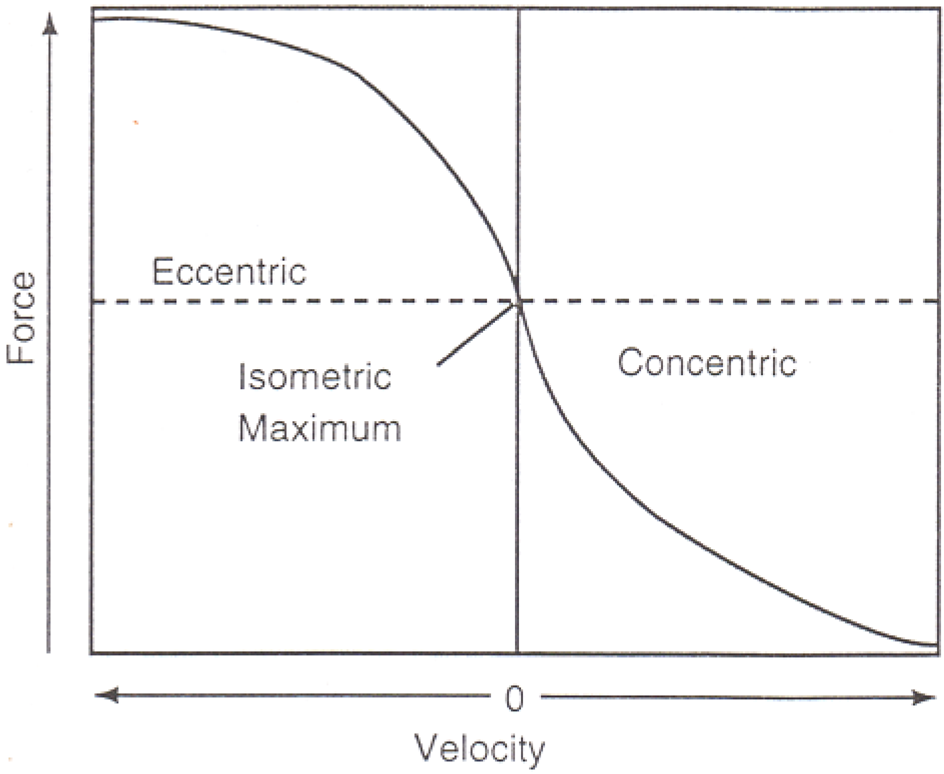


Figure 2.2 The classic force-velocity curve (Reprinted from Hill 1938)

During concentric contractions the F-V relationship has a hyperbolic shape which is described by the formula:

$(P + a)(V + b) = (Po + a)b = \text{constant}$

Where P = force of contraction, V = velocity of shortening, *a* and *b* are constants, and Po is the force exerted at zero speed (Hill 1938).

This equation, while based on heat measurements, was found to be consistent with the cross-bridge mechanism, (Huxley 1957 cited in Gulch 1994) and has been accepted and verified by research to date, (e.g. Wilkie 1950; Fuchimoto and Kaneko 1981; Asai and Aoki 1996). The characteristic Hill equation, clearly indicates that the constants *a* and *b* define the relationship between force and velocity.

The quantity *a* depends on the size, in particular on the cross-section, of the muscle, (Hill 1938). The value *a* also depends on the strength of the contraction. The simplest measure of the strength of contraction is Po, the full isometric tension. Hill (1938) expected the ratio of *a*/Po to be constant, and in the 11 experiments that he reviewed, the variation from the mean value of *a*/Po was only 10%. Hill further hypothesized that this variation was representative of experimental error. Fuchimoto and Kaneko (1981) found the ratios of *a*/Po to be almost constant regardless of age, whereas Asai and Aoki (1996) found significant differences in this ratio between 6 year old children and adults. Hill (1938) established that the ratio *a*/Po remained "nearly constant" at different temperatures. Both *a* and Po increased with elevated temperatures, but at the same rate. The constant *b* is of the dimensions of a velocity and when due account is taken of the dimensions of the muscle, is very constant at a given temperature (Hill 1938). Hill also stated that *b* should be proportional to the length *l* of the muscle. Based on his review of 11 studies, Hill (1938) concluded that *b*/*l* was "nearly constant" from one muscle to another at a given temperature.

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. 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.

2.2.4 Muscle size

In children, the gender related growth curve patterns for body muscle are virtually identical to those for strength (see figures 2.1 and 2.3). It is logical to assume, therefore, that the significant increases in muscle bulk accompanying growth in children would largely if not fully, explain parallel increases in their muscular strength. Blimkie (1989 cited in Rowland 1996) concluded that it was likely that quantitative differences in muscle width account for a large portion of the observed age and gender differences in strength development during childhood and adolescence. In a review of literature relating to muscular strength development in children and adolescents Beunen and Thomis (2000) found that associations between strength and body size/muscle mass, to vary between 0.3 and 0.6.

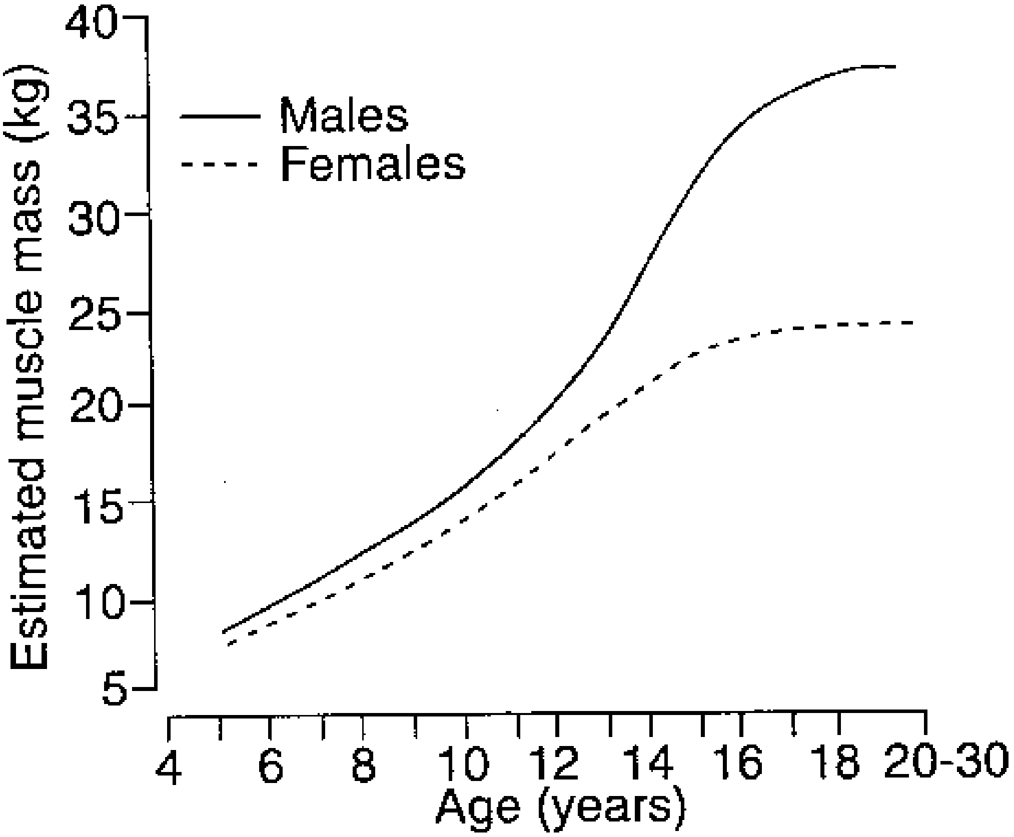


Figure 2.3 Muscle mass relative to age in boys and girls. (Reprinted from Rowland 1996).

The increase in muscle bulk may not be solely responsible for the observed increases in strength. Studies have used a variety of scaling techniques to negate the influence of muscle size differences when examining muscle function characteristics. Ratio standards, such as strength per kg body mass, and corrections for body height squared, have been used extensively (Sunnergardh et al 1988; Seger and Thorstensson 1994; Housh et al 1995; De St Croix, et al 1999). These studies have generally found that strength improvements during childhood are too fast to be explained by increases in body mass or height squared and that there is wide variability in the relationship of strength and body mass or height for different muscle groups. These dimensional analyses are predicated on geometric similarity and constancy across the ages studied, an assumption which has been labelled as questionable, (Blimkie 1989, cited in Rowland 1996). Longitudinal data on muscle strength and muscle mass indicated that strength velocity occurred 0.4yrs later than peak muscle mass velocity, (Rasmussen et al 1990). According to the authors, this observation supports the view that muscle tissue increases first in mass, then in functional strength. The authors assumed this to suggest a qualitative change in muscle tissue as adolescence progresses and/or perhaps a neuromuscular maturation affecting the volitional demonstration of strength. This proposal appears impetuous as it is based on small discrepancies between peak muscle mass velocity and peak strength velocity. Furthermore, muscle mass was estimated via a five-component fractionation of body tissues utilizing standard anthropometric measurements and muscle strength was evaluated with a cable tensiometer. The accuracy of these measurements is questionable, and could well account for the small variation in the velocities, on which the proposal is based. Allometric scaling of strength accommodates the non-linear but proportional changes with body mass by using non-linear regression. However because measures of strength are specific to a localised muscle group, using entire body measurements to control for the 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 preferable therefore to correct for the size of the specific muscle group involved rather than some covariate based on whole body size.

A number of studies have implemented single correction on torque or velocity for local muscle group CSA or length respectively. Correlations between isometric strength and muscle CSA range from moderate to high (r = 0.6-0.9) the latter being more common in studies across wider age ranges (Rowland 1996). Fuchimoto and Kaneko (1981), and Asai and Aoki (1996), investigated the influence of muscle length on the F-V relationship. While a correction for muscle length did much to bring the F-V relationships of adult and children closer to each other, the differences in loads were still great between the two groups ($p<0.001$). This finding suggests that the improvement in velocity at any load could not merely be due to the growth of muscle length.

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 and 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. One such study conducted by Doré and colleagues (2000) found that lean leg volume accounted for 88.2% of the variance in short-term cycling power between the ages of 7 and 18 years. Davies, B.N. (1990) attempted to determine the influence of lean arm volume on hand grip strength, and found that in children there is no difference in muscle performance when differences in muscle mass are accounted for. These results would suggest that differences in force measurements between individuals may be entirely as a result of quantitative differences within the muscle. The use of handgrip strength as a measurement of muscle performance is questionable, as measures depend on the size of the grip. Consequently, there is a need for a study that explores the influence of lean segmental volume on valid measurements of maximum force. Studies using superior testing equipment that examine the F-V curve and scale for lean muscle volume of the specific muscle group are needed to provide a clearer understanding of the magnitude of effect that quantitative changes in the muscle have on force measurements.

2.2.5 Neural

Dynamic movements have complex neural demands that involve control and coordination through the higher brain centres, specifically:

- The primary motor cortex
- The basal ganglia and
- The cerebellum

The cerebellum is crucial to the control of all rapid and complex muscular activities. It helps coordinate the timing and of motor activities and the rapid progression from one movement to the next by monitoring and making corrective adjustments in the motor activities that are elicited by other parts of the brain. The cerebellum assists the functions of both the primary motor cortex and the basal ganglia. It facilitates movement that would otherwise be jerky and uncontrolled. The cerebellum acts as the integration system, comparing intended activity with the actual changes occurring in the body, and then initiating corrective adjustments through the motor system.

Specific learned motor patterns appear to be stored in the brain, to be replayed on request. These memorised motor patterns are referred to as motor programmes or engrams. They are stored in the sensory and motor parts of the brain. Little is know about engrams and the mechanisms for their action (Wilmore and Costill 1994).

When an engram is selected the brain has made a conscious decision to initiate and carry out an action. A nerve impulse carrying this message travels through the motor unit along a series of neurons until it reaches the neuromuscular junction. Here the message is received by the receptors on the sarcolemma, invades the muscle fibre via the transverse tubules releasing calcium which induces the sliding of the myofilaments and causes the muscle action.

Neural factors often influence torque-velocity recordings in an unpredictable manner, (Gulch 1994) and it has been hypothesised that neuromuscular factors contribute to the age effect for strength increases during childhood and adolescence (Housh et al 1997). In particular the myelination of motor nerves is thought not to be complete until sexual maturity and may therefore limit the force generating capacity of the motor system (Wilmore and Costill 1994).

Dudley et al (1990) compared the effect of voluntary versus artificial electrical activation in a comparative study of the relation of muscle torque to speed. The results of this study, according to the authors, indicated that with artificial activation the normal speed-torque relationship of the knee extensors in situ is remarkably similar to that of isolated muscle. The relationship for voluntary activation, in contrast, suggested that the ability of the central nervous system to activate the knee extensors during maximal efforts depends on the speed and type of muscle action performed. An effect repeatedly reported is that the relationships differ from Hill’s ideal F-V curve in a very characteristic manner (Froese and Housten 1985), particularly in the range of smaller velocities, which obviously is due to the interaction of the central nervous system and the muscular periphery. Davies, C. T. M et al (1983) applied supra-maximal electrical stimulation techniques to children aged 11 and 14. The authors stated that the major problem with this study was the discomfort associated with the electrical stimulation. Obviously repeating this procedure on children would give rise to major ethical issues. It is therefore necessary to rely on the reports that by age 6 the CNS is able to activate the major muscles fully (Belanger and McComas 1989) and that children of this age should be able to produce a maximum voluntary contraction under instruction, (Blimkie 1989 cited in Asai and Aoki 1996).

Enoka (1988) found that strength gains in adults can be achieved without structural changes in muscle, but not without neural adaptations. Thus strength is not solely a property of the muscle, rather it is a property of the motor system. Motor unit recruitment is quite important to strength gains – and may explain most strength gains that occur in the absence of hypertrophy.

Training status and type may also influence the motor system’s impact on the force producing capacity of the muscle. Trained subjects have a greater ability to recruit high threshold motor units and the specific velocities of training yield greater forces when tested at those same velocities (Sale 1996). Various possible neural adaptations to strength training have been suggested including: Increased activation of agonists; selective recruitment of motor units within agonists; selective activation of agonists within a muscle group and co-contraction of antagonists (Sale 1996). While some research on neural adaptations due to strength training in adults exists, adaptations due to other training types or across different age groups is scant and requires further examination.

2.2.6 Temperature

The mechanical performance of muscle is greatly influenced by temperature. Maximal force generation in vivo is, however, almost independent of muscle temperature over a range of 25-40°C, (Binkhorst et al 1977). Whether age-related differences in temperature regulation with exercise might alter muscle contraction capacities is unknown, (Rowland 1996).

2.2.7 Muscle fibre type and composition

There is a trend for relative peak torque and peak power to be determined by percentage of fast twitch fibres (%FT). Positive correlations have been shown between the percentage of fast-twitch fibres at both angle-specific, (Yates 1981), and peak torque measures, (Ivy et al 1981). However this has not been observed in all studies. It is likely, however, that these earlier studies are invalid, since they failed to correct peak torque values for gravity or impact artifact. Significant errors, ranging from 25 - 43% in extension, can occur in the absence of these corrections, (Winter et al 1981).

Housten et al (1988) applying the recommendations by Winter (1981), reconsidered the relationship between knee extension torque and muscle fibre type. No significant correlations were found between the %FT and corrected peak torque values for any of the velocities tested or the knee angles where corrected peak torques were measured. Housten further reported that there were no significant differences between the male and female subjects for %FT or the %FTA, (percentage of relative fast twitch fibre area), but the CSA of both FT and ST (slow twitch) fibres were smaller in female compared to male subjects. Housten concluded that, “the greater ability of male subjects to produce torque at various angular velocities is most likely due to the larger muscle CSA for males” (p. 5). The force developed in a maximal static action appears to be independent of the fibre type, but related to cross-sectional diameter. Since ST fibres tend to have smaller diameters than FT fibres, a high percentage of FT fibres is believed to be associated with a larger muscle diameter, (Billeter and Hoppeler 1996). Therefore, a higher %FT may correlate to greater CSA which might help to account for the findings of some studies. As discussed above, CSA may not correlate to force production between subjects where the muscle length varies significantly, therefore muscle volume is a superior measurement.

In the previously mentioned study by Ivy et al. (1981), the fat free thigh volumes of the subjects were measured but no further use was made of this data during result analysis. However, using the mean volumes reported for each subject group to normalise the peak torque values a significant relationship between the force at any given velocity for FT and ST fibres appears evident. This finding would further support the notion explored in the last section – that increases in muscular strength may be entirely due to quantitative changes within the muscle. However, as mentioned earlier, the validity of this particular study is questionable, and there is a need for superior measures of both muscle force production and muscle size if a conclusion is to be formed.

2.2.8 Fibre arrangement

Muscle architecture in the form of fibre arrangement also influences the force that a muscle can produce. There are two main types of fibre patterns, fusiform and penniform. Fusiform muscles are characterised by long fibres that run parallel to the line of pull. Penniform muscles have short fibres that run diagonally to the line of pull. Figure 2.4 below presents schematic drawings of the main pattern types.

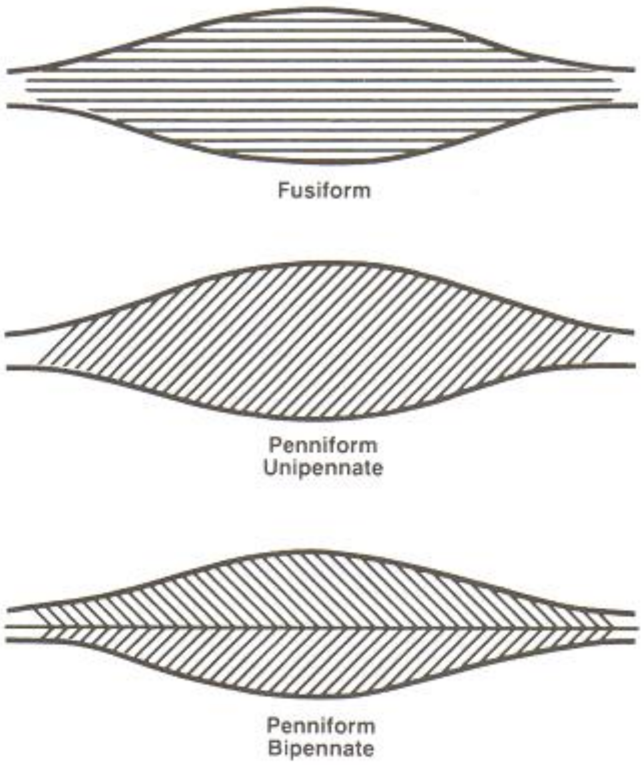


Figure 2.4 Main fibre pattern arrangements found in human muscle. (Reprinted from Westcott 1995).

The architectural design of the muscle can have significant impact on functional properties of force, velocity and power. One consequence of fibre pennation within a muscle of a given volume is that it allows for more sacromeres to be arranged in parallel at the expense of sarcomeres arranged in series and thus enhances the maximum peak force producing capabilities of the muscle (Roy and Edgerton 1996). Rutherford and Jones (1992) found significant positive correlation between fibre angle and muscle CSA using ultrasound scanning on the vastus lateralis and vastus intermedius. This would indicate that scaling for CSA may also negate pennation angle influences however this requires further investigation.

It appears that only one study has investigated whether there are any age related changes in angle of pennation in human muscle. Binzoni et al (2001) found that the angle of pennation increases monotonically from birth and reaches stable values after adolescent growth. While mean values were not detailed in the article the scatter plot graph did indicate that the most dramatic increases in angle occurred in the first 5 years of life with significant rises observable up to the age of approximately 10 years. The authors concluded that their findings might explain in part the low values of muscle power observed in children compared with adults. This study also found that the angle of pennation was linearly related to muscle thickness. Scaling for muscle size might therefore also reduce or negate the influence of angle of pennation on force production values when comparing children to adults.

2.2.9 Measurement of torque

Torque, is the angular equivalent of linear force. Algebraically, torque is the product of force and the perpendicular distance from the force's line of action to the axis of rotation. Thus, an increase in the magnitude of either parameter results in an increase in the acting torque. Muscles are not torque generators, they develop forces that act on the segments to which they attach, (Zajac 1993), creating torque at the joint.

Because directly measuring the forces produced by muscles during the execution of most movement skills is not practical, measurements of resultant joint torques are often studied to investigate the patterns of muscle contributions. However, the predicted values for muscle forces based on calculated values of the joint resultants are at best simply estimates of the forces that are actually present in vivo, (Andrews 1982). The general consensus among researchers appears to be that since there is no generally applicable, direct experimental method to be used to determine the force exerted by the muscle, resultant joint torques are to be attributable solely to muscular activity. This assumption ignores as negligible the "local" moment effects in the muscle force modelling process, (Andrews 1982).

2.2.10 Joint leverage

When muscles develop tension, pulling on bones to support or move the resistance created by the weight of an added load, the muscle and bone are functioning mechanically as a lever. Most muscle-bone lever systems of the human body are of the 3rd class for concentric contractions. The muscle supplies the applied force and attaches to the bone at a short distance from the joint centre compared to the distance at which the resistance supplied by the weight of the body segment or that of a more distal body segment acts (figure 2.5).

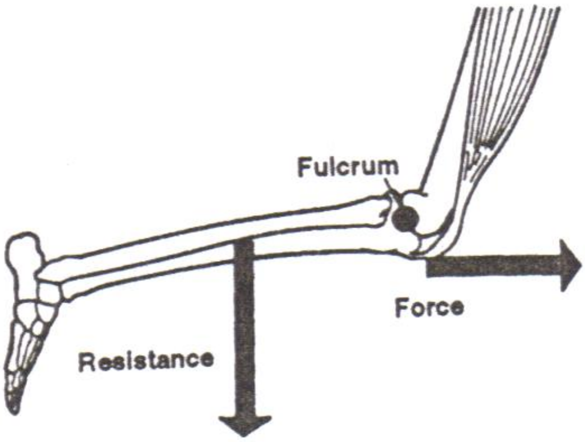


Figure 2.5 and example of a third class lever within the body

The mechanical effectiveness of a lever for moving a resistance may be expressed quantitatively as its mechanical advantage, which is the ratio of the moment arm of the force to the moment arm of the resistance.

$$mechanical\ advantage = \frac{motive\ force\ arm}{resistive\ force\ arm}$$

Whenever the moment arm of the force is longer that the moment arm of the resistance, the mechanical advantage reduces to a number that is greater than one, and the magnitude of the applied force required to move a resistance is less than the magnitude of the resistance. When the mechanical advantage is less than one, a force that is larger than the resistance must be applied to cause motion of the lever. All muscles of the body are at a mechanical disadvantage i.e. they must exert a much greater force than the resistance they are manipulating. The reason for this lies in the fact that muscle's lines of action run very close to the axes of rotation for the joint movements. Consequently, muscles do not have very large force arms, and thus they have a smaller torque producing capability than the resistive forces (Kreighbaum and Barthels 1996). The origin and insertion of each muscle defines the angle of pull of the tendon on the bone and therefore the mechanical leverage it has at the joint centre. This moment arm length changes with joint angle (Winter et al 1981).

2.2.11 Joint angle

The angle at which the muscle pulls on the bone also affects the mechanical effectiveness of the muscle-bone lever system. The angle of maximum mechanical advantage for any muscle is the angle at which the most rotary force can be produced, (Hall 1995). As joint angle changes, the length of the muscle also changes. These changes affect the amount of tension a muscle can generate. As joint angle and mechanical advantage change, muscle length also changes. As discussed earlier, such changes affect the amount of tension a muscle can generate. Marginson and Eston (2001) found that the relationship between torque and joint angle appeared to be affected by age and suggested a mechanical advantage for adults. This study measured isometric torque of the quadriceps at various angles in boys (aged 8-10 years) and men (aged 20-26 years). Further studies using isokinetic measurements would reveal a clearer picture of differences if any in the angle of peak torque between adults and children.

2.2.12 Muscle-tendon Complex

Little research has been conducted on growth changes in the elastic properties of the muscle tendon complex and any possible impact on torque generation in humans. One study by Kubo and colleagues (2001) examined the tendons of boys and young adults and found that the tendon structure were more compliant in younger boys (mean age 10.8 years) than older boys (mean age 14.8 years) and young adult males (mean age 24.7 years). Since the elastic properties of tendon structures influence the transmission force exerted by the muscle fibres this could have implications for any comparison of torques between children and adults.

2.3 Conclusions

It is evident form the above literature review that the classic force-velocity relationship should exist in children's muscles as well as adults. Little work has been carried out on children with regard to the contractile properties of their muscle, as described by the force-velocity relationship, despite the fact that they should have the ability to execute the motor patterns and maximal contractions necessary to measure the relationship. The above literature review also suggests that perhaps the most significant factor affecting the force-velocity relationship may be the size of the muscle.

Chapter 3

Methodology

The methodology for measurements, data collection and initial data manipulation adopted in studies one and two in this document were identical for anthropometric and isokinetic data. The details of each are outlined in this chapter and then summarised and added to separately for each study in the subsequent chapters.

3.1 Subject selection

Convenience sampling was employed in both studies. Adults were selected from the Sports Science Department of the University of Limerick and all participated in regular exercise. The children's groups were sourced from a local primary school. The children were all members of a class group selected on the basis of mean age. The youngest group in both studies comprised of subjects of approximately 6 years of age. It is believed that at this age children, are capable of activating major muscles fully (Belanger and McComas 1989), can perform the simple movement pattern of knee extension (Gallahue and Ozmun, 1995) and are able to produce a maximum voluntary contraction under instruction (Blimkie, C. J. 1989 cited in Asai and Aoki 1996).

Written informed consent was obtained from all subjects and the parents of the children. All subjects reported to be free of any nervous system or muscular dysfunction (see appendix A).

3.2 Anthropometric Analysis

Lean limb volume of the thigh was measured for each subject on the leg being assessed. A series of circumference and length measurements were recorded using a flexible steel metric tape from which the segment volume was calculated as the sum of two truncated cones (figure 3.1). The circumference sites were at the gluteal furrow, one third of the subischial height up from the tibial-femerol joint space and maximum circumference around the knee joint space, (Katch and Weltman 1975). The heights between the adjacent circumference sites were also measured.

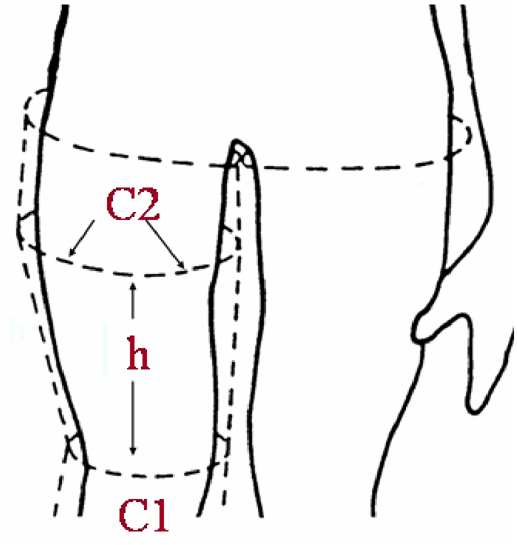


Figure 3.1: Sites of circumference and height measurements for calculation of segmental volumes

Skinfold thickness was measured at two sites – the anterior and posterior thigh in the midline at the one-third subischial height level - with a Harpenden fat Calliper. Because the callipers pick up a double layer of skinfold tissue (figure 3.2) under pressure of 10g/mm^2 the reading is converted to a true single measurement using a regression equation applicable to each sex (Jones and Pearson 1969). This equation is based on comparisons between x-ray fat and calliper fat using a linear relationship which has been found to exist between the two, (Jones and Pearson 1969).

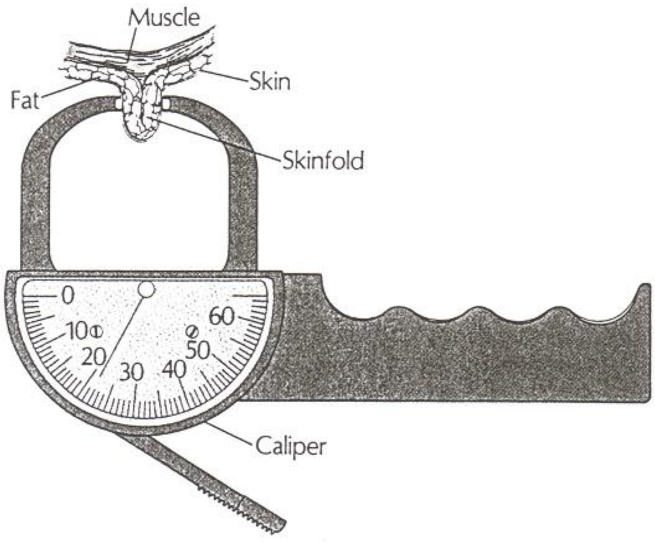


Figure 3.2: Measurement of skinfold

The lean thigh circumference (C) at the third subischial height was calculated by manipulating the formula C = 2πr to subtract the skinfold measurements from the radius (r). The adjusted circumference measurements were then inputted into the formula for the volume of a truncated cone:

$h/12\pi(C1^2 + C2^2 + (C1*C2))$

where C1 and C2 are the circumferences at the top and bottom of the truncated cone and h is the vertical distance between C1 and C2.

The sum of the two truncated cones yielded the measurement for the lean limb volume of the thigh.

3.3 Test procedure

Torque production during concentric contraction of the right quadriceps muscle group was determined during leg extension on a Con-Trex isokinetic dynamometer (CVH AG, Dübendorf, Switzerland). Leg extension was chosen as the movement to be studied as it meets the criteria set out by Wilkie in 1950:

1. The joint should be geometrically simple

2. The movement should involve few muscles, which should have small origins and insertions
3. The movement should not disturb rigid fixation of the rest of the body, and should lend itself to graphic registration
4. The movement should be accurately reproducible. This is easiest to achieve if only a slight skill is involved.

Also knee extension is a simple movement that children by the age of 6 years should be able to perform (Gallahue and Ozmun 1995).

Before each test, the dynamometer was calibrated using the manufacturer’s instructions. 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 3cm proximal to the medial malleolus. Subjects were asked to relax the leg while the gravity affect torque was recorded.

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 (De Ste Croix et al, 1999), which consisted of a 5 minute cycle on a Monarch 814E cycle ergometer (Varberg, Sweden).

Subjects were instructed to cross their arms during the testing procedure. Verbal instruction and encouragement was kept consistent for each attempt and each subject. Instruction was to kick the lever arm up as hard and as fast as possible for 3 attempts. Continuous torque measurements were recorded at nine different velocities (0.524, 1.047, 1.571, 2.094, 2.618, 3.142, 3.665, 4.189 and 5.236 rad.s^{-1}) and the maximum of the three peak torques for each velocity was used for the analysis. The sequence testing at these velocities was randomised to negate any possible effect of fatigue on the results. Two minutes rest was given between trials. Peak torque was corrected for gravity by the Con-Trex software.

The angles of the continuous torque measurements were recorded and in particular the angle of peak torque at each attempt was highlighted for further investigation. The anatomical zero reference point for measurement of angle was set as the point at which the lever arm was perpendicular to the floor. To ensure an accurate reading of maximum torque it was necessary to monitor if the leg was at a constant velocity when the peak torque was measured. Figures 3.3a and b show the acceptable and non-acceptable measurements respectively based on the graphic output of the Con-Trex.

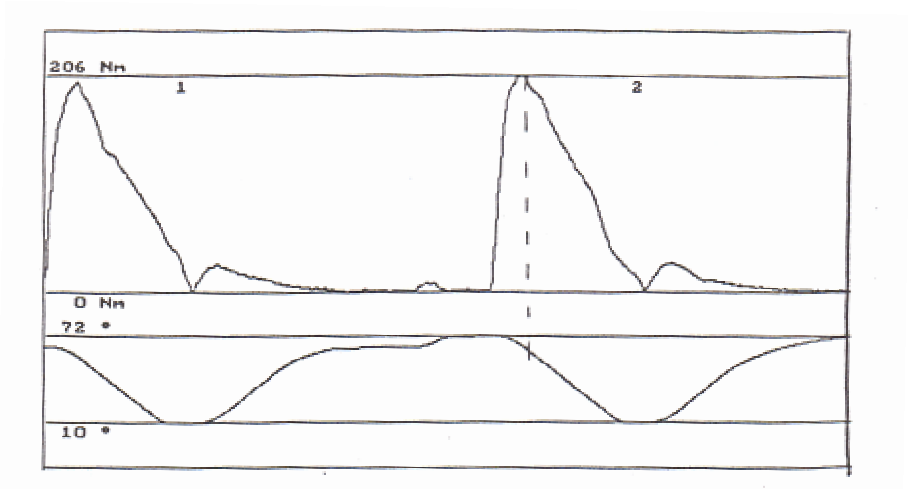


Figure 3.3a: Acceptable peak torque measurement: angle time graph (lower) shows constant velocity trend.

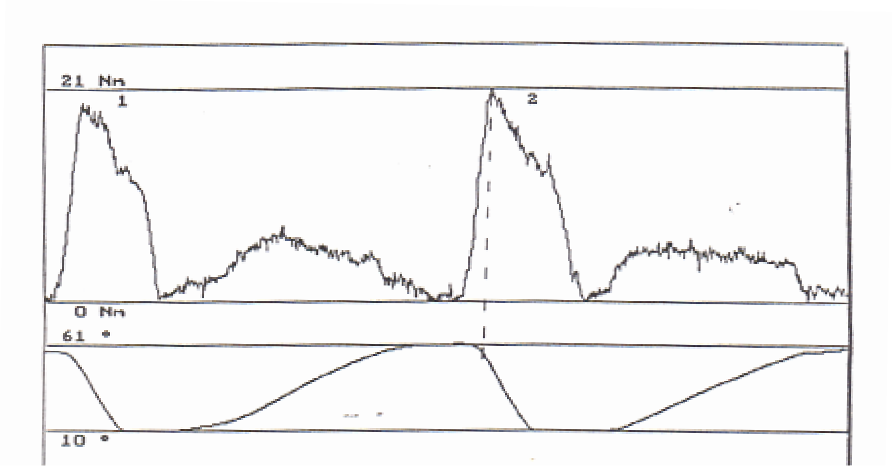


Figure 3.3b Unacceptable peak torque measurement angle time graph (lower) does not show a constant velocity tre

Room temperature was kept constant for each subject, in an attempt to negate the impact of muscle temperature on contraction properties.

3.4 Data Collection and Initial Analysis

Power was calculated as the area beneath the force-velocity curve at each velocity. These values were then corrected for lean limb volume of the thigh as calculated by anthropometric measurements. In order to assess the differences in power values between groups, a general linear model multivariate ANOVA (repeated measures) in SPSS © was used to analyse variability. A probability of $p \leq 0.05$ was used as the significance level in all analyses.

Chapter 4

Study 1

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

4.1 Abstract

The force-velocity relationship of muscle has been well documented in adults. However research on this relationship in children using appropriate scaling techniques is limited. 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.

4.2 Introduction

Performance of many locomotor and ballistic skills may be limited by the force-velocity (F-V) relationship of the muscles (Kreighbaum and Barthels 1996). In an isolated muscle contraction, the F-V relationship can be described by the Hill equation:

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

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 (Hill

1938). 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 (Asai and Aoki 1996). This is not surprising considering the significant increases in muscle size accompanying growth in children. Numerous studies have focused on measuring isometric and isokinetic strength and the increases in both associated with growth and maturation are well documented (Davies, C.T.M., et al 1983; Belanger and McComas 1989 and De Ste Croix, et al 1999). 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 (Sunnegardh et al 1988; Seger and Thorstensson 1994; Housh et al 1995 and De St Croix et al 1999). Corrections for whole body dimensions are controversial since they are based on an assumption of geometric similarities being retained from childhood to adulthood. It has been suggested that this may lead to false correlations and incorrect conclusions (Welsman and Armstrong 2000). Evidence suggests that as children grow, their leg volume increases in a greater proportion to their body mass (Nevill 1994). 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 (Nevill 1994). 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 (Davies, C.T.M. et al, 1983; Belanger and McComas 1989; Pääsuke et al 2001), or velocity for length (Fuchimoto and Kaneko 1981; Asai and Aoki 1996). 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. 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 x muscle length (Kanehisa et al 1995) and limited research has found the isometric force of a muscle to be directly proportional to lean limb volume (Davies, B. N. 1990). 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 suitable 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, this study selected the youngest children (age 6) reported to be able to perform maximum voluntary knee extension under instruction (Belanger and McComas 1989; Jones and Round 1990 and Gallahue and Ozmun 1995).

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 volume as 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:

1. To compare the knee extension torque-velocity curves of children and adults with appropriate correction for CSA and length;
2. To compare the power-velocity relationship of children and adults with correction of power for lean thigh volume.

Angle of peak torque will also be examined to see if this factor offers a mechanical advantage to adults as was found by Marginson and Eston (2001) under isometric conditions.

4.3 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 received ethical approval from the University of Limerick ethics committee and written informed consent was obtained from all adult subjects and from the children and their parents. No participants reported 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 (1969). The lean thigh volume was calculated as the sum of two truncated cones using the method of Katch and Weltman (1975). 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 (Davies, B.N. 1990; Davies, C.T.M. et al 1983).

Isokinetic knee extension torque was determined on a Con-Trex isokinetic dynamometer. 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 (De Ste Croix et al, 1999), 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 $\mathrm{rad} \cdot \mathrm{s}^{-1}$). 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.

4.4 Results

The physical characteristics of the subjects are shown in table 4.1. The anthropometric measurements show that the adults have a larger lean thigh volume than the children. The circumference measurement is taken as the corrected (for skinfold measurements) value taken at the one third subischial height level. The length measurement is the vertical distance between the gluteal furrow and the maximum circumference around the knee joint space.

	Children		Adults	
	Mean	SD	Mean	SD
Age (years)	6.1	0.51	21.75	1.62
Circumference (cm)	22.3	3.67	46.85	3.66
Length (cm)	21.3	3.34	31.15	3.1
Volume (cm^3)	558.42	216.2	5053.93	750.43

Table 4.1 Physical Characteristics of the subjects.

Figure 4.1 displays the angle of peak torque at each velocity for both groups. The adult group attained peak torque at notably greater angles than the children's group.

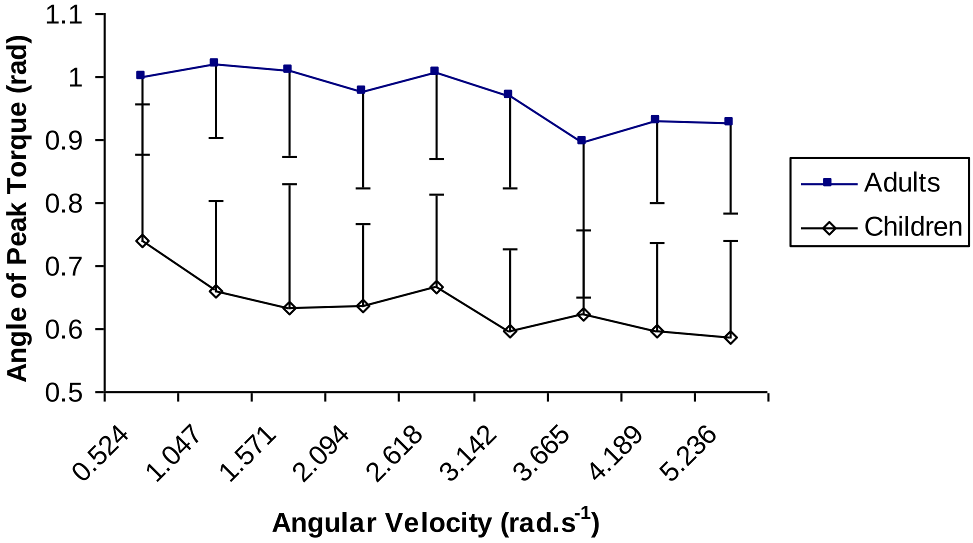


Figure 4.1 Angle of Peak Torque

Figure 4.2 shows the uncorrected F-V curves for children and adults. Both groups conformed to the classic F-V relationship. Figure 4.3 shows the same curves with corrections for lean thigh CSA on torque and length corrections on velocity. Despite these corrections, the differences in the FV relationship between the children and adults were still obvious.

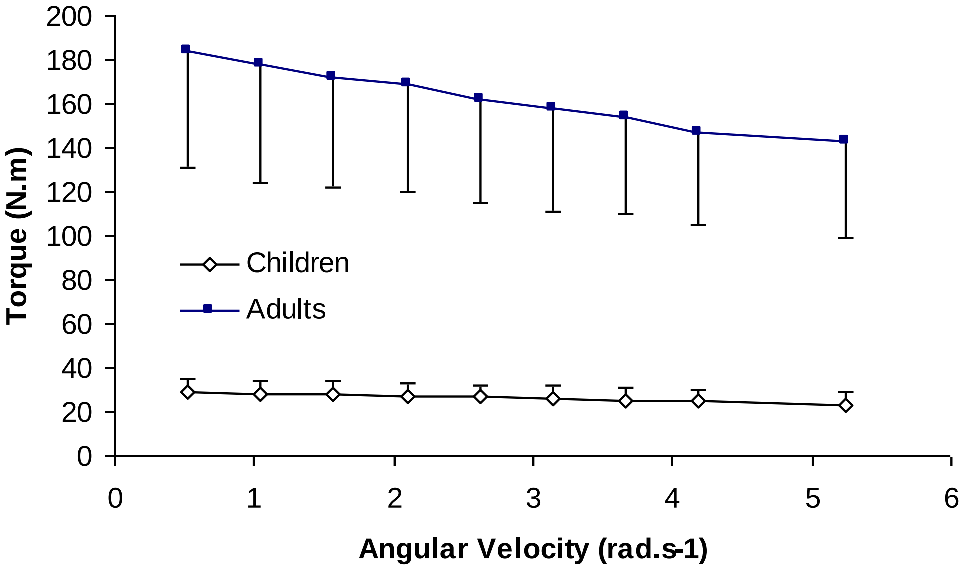


Figure 4.2 — Uncorrected F-V curves.

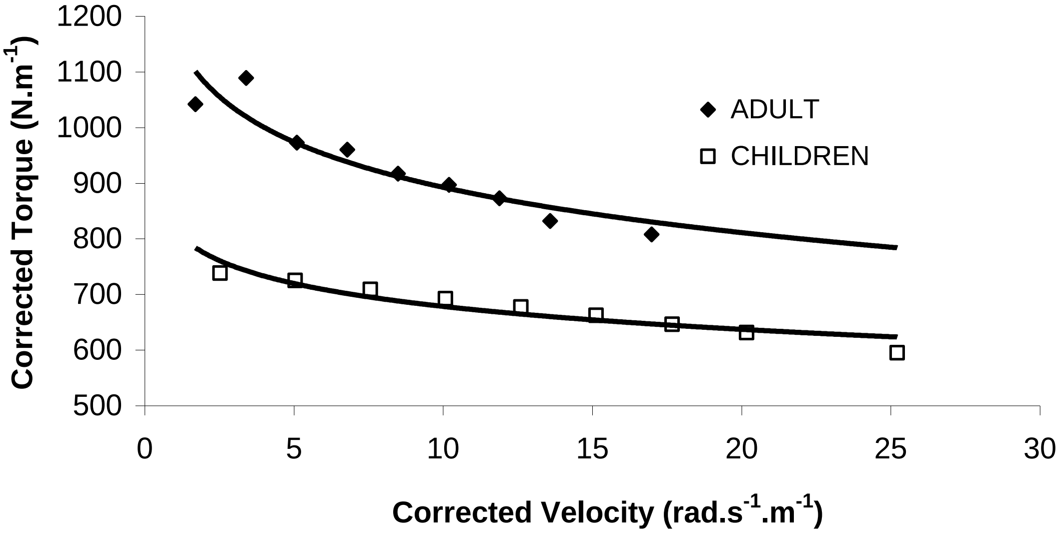


Figure 4.3 — F-V curves corrected for lean thigh CSA and length.

Figure 4.4 shows the uncorrected P-V curves for the children and adults. Figure 4.5 shows the effect of correcting the power measurements for lean thigh volume. The corrected P-V curves for children and adults appear almost identical.

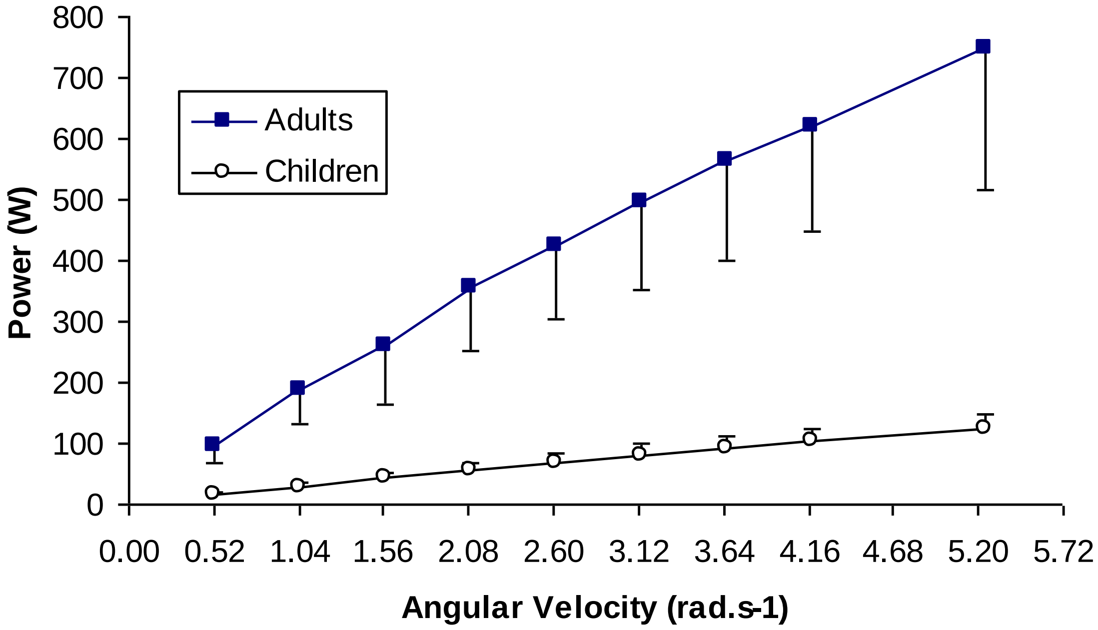


Figure 4.4 — Uncorrected Power-Velocity curves.

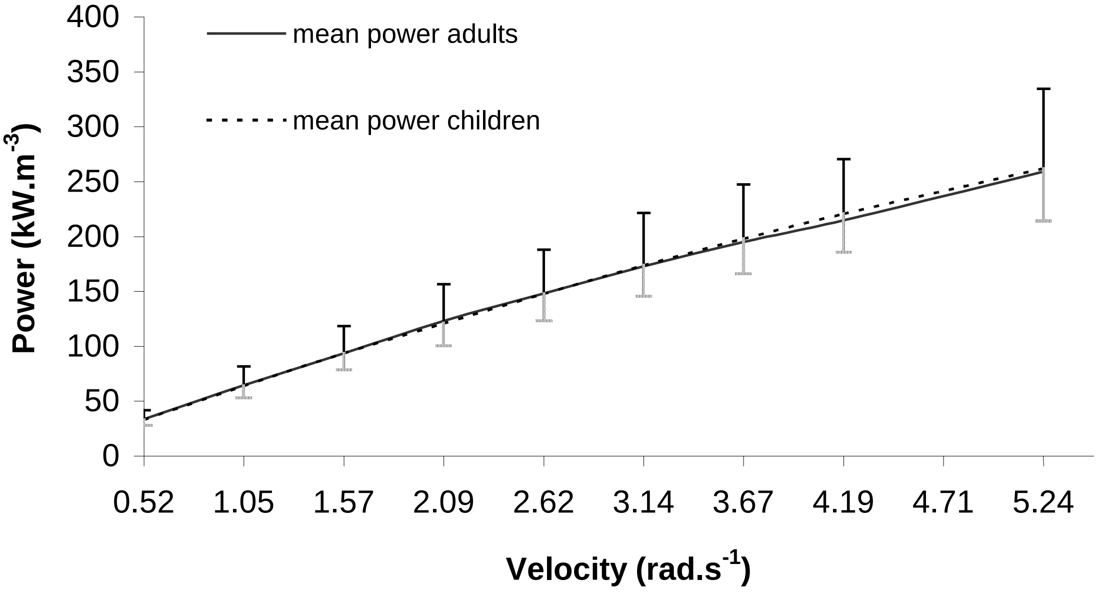


Figure 4.5 — P-V curves corrected for lean thigh volume.

Table 4.2 below shows results of the ANOVA test of within-subjects effects for uncorrected and corrected power scores. These data show that, following correction for thigh volume, the interaction between power and age group was no longer significant across the nine velocities tested.

Dependent variable	df	F	p value
Uncorrected Power	8	138.4	<0.001
Corrected Power	8	0.160	0.996

Table 4.2 ANOVA Test of Within-Subjects Effects for uncorrected and corrected power scores

4.5 Discussion

Due to the distinct lack of published compatible measurements for the age groups used it was not possible to compare the physical characteristics of the subjects tested. Where such data exists a direct comparison of anthropometric data is also limited by differences between sample populations due to variables such as race.

Peak torque, for both groups, occurred progressively closer to full extension and therefore at shorter muscle lengths as the speed of concentric contraction increased (figure 4.1). This was previously found in adults (Wickiewicz, et al1984). In the present study, the angle of peak torque was significantly smaller for the children's group. This was also found in a study comparing isometric torques in children and adults (Marginson and Eston 2001) and suggests that adults have a mechanical advantage for measurement of torque however the magnitude of this advantage remains unclear. It is possible that differences in the elasticity of the tendons as found by Kubo at al (2001) could explain the differences in angle of peak torque observed in the present study.

The torque values of the children were clearly lower than the adults (figure 4.2), which is consistent with other studies (Asai and Aoki 1996; Fuchimoto and Kaneko 1981). When simultaneous corrections for both CSA and length where made, the F-V curve of the children remained lower, while the overall shape curves for the two groups were very similar (figure 4.3). 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 4.3) show large group differences in power values at all velocities. When these data were corrected for lean thigh volume, the resulting curves appeared almost identical, see Figure 4.4. 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 (table 4.2). 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 (1981). 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. If this theory is true it would mean that the F-V relationship does not limit children's performance of activities that require a combination of strength and speed. Muscle size may be the main limiting factor in executing various motor skills. However it would be impetuous to draw such conclusions at this stage as 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 in this study. 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 (Thorstensson et al 1976). 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 (Davies, B. N. 1990).

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 almost fully 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. 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.

4.6 Future Studies

This study found no significant difference in power values of the quadriceps between children age 6 years and young adults once values were corrected for lean thigh volume. It is difficult to draw any conclusions from these results as they are they appear to be the only such findings in current literature. A follow-on study could re-examine this relationship with the addition of an older yet still prepubescent children’s group to ascertain if the differences remain insignificant across three age groups. Furthermore a follow-on study could explore if any differences in peak power values exist between males and females at each of the age groups tested once corrections have been made for lean muscle volume.

Chapter 5

Study 2

Age and Gender Comparison of Muscle Function.

5.1 Abstract

The quality of movement is determined in part by the force velocity relationship of the muscle involved. Conflicting results have been reported in studies comparing this relationship in adults and children due mainly to the variety of scaling techniques employed. This study examined the force-velocity and power-velocity relationship of the quadriceps muscle of children aged 6 years, 10 years and young adults while scaling for local muscle volume. Lean thigh volume was calculated for each subject using previously validated anthropometric measurements. The angle of peak torque was also examined. Sixty subjects (20 in each age group) performed maximum effort knee extension on the Con-Trex isokinetic dynamometer at ten different velocities. Results revealed a significant mechanical advantage in the angle of peak torque for females' age 10 years. The mean force-velocity curves showed a predictable shift upwards in the curves with each ascending age group. No gender difference was observed in the children's groups but adult males achieved superior scores than female adults. Power velocity values corrected for lean thigh volume yielded no differences between six year old boys and girls and 10 year old males, however despite corrections for muscle size 10 year old females and, male and female adults all exhibited higher power values at all ten velocities. These findings are not consistent with the preceding study (chapter 4). The question as to whether there are qualitative differences in the muscle of children and adults remains open. Results of this study suggest that quantitative differences do not entirely account for the differences in the power velocity curves. Future studies should preferably be longitudinal in nature and examine known covariates while simultaneously using appropriate scaling techniques

5.2 Introduction

An individual’s ability to exert force in static or dynamic activities is limited by the force-velocity relationship of the muscle group responsible. While it is generally accepted that an individuals’ ability to execute tasks improves with age only a small number of studies have examined the development of the force-velocity relationship from childhood to adulthood. Clearly there are growth related differences in muscle size between children and adults – but are there qualitative differences?

Conflicting results have been found to date – mainly due to the variety of testing procedures and scaling techniques adopted by different researchers. Asai and Aoki (1996) and Fuchimoto and Kaneko (1981) found significant differences in the force-velocity relationship of children and adults, before and after corrections for muscle length. Davies C.T.M. et al (1983), and Belanger and McComas (1989) on the other hand found no age related differences in muscle force generating capacity (per CSA). An interesting observation on the treatment of the data in these studies was that scaling for differences in muscle size of the groups utilised size values in one or two dimensions rather than taking account for the three dimensional changes that occur in muscles as children grow and mature. Other studies in this area have scaled results for body size based on a variety of regression equations. Since isokinetic dynamometry isolates particular muscle groups it would appear more appropriate to scale for size based on three dimensional measurements of the local muscle group being tested. This type of correction would reduce the impact of other variables which could impact on the results. Barrett and Harrison (2002) found no significant difference between 6 year old children and young adults when power values were corrected for lean limb volume. These findings imply that muscle fibre composition and function are consistent during mid-to-late childhood through adult years. That is, changes in muscle strength as children grow do not appear to be explained by developmental alterations in the contractile mechanism. However based on the lack of consistent findings growth and maturation related differences in muscle function remain unclear and require further investigations at different ages.

In addition to the lack of appropriately scaled studies comparing muscle function in children and adults, there is a distinct lack of comparisons across gender and age combined. The majority of studies that have been published have shown the trend for males to be stronger than females however the reasons for these differences remain unexplained. It has been suggested that sex differences in strength might relate to the size advantage in boys (Beunen and Thomis 2000). Many studies have made allowances for the differences in body size (Seger and Thorstensson 1994; De Ste Croix et al 1999 and Pääsuke et al 2001) however only a few have made allowances for the well documented increase in females body fat/muscle mass ratio as they move from the early teen years into adulthood. Studies comparing isometric strength in males and females at different ages that have corrected for lean muscle volume have found less of a difference between the genders in particular at the younger ages (Davies C.T.M and Young 1984; Davies B. N. 1988; Davies B.N. 1990). These results support the conclusion that differences in strength between boys and girls are related to differences in body composition and hormonal stimulation rather than to gender-related influences on the contractile properties.

Peak torque measurements at each velocity may register at different angles. It has previously been suggested that adults have a mechanical advantage over children aged 6-10 years as they tend to record peak isometric torque at greater angles (Marginson and Eston, 2001; Barrett and Harrison, 2002). Gender differences in angle of peak torque at different ages have not yet been examined. It has been highlighted that differences exist in the elastic properties of tendon structures in young boys and it is well documented that females exhibit greater muscular flexibility than males at all ages. It is possible that elastic properties in the muscle and tendon complex contribute to variance in the angle of peak force production.

There remains a need to examine the differences between males and females under isokinetic conditions taking account for three dimensional differences in size of the local muscle group being tested. The purpose of this study is to compare male and female size free peak power values across three age groups - two age groups of pre-pubertal children and post-pubertal young adults. It is hoped that the results of this study will contribute to the growing body of knowledge and understanding of the contributions of qualitative and quantitative changes in the muscle of children as they grow and mature into young adults.

5.3 Methods

Sixty subjects participated in the study. Group 1 consisted of 20 young adults, 10 females and 10 males of average age 22.95 ± 3.03 years. Group 2 consisted of 20 year 6 primary school children, 10 females and 10 males of average age 10.05 ± 0.36 years. Group 3 consisted of 20 year 2 primary school children, 10 females and 10 males aged 6.31 ± 0.32 years. The study received ethical approval from the University of Limerick ethics committee and written informed consent was obtained from all adult subjects and from the children and their parents. No participants reported any past histories related to either the nervous or muscular systems. Lean thigh volume was measured on the subject's dominant leg and calculated as the sum of two truncated cones using the technique described by Barrett and Harrison (2002).

Isokinetic knee extension torque was determined on a Con-Trex isokinetic dynamometer utilising the same warm-up, habituation and set-up procedures outlined previously in this document (chapters 3 and 4). Maximum concentric knee extension torque was measured at ten 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. The accuracy of measurements was ensured using inspection technique outlined in chapter 3. Peak power was calculated as the product of torque and velocity and the values were corrected for lean thigh volume. 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 10 levels) and 2 between subjects factors (age, with 3 levels and gender with 2 levels). The dependent variables were uncorrected and corrected power.

5.4 Results

The physical characteristics of the subjects are shown in table 5.1. All anthropometric measurements were greatest for adults. Group 2, the older children’s group exhibited higher values than the younger children’s group on all measurements. The skinfold measurement is the mean total of anterior and posterior skinfold readings taken at the one third subischial height level. The circumference and CSA measurements are taken as the values corrected for skinfold measurements. The length measurement is the vertical distance between the gluteal furrow and the maximum circumference around the knee joint space. The volume measurement is the sum of two truncated cones modified to account for skinfolds.

	Group 1 - Adults		**Group 2 - Children**		**Group 3 - Children**	
	Male	**Female**	**Male**	**Female**	**Male**	**Female**
Age (years)	22.5 ± 3.1	23.4 ± 3.06	9.99 ± 0.33	10.12 ± 0.38	6.25 ± 0.32	6.34 ± 0.32
Height (m)	1.795 ± .054	1.683 ± .065	1.398 ± .053	1.373 ± .048	1.204 ± .052	1.223 ± .047
Weight (kg)	74.42 ± 4.11	63.475 ±7.02	34.01 ± 4.87	33.04 ± 6.43	22.32 ± 2.76	23.83 ± 2.82
Skinfold (mm)	22.12	28.2	34.69	43.3	25.85	32.0
Thigh CSA (cm^2)	210.39 ± 43.8	165.37 ± 21.2	96.49 ± 10.0	83.01 ± 15.25	64.01 ± 7.95	68.63 ± 11.94
Circumference (cm)	51.137 ± 5.28	45.47 ± 2.88	34.75 ± 1.81	32.15 ± 2.96	28.59 ± 1.79	29.26 ± 2.43
Thigh Length (cm)	31.98 ± 3.42	26.22 ± 2.15	26.5 ± 1.83	22.1 ± 3.11	17.9 ± 1.53	18.05 ± 1.55
Thigh Volume (cm^3)	5978.92 ±1171.33	4137.98 ± 534.68	2620.61 ± 317.87	2008.51 ± 505.12	1180.89 ± 199.48	1282.84 ± 187.21

Table 5.1 Physical Characteristics of the subjects.

Figure 5.1a shows the mean angles of peak torque at each velocity for the 3 groups. The 10 year olds attained peak torque at greater angles than the adult and 6 year old groups. The adult group’s angles of peak torque were found to be higher than that of the 6 year olds. Further analysis of the groups by gender showed a difference in the mean scores of males and females in the adult and age 10 groups (figure 5.1b). In both age groups females achieved peak torque at greater angles than the males. No significant difference was evident between the 6 year old males and females.

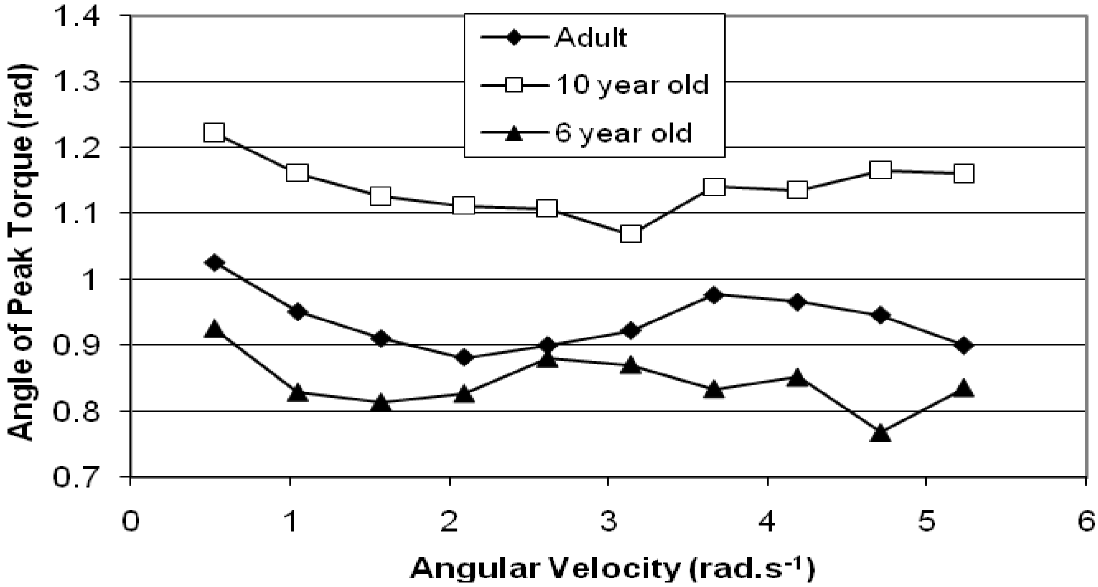


Figure 5.1a Angle of Peak Torque for each age group

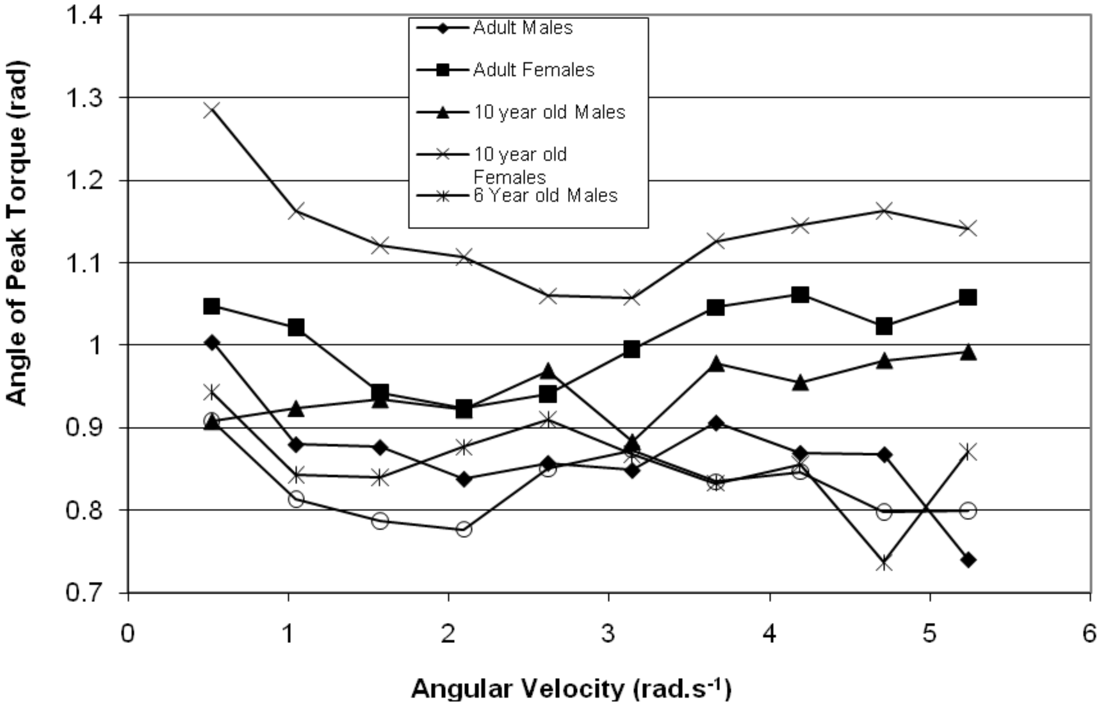


Figure 5.1b Angle of Peak Torque for males and females in each group

Figure 5.2 shows the uncorrected F-V curves for the 3 age groups. The adult group obtained the highest torque values at each velocity. The 10 year old children's torque values were superior to those achieved by the six year old children's group.

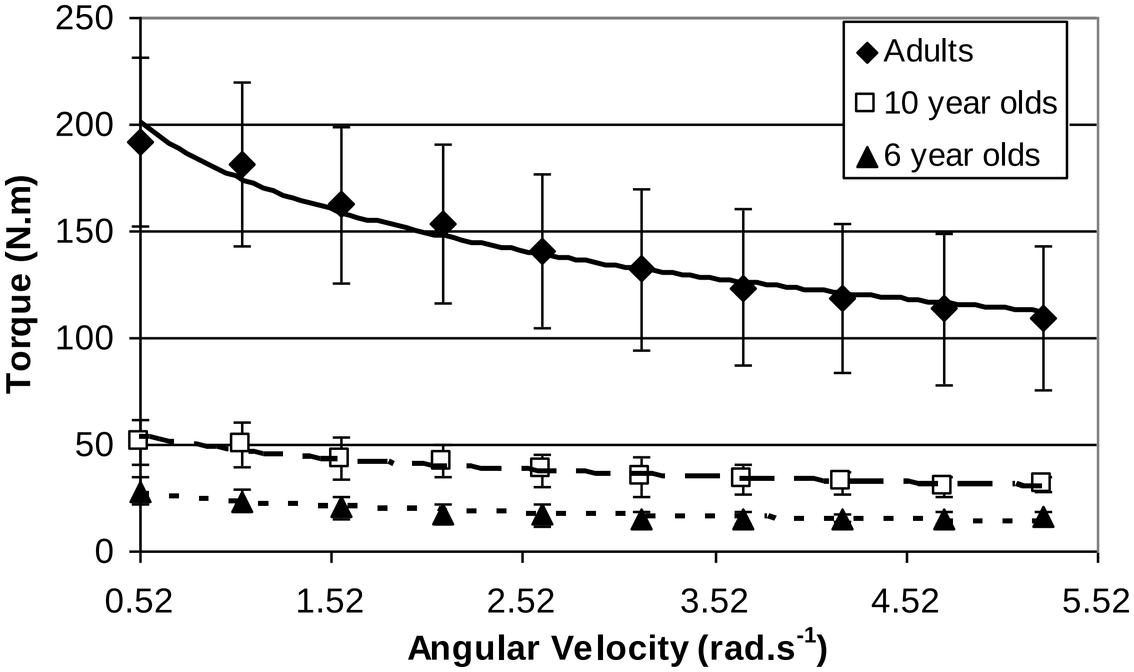


Figure 5.2 — Uncorrected F-V curves.

Figure 5.3 illustrates the absolute power-velocity curves for males and females in each group. Adult males scored the highest values. Female adults' power values were lower than male adults but higher than all of the children's groups. For the children's groups the 10 year old groups curves are higher than that of the 6 year olds and there appears to be little difference between males and females in each group.

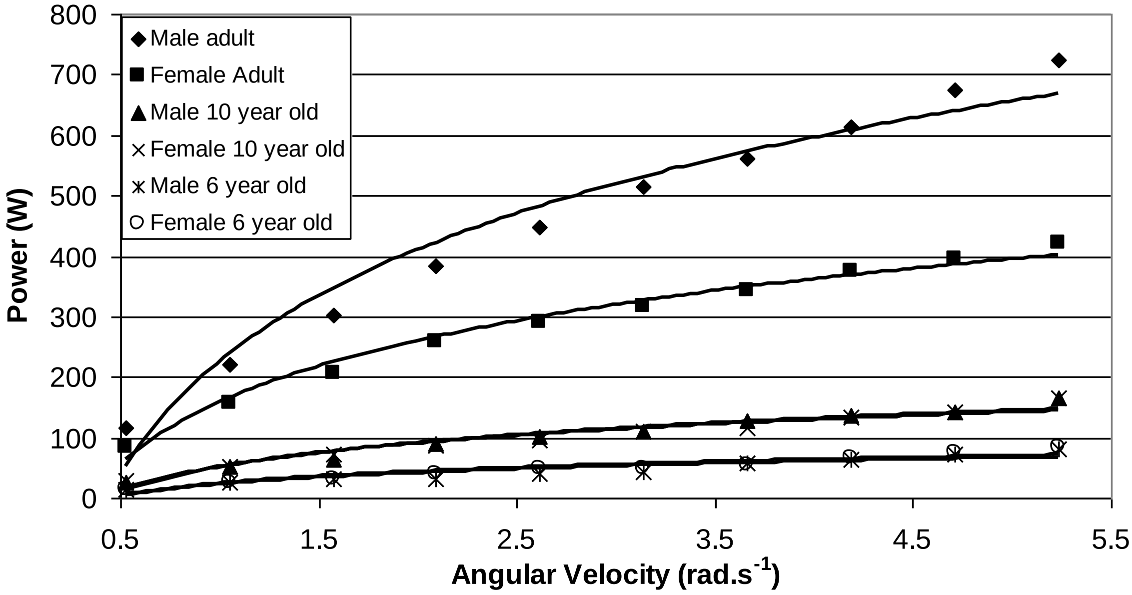
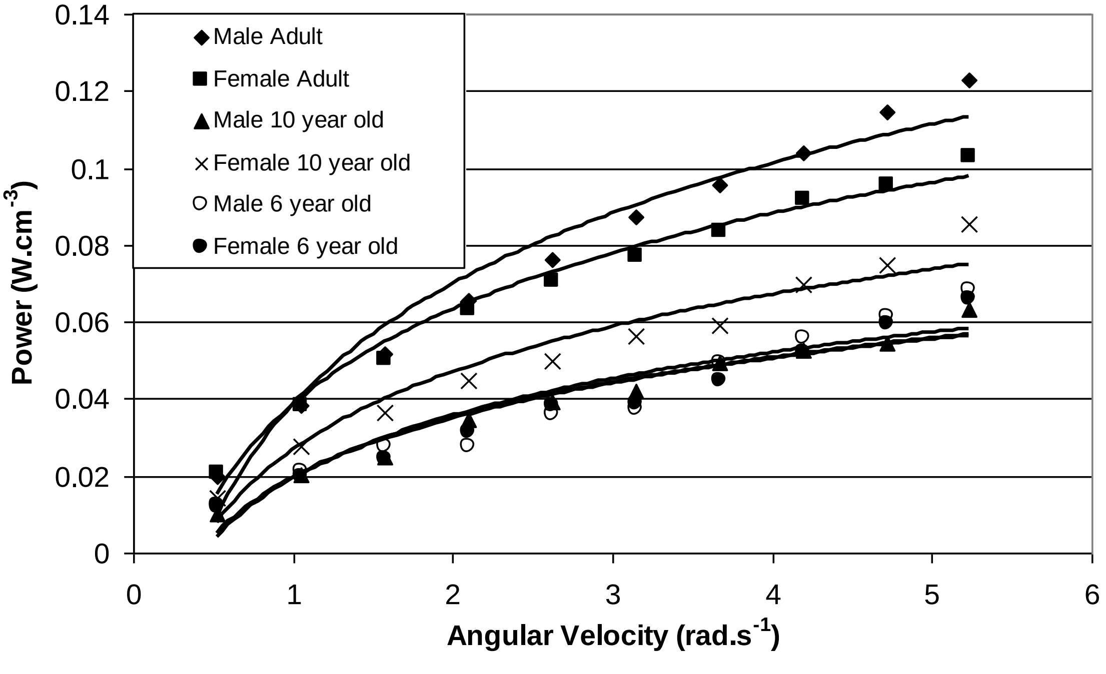


Figure 5.3 Uncorrected P-V curves.

Figure 5.4 graphs the mean power values, corrected for lean thigh volume at each velocity. Similar to figure 5.3 the power values for adult males are highest, followed by adult females. The children's corrected power results reveal superior values for 10 year old females, with little differences in the curves of the 10 year old males and the 6 year old males and females.



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igure 5.4 — P-V curves corrected for lean thigh volume.

Table 5.2 below shows results of the ANOVA test of within-subjects effects for uncorrected and corrected power scores. These data show that, following correction for thigh volume, the interaction between power and age remained significantly different. Gender alone accounted for some of the variance observed in the uncorrected power scores however gender and age combined remained significantly different also.

Dependent Variable × group	**df**	**F**	**p value**
Uncorrected Power × age	18	210.67	<0.001
Uncorrected Power × gender	9	29.904	<0.001
Uncorrected Power × age × gender	18	29.02	<0.001
Corrected Power × age	18	25.334	<0.001
Correct Power × gender	9	1.158	0.32
Corrected Power × age × gender	18	5.644	<0.001

Table 5.2 ANOVA Test of Within-Subjects Effects for power scores across 10 velocities.

5.5 Discussion

A comparison of anthropometric data obtained in this study (table 5.1) to that in study one (table 4.1) reveals a number of differences. Most notable is the large difference between the mean volume scores of the six year old children in each study. When values for volume for both males and females in group 3 of this study are combined they yield a total thigh volume of 1231.865 cm^3. This is more than double the volume measured in the same age group in study one (558.42cm^3). Further analysis of the component measurements reveals that mean thigh lengths were shorter while corrected circumference values were higher in this study compared to study one. Table 5.1 also shows that age 10 females measured the highest skinfold values and that adult males had the lowest. The higher fat values obtained from the 10 year olds may suggest a more sedentary lifestyle and poor dietary habits amongst this group. However a distinct lack of published compatible measurements for the age groups used renders it difficult to draw conclusions from the disparity in results in the two studies presented here. A direct comparison of anthropometric data is also limited by differences between sample populations due to racial differences. This highlights the need for more detailed reporting of anthropometric data in published literature for comparison with similar populations. The lower fat values obtained in the adult group in this study could be the result of a more active lifestyle. A higher training status could have an impact on the ability to produce torque at various speeds. A correction for muscle size would negate the influence of higher muscle mass however research has also pointed to a number of neural adaptations which would allow trained subjects to generate greater torques e.g. the greater ability to recruit high threshold motor units in trained subjects (Sale 1996). If the differences in activity levels and training status between the groups in this study are high this could have an impact on the comparison of torque and power measurements obtained.

The mean angle of peak torque was greatest for the 10 year old group, and the adult group measured greater than the 6 year olds (figure 5.1a). Similar results between the adult and 6 year old group were found it study one suggesting that the adults had a mechanical advantage for measurement of peak torque. This relationship was also found by Marginson and Eston (2001) when they compared the angle of peak isometric torque in male children aged 8-10 years and young male adults. The current study further revealed that the 10 year old group demonstrated higher angles of peak torque than the adults' at all ten velocities (figure 5.1a). It is unclear why the trend for increasing mechanical advantage with age would be reversed in this middle age group. Examining the angles for gender differences gives more insight into the group differences (figure 5.1b). The 10 year old female group recorded the highest angles of peak torque at all ten velocities thus skewing the overall group means. Marginson and Eston (2001) suggested that differences between torque and joint angle in men and boys could be explained by muscle stiffness, due to decreasing flexibility with age. Superior flexibility of females over males could explain the gender differences in angles of peak torque found in this study but age and gender flexibility differences do not explain the trend in this study for mechanical advantage to increase from age 6 to age 10 and then decline by adulthood. A further implication of differences between young children and adults in elasticity of the tendons (Kubo at al, 2001) is its influence on the transmission of force exerted by the muscle fibre to the bone. This difference implies that torque readings across some age groups may not accurately reflect the force generated by the muscle fibres. Varying inter- and intra-group growth velocities, muscle flexibility and tendon elasticity properties could explain some of the differences in angle of peak torque observed in the present study. It would be necessary however to control or measure these variables in order to draw any conclusions. A longitudinal study of angle of peak torque would reveal if such a phenomenon exists or if it is a product of the samples used in this study.

All three groups conformed to the classic F-V and P-V relationships (figure 5.2 and 5.3). As has previously been found the F-V and P-V curves shift upwards with increasing age (Asai and Aoki 1996 and Barrett and Harrison 2002). Age comparisons of the F-V relationship to date have attempted to eliminate the size variable using a variety of scaling techniques. Since isokinetic measures of the F-V relationship isolate particular muscle groups it is more appropriate to scale for size using measurements of the muscle groups being tested rather than any full body scaling technique. Additionally since the force-generating capacity of muscle is dependant on both the length and CSA of the muscle corrections for one or two dimensional differences do not effectively eliminate the size differences between subjects or groups. Both the length and circumference of limbs increase substantially with age therefore a correction for both is vital when comparing muscle function of children and adults. This study used previously validated methods for calculating lean thigh volume (Jones and Pearson 1969; Katch and Weltman 1975) to correct for three dimensional differences in the size of the muscle group contributing to force production during knee extension. The resulting corrected P-V values illustrated in figure 5.4 yielded significant differences between adults and children and also between 10 year old girls and the remaining children tested. Furthermore a gender difference was found in adults with males exhibiting higher power scores per unit muscle. These results appear to contradict the findings of the previous study outlined in this document despite identical methodologies. A review of studies examining the F-V relationship at various ages shows that this is typical of the research currently available. Asai and Aoki (1996) and Fuchimoto and Kaneko (1981) also found significant differences in the force-velocity relationship of children and adults, before and after corrections for muscle length. Whereas Davies C.T.M. et al (1983), and Belanger and McComas (1989) on the other hand found no age related differences in muscle force generating capacity (per CSA). Study 1 in this document also found no significant difference between adults and six year old children after corrections for muscle volume which added credence to the suggestion that muscle size accounted for most of the differences observed in strength from childhood to adulthood. All of the above age comparative studies have found less of a difference in the F-V relationship of children and adults after correction to measured values for muscle size. The findings of this study would suggest that quantitative changes in the muscle associated with growth do account for a large proportion of the differences between different age groups. However quantitative differences are not the only covariate responsible for the observed strength gains. It is possible that neuromuscular and biochemical changes also occur. In the only longitudinal study available the authors purported that muscle tissue increases first in mass then in functional strength. This proposal was based on a time delay of 0.4 years from the occurrence of peak muscle mass velocity to strength velocity. While the accuracy of measurement would evoke caution in drawing conclusions the authors did suggest that qualitative changes and/or neuromuscular maturation may occur during adolescence. Housh et al (1997) suggested that neuromuscular maturation due to the myelination of motor neurons and neural maturation may contribute to the superior force generating capacity of muscle observed in adulthood. Additional longitudinal studies with more accurate measurements of strength and volume would expose the magnitude of qualitative and quantitative differences from childhood to adulthood and whether or not a time delay exists between gains in muscle mass and strength.

Results illustrated in figure 5.4 show a gender difference in strength at age ten after correcting data for muscle size. Previous studies have found that no strength differences exist between males and females aged 11.6 - 13.2 years (Davies B. N. 1990) and before the age of 14 years (De Ste Croix et al 1999). Other studies have shown that a significant difference exists between boys and girls aged 6-9 years (Kanehisa et al 1995) and adult males and females (Davies B.N. et al 1988) despite corrections for muscle size. What is unique about the findings in this study is that it is the female group that have exhibited the superior force generating capabilities. In all previous studies it was males who yielded superior strength scores. Both males and females have been found to exhibit strength gains with the encroachment and advancement of puberty. Additionally explosive strength has been found to be positively associated with biological maturity even after controlling for variation in chronological age, stature and body mass (Beunen and Thomis 2000). This could help explain how the 10 year old females in this study had greater force generating capabilities than their male counterparts. It is well accepted that in the majority of societies the onset of puberty occurs earlier for females than males. The subjects in this study were selected due to their age (approx 6 and 10 years) as these ages have been considered prepubescent in similar studies of the F-V relationship (Seger and Thorstensson 1994). It is possible however that some of the 10 year old females participating in this study were in the early stages of puberty and therefore not prepubescent. Recent research suggests that for reasons such as diet and high body mass index that the onset of puberty is being experienced earlier in modern societies. A recent review of relevant literature by Coleman and Coleman (2002) found that the age of onset of puberty (Tanner stage 2) ranges from 9.96 to 11.2 years in white females. The Oakland Adolescent Growth Study (cited in Beunen and Thomis 2000) found that in early adolescence, early maturing girls were found to be slightly stronger than other maturity groups. If some of the subjects in group 2 were in the early stages of puberty it possible that this factor contributed to the gender differences observed. However maturity levels were not assessed and would need to be included in future studies to gauge if this is a contributing factor to gender differences in muscle function.

Significant gender differences have been reported in young adults for both isometric (Davies B. N. et al, 1988) and isokinetic (De Ste Croix et al, 1999) strength despite efforts to scale for differences in muscle mass. The absence of gender comparative studies employing isokinetic measurements and corrections for local muscle volume leaves the question of the magnitude of this difference unresolved. This study found significant differences in corrected power between male and female adults at the higher velocities. Davies B. N. et al, (1988) suggested that a possibility for the gender differences observed in handgrip strength could be the composition of male and female muscle with respect to fibre type. Simoneau and Bouchard (1989) found the mean proportion of type I fibre to be lower in male than in female muscles. While there is no consistent evidence for this theory it could help explain why in this study there are no significant differences between power values at the lower velocities but there is at the higher speeds. A higher percentage of fast twitch fibres could allow males to produce greater torque at higher velocities (Ivy et al, 1981; Tihanyi et al, 1982). MacIntosh and colleagues (1993) found that the relationship between power output and fibre type distribution was greatest in the range of 3-8 rad.s^{-1}.

It has been suggested that hormone levels (of testosterone in particular) may explain some of the gender differences in strength observed during and after adolescence (Davies B.N. et al, 1988; Ramos et al, 1998). As well as stimulating muscle tissue growth testosterone is thought to directly and indirectly enhance the development of the muscle's protein contractile unit thereby providing for the improved force production capabilities observed (Kraemer 1996). It is also thought that testosterone may influence neural factors and the muscle fibre transition of type 11 fibres to more glycolytic profiles (Kraemer 1996). The results of this study suggest that quantitative differences between adult males and females do not account for the differences in strength observed however the exact qualitative differences have yet to be isolated. Future analyses of the differences in muscle function of adult males and females need to examine the influence of variables such as muscle volume and hormone levels.

This study has identified a number of gaps in knowledge and understanding of age and gender differences in muscle function. Limitations in experimental design, testing modalities and data treatment in research to date all contribute to the lack of consistent results and conclusions. In particular there is an urgent need to standardise the approach to scaling data to allow for direct comparisons across studies. It would be preferable to scale for the three dimensional differences in the local muscle group being tested. The use of simple anthropometric measures to estimate lean volume have been found reliable, however more accurate tools such as ultrasonic, computerised tomography etc. would yield more precise measures of active muscle volume especially in children. There has been in the past an over reliance on isometric handgrip data as a measure of muscle strength. More accurate and reliable instruments that examine both isometric and isokinetic contractions should be employed in further studies of muscle function. Inferences based on results of small convenient samples are questionable. Perhaps a large scale, highly controlled longitudinal study will be the only approach that will answer the many unresolved questions with relation to the maturation of the muscular system and its contractile mechanisms.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

Clearly there are still questions to be answered in relation to the qualitative development in muscle over time for both males and females. There are obvious limitations to cross-sectional studies particularly those conducted on convenience samples. Longitudinal studies using accurate and reliable methods for determining muscle function, muscle volume as well as other variables such as maturation, hormone levels, rate of force development etc are needed if we are to finally understand the mechanisms that contribute to enhanced force production in adulthood. This understanding will add to our overall comprehension of how various motor system subsystems combine to progress motor skills and how we can promote rate affordances to such development.

6.2 Recommendations

Chapter 1 listed the components of a skilled movement as force, velocity, accuracy and purposefulness (Kent 2001). This document has focussed on the development of the first two elements and there is a need to explore the development of the latter two. Chapter 1 also stated that research in the area of motor development has been primarily observational in nature and there is a need to approach future examinations from a multidisciplinary and multidirectional perspective. There appears to be general consensus on the power of techniques of biomechanics to explain mechanisms for developmental change (Jensen and Korff 2005) yet its use is limited in published studies in the area of motor development. Technological advances in 3-D motion analysis now allow for large amounts of kinematic data to be collected resulting in detailed knowledge of movement characteristics as well as changing patterns over time. Motion analysis techniques allow the researcher to investigate individual joints or segments, and to examine the relationship between these. These measurements can also be utilized to provide a descriptive account of movement variability

(Piek 2002). Motion analysis affords the opportunity to examine age related differences in motor skill execution that may complement observational studies and need to be better integrated in contemporary research efforts. This multidisciplinary approach will deepen our understanding of the development of motor coordination and control.

An extension to the area of research conducted as part of this document would be to examine the age and gender differences in the muscular strength and power of the legs when performing a fundamental skill such as jumping. Maximum vertical jump has routinely been used as an index of muscle power (Markovic and Jaric 2007). Limitations in the assessment of power based on measures of performance in vertical jump may be related to differences in body size. Markovic and Jaric (2007) found that after normalisation for body size, muscle power and jump height appeared to be closely related among young adults. The authors concluded that heights of vertical jumps can be considered as a body-size independent index of muscle power and it only direct assessment of power that is related to body size, however, this hypothesis has only been tested in adults and not in children. It would seem logical that when comparing groups of subjects of different ages where the size differential is greater appropriate scaling would be essential. The hypothesis of Markovic and Jaric (2007) therefore needs to be re-examined in relation to children.

Jensen and colleagues (1994) asserted that age related differences in executing the vertical jump are in the movement’s control not its coordination. The authors defined coordination variables “as those variables that capture an invariant relationship between the system’s elements” (p. 259) i.e. timing of joint reversals, and timing of maximum joint extension velocities. Control on the other hand was described as “the scalar parameterization of such features as displacement, amplitude and speed” (p. 259) i.e. spatial configuration and joint velocity magnitudes. In their study the authors only looked at children aged approximately 3 years. There remains a need examine coordination and control variables across a broad range of paediatric years and to compare with adults.

Variability as a function of normal development has gained much attention in recent years. Some level of variability is now seen as a normal and essential part of motor control and development (Piek 2002). Sporns and Edelman (1993) suggest that through an organism's exploratory activity of its perceptual-motor apparatus, sensory and motor neurons become increasingly correlated and selected as a task is solved or goal attained. According to this biodynamic view, skilled action does not simply passively mature, but involves a process of exploration and discovery in which perception and action are integrally linked. In order to understand the process of normal motor development, an analysis of the probable sources of variation needs to be carried out. Such analyses should focus on quantifying the normal degree of, within-subject and between-subject variability of motor behaviour with respect to age, size and developmental stage. The prevailing theoretical approach to variability and motor control has been to treat within-subject variability as a reflection of noise in the sensori-motor system. However a review by Deutsch and Newell (2005) challenged this view by examining variability from a dynamical systems perspective. They hypothesised that structure of the variability changes is linked strongly to level of skill and is to a large degree independent of chronological age. This was also true in relation to the fundamental motor skill of jumping, where variability was found to be a function of developmental stage rather than noise or chronological age (Harrison and Bowker, 2000). Deutsch and Newell's review demonstrated that motor skills are affected by factors including practice, feedback information, body scaling and physiological factors rather than age per se. The authors suggested that the essential consideration for developmental approaches to the study of variability, such as in children's perceptual motor skills, is including the most influential developmental constraints as variables in modelling the dynamics of motor performance variability. This remains the challenge to future research projects investigating variability as a function of motor development. Objective data from motion analysis of repeated trials of basic motor skills can offer insights into motor development mechanisms. However as Holt (2005) cautioned such understanding can only happen if "(a) motor control theory precedes the use of biomechanical tools and (b) biomechanical models are developed that can formally capture the theoretical underpinnings of control and coordination" (p. 523).

In conclusion the following are the four main areas of investigation are recommended for future study:

1. Scaling techniques employed in all studies comparing subjects (in particular those comparing children and adults where the size variable has strongest influence on the results) need to be further explored and validated. This applies not only to laboratory measures of strength but also commonly used field tests.
2. Longitudinal studies measuring muscle function from childhood to adulthood controlling all identified covariates should be commenced.
3. Age comparison of coordination and control of the vertical jump using kinematic data should also be conducted.
4. The role of variability as a function of motor development needs to be examined using objective data.

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Appendices

Appendix A

Consent Forms

Dear parent

I am a postgraduate student in the Physical Education Sports Science Department of the University of Limerick. My research is examining the development of muscle function from childhood to adulthood. I hope to gain a clearer understanding of the developing ability to perform simple movements at various speeds thus aiding research in this area and ultimately aiding those who have difficulty performing such tasks.

I would hope that you would allow your child to take part in my study with his/her classmates. Your child will simply be asked to move a lever with their leg while sitting in a chair. The lever arm will record the measurements required. In addition it will be necessary for me to take 2 height and 3 circumference measurements on your child's leg so I can take their leg size into consideration when examining the data later.

All of the activities will be carried out in a safe environment and any risk involved in these activities is minimal i.e. less than those associated with playing in the playground. Each test will take no longer than 10 minutes and children will be kept in pairs in the presence of two adults at all times.

If you are willing for your child to participate please return the note below to their class teacher who will notify you of the date of testing. Your child will be required to bring their PE clothing (including shorts) with them on the day they attend the University. Should your child feel uncomfortable at any time or wish to stop they can do so simply by saying this to me on the day.

If you have any questions please do not hesitate to contact me on 087-9349005.

Thanking you in advance for your time and cooperation

____

Ursula Barrett

Cut away and return to class teacher

\- -

I agree to my child taking part in the study on "Muscle Function" at the University of Limerick

Child's name: ________________

Parent/Guardian: ________________

Date: ________________

Exclusion criteria:

Has you child recently sustained a leg injury	Yes ☐	No ☐
Does your child suffer from any movement coordination disorder?	Yes ☐	No ☐
Is your child currently taking any medication?	Yes ☐	No ☐

Adult Consent Form

Various motor skills become part of the motor repertoire during childhood. One of the important factors in improving motor skills at a certain stage in the development is assumed to be the ability to exert the necessary force in a proper and timely manner. However there are still unknown areas regarding the development of this muscle function from childhood to adulthood.

The purpose of this study is to compare the force, velocity and power relationship of children and adults. It is hoped to gain a clearer understanding of children's ability to perform a simple lef action at various speeds thus aiding research in this area and ultimately aiding those who have difficulty performing such tasks.

Volunteers will be asked to attend the laboratory, on one occasion only. The procedure will involve the volunteer sitting in an upright position and moving a lever by straightening the leg at various speeds. In addition it will be necessary for me to take 2 height and 3 circumference measurements on your leg so I can take leg size into consideration when examining the data later. All of the activities will be carried out in a safe environment and any risk involved in these activities is minimal i.e. less than those associated with playing in playing sport. Each test will take approximately than 10 minutes following a brief warm-up.

Volunteer information is kept confidential and names will not be used in any work published as a result of this study. You will be required to wear typical sports attire (i.e. tracksuit, shorts and trainers) and with the signed consent form. If you have any questions please do not hesitate to contact me on 087-9349005.

Thanking you in advance for your time and cooperation

____

Ursula Barrett

Cut away and retain

- -

I fully understand what is involved in taking part in this study. Any questions I have about the study, or my participation in it, have been answered to my satisfaction. If I decide to withdraw from the study I understand that it will not affect my future treatment or care.

Name in print: _________________ Signature: _________________

Witness: _________________ Date: _________________

Exclusion criteria:

Have you recently sustained a leg injury	Yes ☐	No ☐
Do you suffer from any movement coordination disorder?	Yes ☐	No ☐
Are you currently taking any medication?	Yes ☐	No ☐

Appendix B

Contrex set-up

Photo of adult subject in position on the Contrex dynamometer.