RELATIONSHIPS BETWEEN AGE AND VOLUNTARY FORCE GENERATION IN MOVEMENTS AT CONTROLLED VELOCITIES

by

M. Julie Ommer, B.Ed. (Hons.)

being a thesis submitted for the degree of
Master of Science in the University of Glasgow,
Department of Physiology

April, 1987

TABLE OF CONTENTS

CONTENTS PAGE

TABLE OF CONTENTS (Continued)

Contents Page

TABLE OF CONTENTS (Continued)

Contents Page

TABLE OF CONTENTS (Continued)

Contents Page

TABLE OF CONTENTS (Continued)

Contents Page

LIST OF TABLES

LIST OF TABLES (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF FIGURES (Continued)

LIST OF PLATES

ACKNOWLEDGEMENTS

I wish to acknowledge the efforts of all those who have helped me during this study. In particular I wish to thank my supervisor Dr Peter Radford, whose guidance and support have been invaluable. My thanks also to Professor Jennett of the Physiology Department who was particularly helpful in supervising my study during Peter's sabbatical year.

Appreciation is also extended to Mr Tom Aitchison for his expert statistical assistance and to Dr Rowena Murray for her immense help in the editing of this study.

I would also like to acknowledge the debt I owe to the Department of Physical Education and Recreation both for the practical facilities afforded to me and for the support of the staff; particularly Dr Nanette Mutrie for her advice and encouragement and to Mrs Marion Colvin for typing the more complex material that my rudimentary typing skills could not manage.

SUMMARY

This study was undertaken to investigate the development of children's torque generating capacities in maximal limb movements performed at a range of angular velocities.

To be able to obtain meaningful information from this investigation the answers to five specific questions were sought:

1. what is the relationship between the peak torque and velocity for the subjects?
2. what effect does age have on the peak torque scores?
3. to what extent do commonly used parameters of growth i.e. age and measures of body size, explain the variation in peak torque scores?
4. are there any sex differences in (a) peak torque scores? (b) body size measurements?
5. is it possible to obtain PT scores representative of the subject's maximum voluntary effort?

In the review of literature three reasons were highlighted for asking these questions: firstly, little has been done to investigate limb strength. Indeed, the majority of studies to date have investigated general body strength, with one or more isometric strength tests representing this measure. Secondly, the isokinetic technique for measuring torque developed in early 1970's is an ideal method measuring limb strength; it not only

provides an objective and safe means of measuring strength throughout the range but also allows strength to be measured specific to velocity. Although the velocity specific nature of strength is receiving more attention little is known about the effect of velocity on the development of strength. Thirdly, there is little information about the use of this device with children; indeed, a pilot study was necessary to provide a workable method for the main study. Clearly there was a need for studies to provide information about the testing of children on this device.

To answer the five questions outlined a design was implemented which used boys and girls of four distinct age groups (age 14, 11, 8 and 5; n = 114), in a repeated test, to obtain measurements of PT in left leg knee extension at four angular velocities, and measurements of body size.

From the results and discussion five conclusions could be drawn from the present study:

1. For each subject, irrespective of age and gender, there was a negative exponential decrease in PT as the velocity of angular motion increased. Furthermore, the intercept and slope values calculated from the regressions of log PT on velocity, when used in the equation Log PT = intercept + slope velocity, were highly accurate representations of each subject's PT-V relationship.

2. The PT generating capacities of children significantly increased ($p < 0.05$) with age; this was true for all velocities tested. In addition, there were velocity-specific differences in this development. Although these differences were only significant for the males the females showed a similar pattern of differences. Further research is required to examine these differences in more detail.

3. The correlations between the PT scores and body size measures were significant ($p < 0.001$), lying between 0.83 to 0.94; each body size measure accounted for between 69% and 88% of the variation in the PT scores. These relationships are a reflection of the fact that the PT scores increased because the subjects were getting bigger and more mature.

4. Sex differences in ability to produce PT at a range of velocities were only apparent at age 14; boys were found to be significantly stronger at 3 out of the 4 velocities; that is, at 300 deg/sec ($p < 0.01$), 210 deg/sec ($p < 0.01$) and 120 deg/sec ($p < 0.05$). At this age there was also a signifcant trend ($P < 0.01$) indicating that as velocity increased the magnitude of the sex difference increased. This result adds to the number of studies which have found this velocity-specific sex difference.

5(a) Using the recommended calibration procedures of the manufacturers the Cybex II was shown to be both valid and reliable. Recent studies, however, have suggested that limitations of the Cybex could lead to velocity-specific inaccuracies in the measurement of PT. However, the ability to successfully predict the PT scores at one velocity from the PT scores at the other three velocities gave evidence against there being any velocity-specific inaccuracies in the mesurement of PT.

5(b) In terms of subject reliability the results indicated that the best PT scores obtained were reliable estimates of the subject's best effort. There was a tendency, however, using this protocol, for better PT at the fast velocities to be produced in the second week, and for better PT scores at the slow velocities to be produced in the first week. This tendency was related to the different experience of being tested at fast and slow velocities.

This study, then, made two important contributions: a) it provided information on the development of strength in voluntary limb movements, and in the process, provided additional information about the effect of velocity on this strength development; b) it provided information concerning the use of isokinetic devices to test the strength of children.

Definition of Terms

Torque: Torque is a force which acts about an axis of rotation; it is the product of the force produced and its perpendicular distance from its axis of rotation.

Cybex II: The Cybex II is a device which controls the velocity of a voluntary limb movement at a constant pre-set velocity and measures the corresponding torque produced.

Peak Torque: The peak torque measured in the present study represents the highest torque value attained in a maximum voluntary isokinetic knee extension task.

Foot-Pounds: The Cybex II model used in the present study measures peak torque in foot pounds (ft.lbs). The international units of torque are Newton metres (N.m). Foot pounds can be converted to Newton metres by multiplying foot pounds by 1.355818; i.e. 1 ft.lb = 1.355818 N.m.

CHAPTER 1

INTRODUCTION

It has only been since the early 1970's that Isokinetic devices, which allow for movements to be performed at controlled velocities, have been available on the commercial market. These, devices such as the Cybex II Isokinetic Dynamometer (Lummex Inc.), measure the torque produced throughout the range of voluntary limb movements held at constant pre-set velocities.

These devices, can not only provide an ideal means of measuring an individual's maximum torque generating capacities, but also give more information about the expression of strength in maximal voluntary limb movements.

To date, however, little work has been done, using such isokinetic devices, with children. In this study an isokinetic device, namely the Cybex II, was used to measure the torque generating capacities of children at a range of angular velocities, with a view to obtaining more information about the development of strength in voluntary limb movements.

Previously the studies of strength in children have restricted their investigations to measuring the development of strength under isometric conditions. The main concern of these studies has been to investigate the development of general body strength. Indeed in some of these studies the only measure used to represent general strength has been grip strength, particularly in children below the age of 10 years. There is little information on the development of voluntary joint movements.

A limitation of isometric strength tests is that the emphasis is placed on the measurement of maximum forces that can be generated by muscles. This fails to recognise that force generation in the body is not simply a question of the maximum force generated by muscles, but a complex phenomenon involving the integration of many factors, not least the central nervous system. Moreover, there is much evidence to suggest that the maximum force an individual can generate is specific to the movement condition in which it is measured.

The development of strength in movement has typically been evaluated from performance scores in running, jumping, or throwing activities. While these tests involve maximal efforts, they do not allow for any objective measure of the force generated, and are therefore limited measurements of strength. The isokinetic technique, by contrast, provides a means of obtaining measures of strength with respect to voluntary limb movements performed at a range of constant angular velocities; the isokinetic technique takes into account the various factors involved in strength.

This study, then, makes two important contributions: a) that it will provide information on the development of strength in voluntary limb movements, and in the process, provide additional information about the effect of velocity on this strength development; b) it will provide information concerning the use of isokinetic devices to test the strength of children.

1.1.1 Statement of the Problem

This study was undertaken to investigate the development of children's torque generating capacities in maximal limb movements performed at a range of angular velocities. To be able to obtain meaningful information from this investigation the answers to five specific questions were sought:

1. what is the relationship between the peak torque and velocity for the subjects?
2. what effect does age have on the peak torque scores?
3. are there any sex differences in (a) peak torque scores? (b) body size measurements?
4. to what extent do commonly used parameters of growth i.e. age and measures of body size explain the variation in peak torque scores?
5. is it possible to obtain PT scores representative of the subject's maximum voluntary effort?

1.1.2 Pilot Study

Central to this study was the test on the Cybex II. The lack of previous work with children using this device meant that it was necessay to undertake a pilot study to obtain information to provide the basis for the design and the method for this test. More specifically, the pilot study provided the following information:

1. a workable method including guidelines for appropriate testing procedures,
2. an indication of the number of trials and retests required to obtain PT scores representative of subjects' maximum effort.
3. guidelines for a suitable age and velocity range.

The pilot study is reported in appendix G.

1.1.3. Limitations of Study

Since little work had previously been done in this area, the problem set for this study was by necessity broad in nature. To be able to answer this problem meaningfully it was necessary to impose limitations on the scope and design of this study; potentially there were many related aspects that could have been studied. The limitations concerned the use of equipment, selection of movement, and selection of subjects.

1.1.3(a) The Equipment Used

The Cybex II Isokinetic Dynamometer was to be used to control limb velocity and to record the maximum torque produced throughout the range of the movement. The use of this equipment was limted in two respects: the measurements obtained and the number of velocities used.

(i) the measurements

Peak torque, the highest torque value obtained throughout the range, was the only measurement used to represent the subjects' maximum torque generating capacities.

It could be argued that only measuring peak torque provides limited information on maximum torque generating capacities; the manufacturers claim that several parameters of torque generation can be obtained from a single maximal effort: rate of torque development, total work, and torque at a specific joint angle. However, the main interest in this study was the fact that torque could be measured at a range of velocities. To include a range of measurements was beyond the scope of this study.

It was also felt that peak torque was the most accurate measurement that could be obtained from the Cybex II model used in this study. The Cybex model used in this study demands that any analysis be done by hand.

This is a fairly simple process in the case of peak torque, but more complex for other measures, such as rate of torque development. It has only been in the past few years that the Cybex manufacturers have developed adaptations that will allow the accurate analysis of these measurements.

(ii) the velocities

To measure torque generation at a range of velocities the number of velocities was limited to four: 300 deg/sec, 210 deg/sec, 120 deg/sec, and 30 deg/sec. The aim was to sample velocities that represented the velocity range of the Cybex II, which is from 0 deg/sec to 300 deg/sec.

1.1.3(b) selection of limb movement

One of the limits imposed on this study was that the torque generating capacities would only be measured for one task. The task selected was voluntary knee extension, and one limb only, the left leg, was employed.

Since PT scores were to be obtained at four velocities, testing at more than one task would have made the test too lengthy. In doing this, it is recognised, moreover, that torque generation is specific to the task; therefore, these results refer only to torque generation in the task of knee extension. Ideally, it would have been preferable to obtain results from a range of joint movements.

Knee extension was chosen because it involves a large muscle group, and is therefore more likely to produce peak torque scores at the higher velocities in the younger age groups. It was also chosen because most of the previous work that has been done on the Cybex II has used knee extension.

It is also recognised that there are strength differences between the right and left sides of the body. Asmussen and Molbech (1958) reported that the average differences of strength between symmetrical muscle groups in 150 normal children was between 5% to 10%. It was also reported that these percentages were not affected by the subjects age or sex. In the present study, since the measurement of PT was limited to the left leg, a possible source of variance in the PT scores would be differences in leg dominance.

1.1.3(c) selection of subjects

To study the development of maximum torque generating capacities, age was chosen as the means of selecting children of varying developmental stages; four age groups were selected: 5, 8, 11, and 14 years. In order to show differences between these groups in terms of growth, measurements were selected with the aim of showing differences in body size, particularly in the left leg.

A major limitation of using age to select subjects was that it only allowed general trends in the development of peak torque to be investigated. However, since little previous work had been done in this area, particularly with respect to the development of PT at a range of velocities, it was felt that studying only broad trends was justified; a more detailed study of developmental trends would be more appropriate for future research.

CHAPTER TWO

REVIEW OF LITERATURE

In reviewing the literature for the study outlined in chapter one, three major, but interrelated, aspects were considered:

1. usefulness of isokinetic devices in measuring strength,
2. effect of velocity on torque generation,
3. factors that affect the development of strength.

Section 1.

The Usefulness of Isokinetic Devices for Measuring Strength

Isokinetic devices, as suggested in chapter one, can provide not only an ideal means of measuring strength but also more information about the strength of maximal voluntary joint movements. In this study the purpose of measuring strength is to obtain more information on the development of strength in children. In previous studies in this area the two methods used to measure strength were isometric strength tests and performance scores in gross motor tasks.

The first part of this review will therefore examine these two methods, in terms of their uses and their limitations. This will then lead on to a discussion of the isokinetic technique, its advantages over other methods of measuring strength, and, finally an assessment of its usefulness in investigating the development of strength in children.

2.1.1 Uses of Isometric Strength Tests in Children

In studies investigating the development of strength the most common type of strength tests are isometric strength tests.

Isometric strength tests measure the force generated, in a maximum effort where no or pratically no movement takes place and the muscles maintain a constant length (Asmussen, 1973; Espenchade and Eckert, 1980; Lamb, 1984). There are many different types of equipment for measuring the force produced in a maximum effort while allowing no movement, equipment such as spring dynamometers (Martin, 1918; Jones, 1949), cable tension dynamometers (Clarke, 1957; Asmussen, Heeboll-Nielsen and Molbech 1959). Reviews of the different types of equipment and methods of use can be found in Clarke (1950) and Hunsicker and Greey (1957).

The most widely used isometric strength test is grip strength. The extent of the use of grip strength is highlighted in the following statement by Burke et al. (1953):

> Experiments in which grip strength was used as a measure of general strength and physical growth and for the prediction of general athletic ability include a wide range (p. 628).

Indeed, in many of the studies investigating the development of strength in children grip strength was the only measure used, although it was used to represent general body strength (Meredith, 1935; Metheny, 1941a; Montoye and Lamphiear, 1977).

This would appear to be particularly true for studies of younger children. For example, Metheny (1941b), in a review of studies measuring the strength of children under the age of ten years, found that all the studies she reviewed used grip strength as the representative measure. She concluded that:

> With very few exceptions, strength testing at this age level, particularly in the school situation, has been restricted to grip strength (p. 115).

Moreover, a more recent assessment by Espenchade and Eckert (1980) of the state of strength testing, in their text book Motor Development, confirms that for young children the state of strength testing has not changed much since 1941:

> Studies of the development of static strength in preschool and elementary school children have usually employed grip strength (p. 186).

It could be concluded from these studies that the wide use of grip strength means that most of the information about the development of strength is based on grip strength.

There are a few studies, however, which have used a much larger selection of measurements to represent general strength. For example, Martin (1918) obtained 22 different measures from muscle groups of the feet, hips, knees, shoulders, forearms, wrists, and fingers to represent general body strength. Similarly, Carron and

Bailey (1974), in a longitudinal study of the strength development of boys aged from 10 years to 17 years, used seven individual strength tests, measured isometrically with cable tensiometers: shoulder extension, wrist extension, elbow flexion, elbow extension, hip flexion and knee extension. These seven tests provided three derivative measures:

1. general strength - the average of the seven strength measures;
2. upper body strength - the average of the scores obtained for wrist extension, elbow flexion, elbow extension, shoulder extension and wrist flexion;
3. lower body strength - the average of the score obtained for knee extension and hip flexion.

Although these studies have used a much wider selection of measurements, the interest of these studies lies not in the individual measurements themselves but in their combined effect to represent general strength. It could be concluded that there is little information on the development of strength in different muscle groups.

What little information there is has been provided by, for example, Jones (1949) and Asmussen et al. (1959). Jones (1949) investigated the development of strength in children over a six-year period in four different measures: right grip, left grip, thrusting, and pulling. His interest was both in development and in the factors which affected commonoly used measures of strength. More specifically, Jones (1949) gives detailed developmental information on strength for four different measures. Similarly, Asmussen et al. (1959), in a cross-sectional study, obtained measures from 300 boys and 300 girls, 7 to 15 years, for 25 objective isometric tests of different muscle groups. These measures included flexion, extension, pronation, adduction, and abduction for different muscles. The results of this study were used to provide norm values for the 25 strength measures. Other investigations using similar measures considered the effect of body size, age, and sex in the development of strength (Asmussen and Heeboll-Nielsen, 1955; 1956; Asmussen, 1980).

These studies mentioned above (Jones, 1949; Asmussen and Heeboll-Nielsen, 1955, 1956; Asmussen et al., 1959; Asmussen, 1980) were able to show that although there were general trends in strength development there were variations amongst the measurements. For example, Asmussen et al. (1959) was able to show that the sex differences in the lower body strength measurements were relatively lower than in the trunk and upper body strength measures. Jones (1949) indicated that the mean age period of the greatest gain in strength varied depending on the site at which strength was measured. These studies highlight the fact that there is a need to study, not only the development of general strength, but also the development of individual strength measurements. The results of these two studies will be discussed in more detail later in the review of literature.

The need for information on specific muscle groups has perhaps been most clearly voiced by those involved in rehabilitation. For example, Murray et al. (1980), discussing strength related to specific muscle groups, concluded as follows:

> The ability to measure changes in muscle strength and to relate these changes to expected normal performance is essential to all clinicians involved in the rehabilitation of the physically disabled (p. 412).

Murray et al. (1980) further suggested that one of the problems with previous studies was that very few had been concerned with investigating what normal performance is; for example, Murray et al. (1980) could find no studies which had produced objective standards in muscle strength testing for subjects above the age of 69, while norms for those under 69 were limited to one joint angle, 90 degrees.

It could be concluded that the main use of isometric strength tests in studies investigating the development of strength has been to measure general strength and that there is a need for more information on the development of strength in specific muscle groups.

2.1.2 Limitations of Isometric Strength Tests

There are two limitations of isometric strength tests: (1) strength is only measured at one joint angle; and (2) they represent a narrow definition of strength.

2.1.2(a) strength measured at one joint angle

As indicated above, isometric tests measure the force that can be generated in a maximum effort where there is no or practically no movement. However, using this method maximum force generation is only measured at one point in the joint range of the muscle group, or groups, involved in the movement.

In movement the tension generated in the muscle will be affected by many factors, including its length and its angle of force application. These two factors will both vary throughout a movement (Williams and Stutzman, 1959; Haffajee, Moritz and Svantesson, 1972; Murray et al., 1977). Williams and Stutzman (1959), for example, measured isometric force at 30-degree joint-angle intervals, throughout the range of several joint movements. They were able to show the torque variations which occurred. Figure 1 shows the results they obtained for the knee extensors and elbow extensors. This figure shows that in the case of the knee extensors, at 40 degrees, the percent of maximum force was about 75%, at 120 degrees it was 100%, whereas at 180 degrees it was less than 50%. This highlights

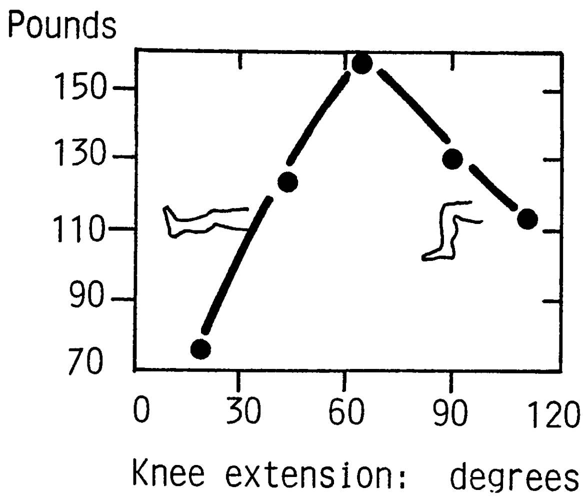


Figure 1 Isometric joint torque curve for knee extension from "Strength variation throughout the range of joint motion" Williams and Stutzman, 1959, The Physical Therapy Review 39, 3

the dramatic variations in the force-generating capacities of a muscle throughout the range of a joint movement. Williams and Stutzman (1959) drew the following conclusions from the force variations they observed:

> Not only do force values vary among muscle groups but the rotational effects of a given group depend on the position of the joint it moves (p. 152).

Therefore, in order to obtain representative strength scores for a muscle group, one would have to obtain strength measurements at a range of positions throughout the range of the movement (Gleim, Nicholas and Webb, 1978; Murray et al., 1980). This was confirmed by Murray et al. in 1980:

> A measurement of isometric strength, although valuable to the clinician, supplies only partial information about muscle function (p. 412).

It could be concluded, therefore, that isometric tests are limited, in that they only measure strength at one joint angle and provide limited information on the strength of a muscle group, unless several measurements are taken throughout the range of the movement.

2.1.2(b) isometric strength tests: narrow definition of strength

A major study by Fleishman, Kremer and Shoup (1961), concerned with defining strength, concluded that strength measured as only one value, i.e. the highest maximum force that can be attained, as in isometric tests, represented a narrow definition of strength. In Fleishman et al.'s study a factor analysis technique was used to identify and define types of strength, from a total of 38 strength tests. These tests included a diverse range of tasks, such as weight lifting, dynometric strength tests (grip strength), and various types of running, jumping, and throwing. Fleishman et al. (1961) were able to define four types of strength from the factor analysis:

1. Static strength. The critical feature of the static strength factor was that maximum force is exerted for a brief period of time where the force is exerted continuously up to its maximum. Examples of measures loaded on this factor were isometric strength tests and weight lifting, as used in isotonic strength testing.

2. Dynamic strength. Fleishman et al. (1961) suggested that in the dynamic strength factor a common requirement is for the muscles involved to propel, support, or move the body repeatedly, or to support it continuously over a period of time. They also suggested that this factor was the most analogous to the concept of power, the rate at which energy is released. Typical tests in this factor were chins to limit and push-ups to limit.

3. Explosive strength. This factor emphasises the ability to expend a maximum of energy in one

explosive act. The common feature of tests with the highest loading on this factor is that subjetcs are required to jump or to project themselves, or to project some object, as far or as high as possible. This factor is distinguished from other strength factors in that it requires the mobilisation of energy for a burst of effort, rather than continuous strain, stress or repeated exertion. Typical tests loaded on this factor were 50-yard dash or shuttle run, softball throw, and standing broad jump.

4. Trunk strength. Although Fleishman et al. (1961) suggested that static, dynamic, and explosive strength were the three primary types of strength a fourth type of strength, trunk strength, was also identified. Loadings on this factor were confined to three tests: leg lifts (in 20 secs.), half sit ups, and leg raise. These three tests all had secondary loadings on the dynamic strength factor and led Fleishman et al. (1961) to suggest that trunk strength was a second type of dynamic strength specific to the trunk muscles and particulary the abdominals.

In some of the comments on these results Fleishman et al. (1961) suggested that static strength was only one type of strength, that it differed from the other factors identified, and that too many tests of strength emphasised static strength:

> The independence of this factor from the other strength factors, together with the greater practical implications of these other factors in significant human activities, would argue against such overemphasis on tests of Static Strength (pp. 27-28).

It could be concluded, therefore, that strength in voluntary human movement is not simply a question of muscles and the maximum force they can generate, but rather a question of the movement conditions in which force is developed. This was highlighted in Fleishman et al.'s (1961) study, where four types of strength were identified. The features that distinguished each type of strength were the movement conditions in which force was developed. For example, in static strength force is developed continuously to maximum, whereas in explosive strength maximum force has to be expended in one explosive act. Since isometric tests do not take this distinction between kinds of strength into account, measuring strength isometrically represents a narrow view of strength.

2.1.3 Use of Gross Motor Tasks to Measure Strength in Children

Although the majority of studies investigating the development of strength in children have only used isometric strength tests, there are a few studies which have included other types of tests. For example, Jones (1949) suggested that there were two recognised types of strength:

1. Static dynamometric strength, shown by tests of gripping, pulling, and thrusting strength;

2. Dynamic strength, involving lifting or propulsion of the body weight, represented in Jones' (1949) study by athletic performances such as dash, standing broad jump, jump and reach, and distance throw.

Similar measures have been used in other studies to represent what Jones (1949) refers to as dynamic strength (Carpenter, 1942; Cullumbine et al., 1950; Asmussen, and Heebol-Nielson, 1956; Asmussen, 1980), although it must be noted that in some of these studies different terminology is used for the same measures. For example, where Jones (1949) would describe the standing broad jump as dynamic strength, Carpenter (1942) would refer to this as a measure of explosive strength and Asmussen and Heebol-Neilson (1956) would describe it as a measure of strength in action. However, in spite of these differences in terminology a common feature of the evaluation of maximum force production, where the force generated results in movement, is that it is almost exclusively evaluated from performance in gross motor tasks. As Espenchade and Eckert (1980) suggest:

> Contractions resulting in movement (isotonic muscle action) are referred to as dynamic strength, strength in action, or power (p. 186).

They define dynamic strength as follows:

> Dynamic strength is usually determined by the level of performance in events which measure the ability of the body to develop momentum in propelling external objects or the individual's own body (p. 186).

It could be concluded, therefore, that there are studies investigating the development of strength in children which have attempted to construct a wider definition of strength. Tests other than isometric tests have been used to measure strength under different movement conditions, and all involve obtaining performance scores in gross motor activities.

2.1.4 Limitation of Performance Scores to Measure Strength

Performance scores in gross motor tasks, however, also have limitations as measurements of strength. The major limitation is that they lack an objective measure of force; there are many factors other than the capacity to generate force which could contribute to a high performance score. Indeed, their use in studies to evaluate the development of strength in children is particularly problematic, since these same motor tasks are also used in evaluations of the general development of motor proficiency. For example, Glassow and Kruse (1960) used the standing broad jump and distance throw to investigate the development of motor performance in children aged 6 years to 14 years. These same tests are used in some studies to investigate the development of strength. Moreover, it would be expected that changes in motor performance during these years would be attributable to other factors than maximum force-generating capacities.

To highlight this a study by Teeple et al. (1975) investigated the contribution of physical development and muscular strength to the motor performance capacity of 7 to 12 year-old boys. In this study, strength was evaluated from isometric tests, and motor performance was evaluated from a softball throw, vertical jump, standing broad jump, shuttle run, 50-yard dash, and mile run. Although the majority of these tests have been used to evaluate strength, this study suggested that the strength measures accounted for only 18% to 43% of the motor performance variability. Similar results were found by Jones (1949) using the same measures. However, while both these studies reported similar results the interpretations varied; that is, Teeple et al. (1975) used them to describe the relationship between strength and motor performance, whereas, Jones (1949) used them to describe the relationship between static and dynamic strength.

These studies suggest that in children there is a poor relationship between static strength and measures of motor performance and/or dynamic strength. It is not clear, however, whether this poor relationship is due to differences in strength and growth of strength or to the fact that there were other factors which could cause individual differences. More importantly, the confusion over terminology suggests that the nature of the specificity of strength is not clear.

In an attempt sort out this confusion, Fleishman et al. (1961), as was shown above, used a factor analysis technique on 38 different strength tests to define four types of strength. However, one of the limitations of Fleishman et al.'s (1961) study is that it only provides very broad generalisations about the nature of the specificity of strength. The reason for this is that the majority of strength tests are evaluated not in terms of force produced, but by performance scores in events which demand force generation under various conditions, i.e. strength in action. Espenschade and Eckert (1980) assessed the problem as follows:

> There is still a marked tendency to use end-product data such as the speed of the run and the distance of a jump, as indicative of either speed of movement or muscular power. Statistical techniques such as factor analysis are highly dependent upon this original input data for the identification of factors (p. 196).

These findings confirm the need for more precise and objective measurements.

2.1.5 Isotonic Strength Tests: Uses and Limitations

So far the use of isotonic strength tests, using weight, have not been mentioned. Isotonic strength tests attempt to evaluate the maximum force that can be produced in a movement. It is usually evaluated as the maximum weight that can be lifted throughout a range of movement. A typical test would involve repeated trials to find the maximum weight a subject could lift. Strength is evaluated as the maximum weight lifted successfully, the weight prior to failure.

Isotonic tests have not been used to any extent in studies investigating the development of strength of children. Perhaps the major reason for this concerns two administrative aspects of the isotonic method that would be particularly problematic for children. Firstly, particularly if free weights are used, the isotonic method demands great care to ensure safety in lifting the weights; ensuring this safety for children would be more difficult than for adults. Secondly, the fact that the isotonic method requires repeated tests, with a range of loads makes this test lengthy and tiring for the subjects; best performance in a lengthy and tiring test would be more difficult to achieve with children than with adults.

It could be conluded then that these administrative limitations provide an argument against using these tests with children.

These administrative limitations are not the only limitations of isotonic strength tests; they are also limited as measures of strength. The first limitation concerns its ability to measure maximum force throughout the range of a movement. Isotonic is the term used to describe the constant tension in a muscle as it contracts against a constant load. However, the term isotonic is misleading when it is applied to the maximum forces produced in a movement; even if the external load is kept constant, the force developed by the muscles varies as the lever arm changes throughout the range of movement. In other words, this test is limited in that the measurement of the weight lifted does not take into account the changing force potentials, and only provides maximal loading at the weakest point in the range of movement. Thus, since strength is evaluated as the maximum weight lifted it means that strength is evaluated at the weakest point in the range of movement (Gliem et al., 1978). Its second limitation as a measure of strength is that it lacks an objective measure of force. By definition, force = mass X acceleration. By evaluating only the strength as the weight lifted, only one factor in this equation, the mass, has been taken into account. Clearly, a source of error will be differences in the speed of lifts in retests between subjects. Moreover, to be able to measure the actual force produced throughout the range of movement the calculation of force would have to take into account the acceleration rate for any specific point in the movement. Its final limitation as a measure of strength concerns the type of strength this method measures. Although this technique measures strength during movement Fleishman et al. (1961) found that the type of strength measured isotonically was the same as the type of strength measured isometrically; they were both defined as static strength. It could be concluded, therefore, that the isotonic strength technique like the isometric technique is limited as it only measures static strength.

In conclusion, studies investigating the development of strength in children have measured strength in the folllowing ways:

1. strength as a general capacity, measured by one or more isometric strength tests;
2. strength in action, measured by performance scores in athletic tasks.

It was notable that isotonic strength tests were not used.

The review of these studies indicated a need to investigate the development of strength, not as a general capacity, but in specific movements, such as voluntary limb movements. To obtain this information, however, it was indicated that the methods of measuring strength traditionally used had limitations:

1. isometric strength tests had two limitations, in that, firstly, strength was measured at only one joint angle, and, secondly, they only measured one type of strength, static strength;
2. isotonic strength tests had three limitations in that, firstly, strength was measured at the weakest point in the range of movement, secondly, only one type of strength was measured, static strength, and, thirdly, the test was difficult to administer to children;
3. performance scores in gross motor tasks to measure strength other than static strength was a limited testing technique, in that it lacked an objective measurement of force.

2.1.6 Isokinetic Strength Testing

From the previous section it could be concluded that there was a need for more information on the development of strength in specific movements. It was also indicated that the methods used in these studies to measure strength had their limitations.

The isokinetic technique, which has been available since 1970's, has been designed to overcome the limitations of the other methods; it provides an ideal means of measuring an individual's strength;

The purpose of this section is, firstly, to assess whether or not measuring strength using isokinetic devices, such as the Cybex II does in fact overcome the limitations of traditional methods, and secondly, to assess the usefulness of this device for research on the development of strength in children.

2.1.6(a) advantages of isokinetic over isometric and isotonic techniques

In reference to measuring strength it has been suggetsed that the ideal muscle test would be one which in one trial measured the maximum tension throughout the whole range of movement (Asmussen, et al. 1959; Gleim, Nicholas, Webb, 1978, Murray et al., 1980).

As has already been shown above, the limitation of the isometric method is that a measure of maximum force is only obtained at one point in the range of movement, and the limitation of the isotonic method is that strength is only evaluated at the weakest point in the movement. In contrast, the isokinetic method allows for the measurement of the maximum torque throughout the whole range of a movement. This is possible because isokinetic devices, such as the Cybex II, control the moving limb to a constant pre-set velocity. More specifically, during the voluntary limb movement the lever arm of the Cybex which is attached to the limb being tested moves freely without resistance until it attains the pre-set operating speed. Once in motion the lever arm is mechanically prevented from surpassing this speed. It does this by a hydraulic feedback system which keeps acceleration to zero; the amount of loading is determined by the efforts of the subject. If a maximal effort is given, then maximal loading is maintained at all points in the range of movement, with the resulting torque being recorded. Plate 1 (p. 142) shows the Cybex II set to test the torque produced in a knee extension task. An example of the torque recorded in a maximal effort knee extension task is shown in Plate 2 (p. 142). The curve shown in this plate represents the maximum voluntary torque produced at all points throughout the range of movement. Peak torque, as the highest point in the curve, also marked in Plate 2, represents the highest torque value obtained.

It should also be noted that in addition to being able to measure strength throughout the range of a movement the fact that the subjects provide their own loadings also means that this method is very safe; at any point during the movement the loading can be increased, decreased or removed altogether. This contrasts with the isotonic method where the loading is fixed throughout the range of movement.

It could be concluded that the isokinetic method provides a safe and objective method of measuring strength throughout the whole range of a joint movement; it overcomes the limitations of isotonic and isometric methods in that isometric tests only measure strength at one point in the range of movement, and isotonic tests only measure strength at the weakest point in the range of movement.

Gliem et al. (1978) assess the isokinetic technique as follows:

> Isokinetic strength testing is the only objective method of quantifying the dynamic strength of a muscle throughout the range of motion (p. 82).

2.1.6(b) gross motor task performance v isokinetic

As was discussed earlier Fleishman et al. (1961), using a factor analysis technique on 38 strength tests, were able to define four types of strength. An important conclusion from their study was that isometric tests or weight lifting, as used in isotonic tests, were only measurements of one type of strength, i.e. static strength. They were able to define three other types of strength: explosive, dynamic strength and trunk strength. Clearly, measuring strength must take into account this specificity.

However, as discussed earlier (section 2.1.4) Fleishman et al.'s (1961) study could be criticised because their definitions of types of strength were limited by the fact that the strength measures used to form their original data base were inadequate, since they relied on performance scores in athletic events and not on objective measures of force generation. It was also shown in this section that Espenschade and Eckert (1980) believed that to measure strength under different movement conditions (strength in action) and to understand the specific nature of strength there was a need for more precise and objective measurements. It could be argued that the Cybex II with its facility to measure strength at a range of angular velocities (zero deg/sec to 300 deg/sec) goes some way in providing these more precise and objective measures of strength; strength can be measured objectively in limb movements where the speed of movement can be varied precisely. More specifically, in terms of understanding the specific nature of strength, this device will allow a more objective investigation of the relationship between strength and the speed of movement than has previously been possible.

Indeed, it would appear from the results of Fleishman et al. (1961) that an important factor distinguishing the four different types of strength they defined was the speed with which forces had to be developed. For example, they showed that in static strength force was generated continuously to maximum, whereas in explosive strength the tasks characteristically required the force to be developed as rapidly as possible in one explosive act. Similarly, between dynamic and explosive strength it was found by Fleishman et al. (1961) that the test loaded on the dynamic strength factor had secondary loadings on the explosive strength factor. These turned out to be those tests which involved the same muscles, but given under a time limit condition. Thus, asking an individual to perform as rapidly as possible is more likely to bring into play the factor of explosive strength, e.g. chins 20secs. chins to limit. It can be seen from these results of Fleishman et al. (1961) that while speed was indentifiable as a factor affecting strength, the nature of the relationship between strength and speed of movement was not clear. Espenshade and Eckert (1980) suggest the following reason for the lack of clarity in the relationship between strength and speed:

> It is increasingly evident that the nature of the input data must become more minute and precise before it will be possible to resolve the equivocal nature of the relationship between strength and speed of movement (p. 196).

In this respect using the Cybex II to measure strength at a range of velocities for a single joint movement will help to provide that "more minute and precise" data.

The ability to measure strength at range of velocities has led to its use in two main areas:

1. the testing of athletes and evaluation of the effectiveness of training. Of particular interest in these studies has been the velocity specific nature of strength training (Lesmes et al., 1978; Caiozzo, Perrine, and Edgerton, 1981; Coyle et al., 1981);
2. the investigation of the underlying neuromuscular mechanisms involved in force and speed production

(Thorstensson, 1976; Gregor et al., 1979; Larrson, Grimby and Karlsson, 1979; Myashita and Kanieshia, 1979).

2.1.7. Use of Isokinetic Technique with Children

There is only a small number of studies that have used the isokinetic technique to investigate the development of strength in children. Most work has been done by the collaboration between two researchers, J. Alexander and G. E. Molnar. They have used the isokinetic technique in three studies investigating the development of strength in children (Alexander and Molnar, 1973; Molnar and Alexander, 1973, 1974, 1979). In these studies PT scores were been obtained at 30 deg/sec using a Cybex II for a variety of different movements including shoulder and hip flexion, extension, and abduction, elbow and knee flexion and extension. Their reason for using the isokinetic technique (Cybex II) was reported to be because it had advantages over the isotonic and isometric techniques in that it provided a safe and objective means of evaluating strength throughout the range of a limb movement.

However, although this advantage has been utilised in children's studies when investigating the development of strength less attention has been given to the fact that using this technique also allows strength to be measured at a range of velocities; little work has been done to study the effect of velocity on the development of strength in children. Indeed, only one study has been found that measured peak torque at more than one velocity (Gillian et al., 1979b). In this study peak torque scores were obtained for 28 boys and 28 girls in knee and elbow flexion and extension at angular velocities of 30 deg/sec and 120 deg/sec. It is interesting that in this study when differences in body size were accounted for, a significant sex difference in favour of boys being stronger was found at 120 deg/sec but not found at 30 deg/sec. It was also reported that the magnitude of this difference increased as the subjects got taller and heavier. Clearly, this velocity-specific sex difference would not have been picked up if strength had only been measured at one velocity. This would indicate that there is a need to investigate the effect of velocity on the strength development of children. Asmussen (1973) sums this up as follows:

> Growth may influence various parts of the neuromuscular system differently, asynchronously, and strength in one situation may be different from strength in another situation because the co-operation of these various parts may be different in the two situations (p. 64).

It could be concluded that isokinetic devices provide a means of obtaining more information about strength than the measurements traditionally used. This was shown to be the case for two major reasons; firstly, that strength was measured throughout the range of a joint movement, and secondly, that the measurements were specific to velocity.

It was also shown earlier in section 2.1.1 that there was little information concerning the development of strength in specific voluntary joint movements. The isokinetic technique was assessed as being a useful means of obtaining this information, in that objective measurements of strength can be obtained in voluntary joint movements at a range of constant angular velocities.

The original aspect of this study is that the development of strength will be investigated at four different velocities within the range of 30 deg/sec to 300 deg/sec (incl.). The second section of this review will consider in detail what is known about the effect of velocity on torque generation.

Section 2

The Effect of Velocity on Torque Production

Since one of the purposes of this study is to examine the effect of velocity on torque production, PT will be measured at a range of velocities. Although much is known about the effect of velocity on the force produced in isolated muscles, the relationship between force and velocity, in voluntary human movement, has been much more difficult to establish. In this section the studies which have investigated the effect of velocity on force production will be reviewed; two areas of research will be considered:

1. the relationship between torque and velocity, its measurement, its form, and its interpretation;
2. the complexity of torque generation in voluntary movement.

These will be preceded by a summary of the relationship between force and velocity obtained from isolated muscle experiments.

2.2.1 The Relationship Between Force and Velocity in Isolated Muscles

The characteristics of force and velocity in muscular contractions are obtained from muscle tetanised against constant loads. The classical observation from these experiments is that there is an inverse relationship between force and velocity in a muscular contraction. When the force is great the velocity is low, and vice versa. A.V. Hill first observed this relationship in 1922, and later, in 1938 described it as hyperbolic. The shape of this relationship has been shown to be the same for all muscles (Close, 1972; McMahon, 1984). Hill (1938) also described this relationship mathematically:

$$(P + a)V = b(Po - P)$$

Where V is the speed of shortening,

Po is the maximum isometric tension,

P is the load,

a and b are constants.

Other studies have suggested that as an empirical equation this could be used to describe all force-velocity (F-V) relationships, although it was recognised that many other equations can be used (Ralston et al., 1949; Close, 1972; Mc Mahon, 1984). This view is expressed in the following statement by McMahon (1984):

> This relation, known as Hill's equation, is found to describe nearly all muscles thus far examined, including cardiac and smooth muscle as well as skeletal muscle and even contracting actomyosin threads (pp. 13-14).

Close (1972) suggested that Hill's equation was valuable because it gave the following information:

1. intrinsic strength of the contractile material, Po at V = O;
2. intrinsic speed of shortening, V at P = O;
3. general shape of the F-V curve, as indicated by the ratio a/Po.

2.2.2 Relationship Between Torque and Velocity in Human Movement

2.2.2(a) measurement

With the introduction of the isokinetic testing devices several researchers suggested that they provided an ideal means of determining the torque-velocity (T-V) relationship in voluntary human limb movements (Moffroid et al., 1969; Rodgers and Berger, 1974; Perrine and Edgerton, 1978).

Rodgers and Berger (1974) stated:

> Many previous studies of the force-velocity relationships employed velocity values determined primarily by the load against which the muscle was contracting. It would seem more appropriate for the velocity to be determined independent of the load and to be held constant throughout the contraction to eliminate the acceleration of a ballistic movement (p. 253).

In other words the main advantage of isokinetic testing is that velocity can be held constant, while allowing maximal loading throughout the whole range of the limb movement. Under isotonic conditions, which test force generation against constant loads, the joint torque and velocity potentials would vary throughout the movement. The measurement of the velocity in movements performed against various weights would therefore have to take into account the acceleration rate for a specific point in the movement (Perrine and Edgerton, 1978; Rodgers and Berger, 1974).

More recently, several studies have used isokinetic devices to study the relationship between torque and velocity in a limb movement (Moffroid et al., 1969; Komi, 1973a; Costill et al., 1976; Jorgenssen, 1976; Thorstensson, 1976; Thorstensson, Grimby, and Karlsson, 1976; Perrine and Edgerton, 1978; Coyle, Costil, and Lesmes, 1979; Gregor et al., 1979; Fugl-Meyer, Gustafsson, and Burstedt, 1980).

These studies have found relationships for various subject populations and for a range of limb movements:

(i) subject populations

- male athletes (Jorgenssen, 1976; Thorstensson, Tesch, and Larsson, 1977)
- female athletes (Gregor et al., 1979)
- subjects classified by age (Larrson, Grimby, and Karlsson, 1979; Fugl-Meyer et al., 1980).

(ii) limb movements

The majority of studies, however, have concentrated on the T-V relationship for knee extension (Thorstensson, 1976; Caiozzo et al., 1981; Coyle et al., 1981). Other limb movements that have been used are elbow flexion (Komi, 1973a; Rodgers and Berger, 1974), plantar flexion of the ankle (Fugl-Meyer et al., 1980), and knee flexion (Knapik and Ramos, 1980; Scudder, 1980).

To obtain these relationships studies have differed both in the measurements taken and in the range of velocities used; measurements have been joint angle specific, where the torque obtained at each velocity was measured at a specific joint angle (Gregor et al., 1979; Caiozzo et al., 1981). Other studies have used the maximum torque recorded throughout the joint range at each velocity (Moffroid et al., 1969; Thorstensson, 1976; Coyle et al., 1979; Knapik and Ramos, 1980; Clarkson et al., 1982).

The range and number of velocities used in the studies also varies considerably. For example, Thorstensson (1976) obtained torque curves using peak torque scores obtained at seven angular velocites of movement, between the range of 0 deg/sec to 180 deg/sec inclusive. In contrast, Gregor et al. (1979) obtained torque curves using the angle-specific torque values (30 degrees before full knee extension) from four angular velocities, within the velocity range of 0 deg/sec to

280 deg/sec inclusive.

Finally, although most of these relationships have been obtained using a Cybex II, a few studies constructed their own isokinetic device to obtain this relationship (Jorgenssen, 1976; Komi, 1973a), or made adaptations to the Cybex II to give a wider velocity range (Ingemann-Hansen and Halkjaer-Kristensen, 1979; Coyle et al., 1981).

2.2.2(b) the form and interpretation of the relationship

In explaining these relationships some studies have interpreted the T-V curves as measures of the tension produced in muscular contractions; they have not considered that torque is the result of many factors, of which the tension produced in muscles is only one factor (Komi, 1973a; Thorstenssen, 1976; Perrine and Edgerton, 1978). It is this emphasis which has led some researchers to describe the T-V relationships as if they were in vivo versions of experiments designed to obtain the force-velocity relationships of muscles in vitro (Rodgers and Berger, 1974; Jorgenssen, 1976; Perrine and Edgerton, 1978). This is highlighted in the terminology they have used; the constant velocity of a limb movement is referred to as a constant velocity muscular contraction. An example of this is Perrine and Eggerton's (1978) description of a method of obtaining an in vivo force-velocity relationship:

> A method wherein the muscle is allowed to first attain some specific contractile velocity without loading and then finding, by some suitable method, the maximum load the muscle can meet and carry past a given position at that speed. These prerequisities are fulfilled by the isokinetic loading dynamometer, which allows for a direct measurement of at least the lower-velocity portions of the force-velocity relationships of various human muscles in vivo (p. 159).

As a result of this interpretation several studies have reported that the T-V relationships obtained from voluntary limb movements show similarities to the in vitro F-V relationships (Komi, 1973a; Jorgenssen, 1976; Thorstensson, 1976). For example, Jorgenssen (1976) reported that the hand-drawn force-velocity curves for elbow flexion and extension were similar to the classical in vitro curve, although it was not possible to fit the data points to Hill's equation. As a result, Jorgenssen (1976) suggested that it was not possible to calculate the muscle's maximum shortening speed.

In contrast, Thorstensson (1976), on the basis that the in vitro and in vivo curves looked similar, extrapolated from the T-V curve obtained in vivo an approximated value for the maximum speed of shortening in the knee extensor muscles. The T-V curve obtained, and the extrapolation, are shown in Figure 2. It can be seen that the torque values were obtained at angular velocities within the range of 0 deg/sec to 180 deg/sec inclusive. the extrapolated maximum velocity was

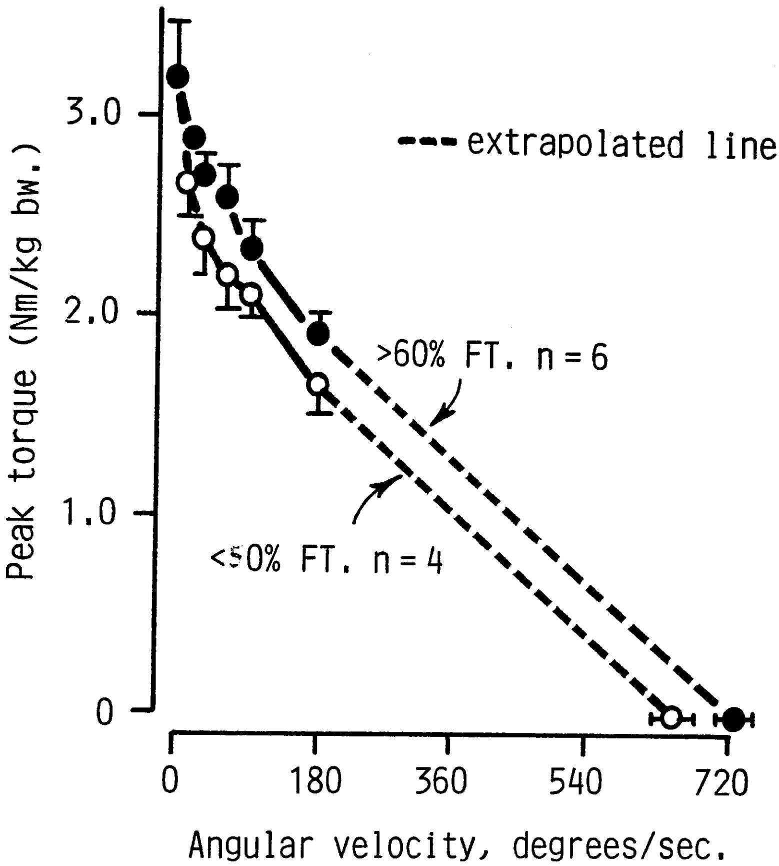


Figure 2 Peak torque-velocity relationships for two groups of subjects differing in fibre composition. The relationships were extrapolated to values for maximal velocity of knee extension.

ote from "Muscle strength fibre types and enzyme activities in man" Thorstensson, 1976, Acta Physiologica Scandinavica Suppl. 443

determined by continuing the hand-drawn line through the average data points for 10 subjects, until the line crossed the x axis, indicating 0 force produced and maximum shortening velocity. The extrapolated maximum velocity was found to be approximately 720 deg/sec.

Komi (1979) also found similarities between the in vivo and in vitro relationships and described them as follows:

> One of the most important aspects of muscle mechanics is the force-velocity relationship, which has a basic form that is similar for a single fibre, one muscle, a muscle group or even for the combined action of several muscle groups in normal movements such as jumping (p. 2).

Other studies would not agree with the above statement; instead, they have used their relationship to point out the differences between the in vivo relationship and the classical form of the in vitro relationship (Perrine and Edgerton, 1978; Gregor et al., 1979; Caiozzo et al., 1981). These differences led Perrine and Edgerton (1978) to the following conclusions:

> The present in vivo muscle force-velocity data deviate markedly from the basic force-velocity relationship that has been found to generally hold for isolated and maximally stimulated muscles from a broad range of animals (p.164).

Indeed, when a comparison was made of all the relationships, in the studies mentioned so far, it would appear that there are differences in the forms of the relationship, not only in comparison to the classical in vitro form, but also between the in vivo studies themselves.

As a result of this comparison it would appear that the major inconsistencies in the form of the T-V relationship are due to differences obtained at the lower velocities. Some studies show that the torque scores decline rapidly as velocity increases from 0 deg/sec (Jorgenssen, 1976; Thorstensson, 1976; Knapik and Ramos, 1980; Scudder et al., 1980). A different trend, however, was described by Rodgers and Berger (1974), although they found, as did the studies above, that there was a rapid decline in the torque scores from 0 deg/sec, they did not find that this decrease continued at the subsequent velocities tested; that is, at 9 deg/sec, 72 deg/sec, 108 deg/sec, and 144 deg/sec. Indeed, they reported that, between these velocities, the torque scores only decreased by 17.4% as the velocity increased. They also reported that the differences between adjacent velocities was only significant ($p < 0.05$) for the difference between the torque scores obtained at 108 deg/sec and 144 deg/sec.

There are also studies which have not found that the torque scores decline as velocity increases in the low velocity, high torque region, even from 0 deg/sec. In these studies the torque scores show a plateau across all the lower velocities, and in some cases there is even an increase in the torque produced as the velocity increases (Moffroid et al., 1969; Perrine and Edgerton, 1978; Gregor et al., 1979; Caiozzo et al., 1981). For example, Perrine and Edgerton (1978) described the relationship obtained as bi-phasic, where, as velocity decreased between 280 deg/sec and 192 deg/sec, a rapid rise in the torque scores was found; however, as the velocities decreased below 192 deg/sec a distinctly different trend was found, where the relationship showed a sharply diminishing rate of rise. Moreover, it was reported that the highest torque scores for two thirds of the subjects was obtained at a velocity of 96 deg/sec, and for the remaining third of the subjects a slight rise in torque was found as the velocities decreased below 96 deg/sec, with the highest torque score being obtained at 0 deg/sec.

Although the differences between the studies are mainly in the low velocity, high torque region, they affect the form of the whole relationship, causing wide variation in the forms reported. This fact makes it difficult to get a clear indication of the form of the torque-velocity relationship.

This lack of clarity was highlighted by Murray et al. (1982b), when they compared the data from the following relationships:

1. classical force-velocity relationship obtained from in vitro studies;
2. the force-velocity relationship of the knee extensors (using a Cybex) obtained by Moffroid et al. (1969), Perrine and Edgerton (1978) and Thorstensson et al. (1976).

These relationships are shown in figure 3 and 4, and it is quite clear that there are major differences in the forms of the relationships. In other words, Murray, et al. (1982b) clearly showed the vast differences not only between the in vitro and in vivo force-velocity relationships, but also between the in vivo force-velocity relationships themselves:

> Firstly, curves often do not follow Hill's classical form. Secondly, group mean observations of particular Cybex studies are frequently described adequately only by unique mathematical functions... Conflicting results and incomplete measures prevent a clear understanding of the nature of the force-velocity associations (p. 2).

The conflicting results of these studies, therefore, make it more and more difficult to clarify the complex nature of the force-velocity relationship.

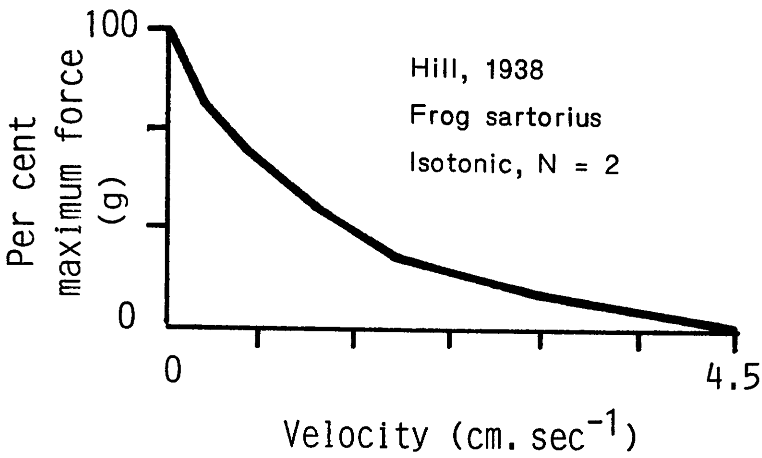


Figure 3 Reported concentric force - velocity curves

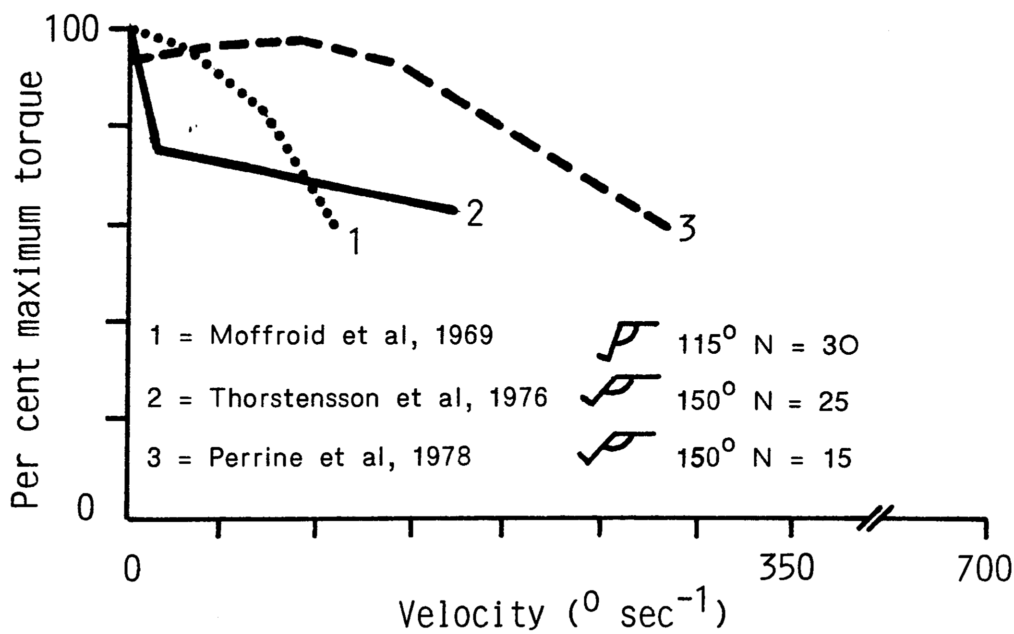


Figure 4 Reported force - velocity relationships using cybex (knee extension).

Note Figures 3 and 4 from "Electromechanical dynamometers for human muscle function testing" Murray, Wood, Mil Cresp and Harrison, 1982. Paper presented at 22nd Ann Conference on Physical Sciences and Engineering in Medicine and Biology, August 9-13, Perth, Western Australia.

2.2.3 The Complexity of Torque Generation in Human Movement

The differences outlined in these studies, particularly when compared to the classical form of the in vitro relationship, are not surprising, given the complexity of force generation in voluntary human limb movements. Indeed, it could be argued that making comparisons between T-V relationships obtained on a Cybex and F-V relationships obtained in vitro is erroneous, or is at best an oversimplification of the force generation processes of human voluntary movements.

In the next section it will be argued that the complexity of limb movements, in comparison to the simplicity of the isolated muscle condition, is responsible for the diverse results reviewed above. Two aspects will be considered: methodological considerations and differences in stimulation. It is essential to highlight the fact that force generation in voluntary movement is complex; there are many factors, other than tension in a muscle, which affect the production of torque.

2.2.3(a) methodological considerations

From a purely methodological point of view criticism has been levelled at those studies using peak torque to represent the force-velocity relationship of the muscles in vivo. Criticism was directed, for example, at Thorstenssen et al. (1976), at Scudder

(1980) and at Coyle et al. (1981). The justification of this criticism has been provided by Moffroid et al. (1969), Knappik et al. (1980), Murray et al. (1980), and Charteris and Goslin (1982), who have shown that, as the velocity of a movement increases, peak torque occurs at a later joint angle in the movement. In this way, the peak torque-velocity (PT-V) relationship will now reflect not simply the effect of velocity on muscle force, but also the effects of different muscle lengths and moment arms, as the joint angle at which PT is measured changes.

Furthermore, other studies have argued that since the in vitro force-velocity relationships are obtained from a constant initial muscle length, they cannot meaningfully be compared to the peak torque relationships obtained using varying muscle lengths (Caiozzo et al., 1981; Gregor et al., 1979).

In addition, Hinson, Smith, and Funk (1979) pointed out that using terminology such as "constant linear rate of muscular contraction", used by Hislop and Perrine (1967) and Perrine (1968) to describe the action of muscle in response to constant velocity voluntary limb movements, is erroneous. Hinson et al. (1979) were able to present a mathematical argument to indicate that when the angular movement of a limb is held at a constant velocity the corresponding change of muscle length is not constant, nor is its acceleration through the range of a joint movement constant. Hinson and co-workers (1979) suggested that the term isokinetic "may be reserved to denote a type of muscular contraction which accompanies a constant angular rate of movement, rather than a constant linear rate of muscular shortening" (p. 34). Clearly this clarification argues against the notion that the isokinetic device can be used to measure the in vivo force-velocity relationship of muscles.

2.2.3(b) differences in stimulation

The complexity of force generation in voluntary human movement, in comparison to in vitro conditions, is further emphasised by the difference in the stimulation. This was summed up by Asmussen (1973) as follows:

> Data obtained on isolated, artifically stimulated muscles cannot uncritically be transferred to muscles in situ. The reasons for this are several, the most important probably being that in the body the muscles are stimulated by nervous impulses coming from the central nervous system, and the functional capacities of this system must, therefore, also be considered (p. 61).

In other words, in isolated muscle the force-velocity measurements are obtained where the muscle is artifically, tetanically stimulated. Under these conditions all fibres will fire at once, and the force-velocity relationship obtained will represent the physiological limits in the muscle, in terms of its maximum force output and contraction velocity at different loads. This is in complete contrast to the stimulation and control of even the simplest of voluntary human limb movements, where force production is controlled by the central nervous system. It has been shown that the C.N.S. controls the amount of force produced by regulating both the number of motor units it recruits and the frequency of firing of these active motor units (Milner et al., 1973a, 1973b; Burke, 1980; Desmedt, 1980). Burke (1980) describes the role of the C.N.S. as follows:

> The final step in the control of movement by the central nervous system thus involves the inter-related mechanisms of recruitment of motoneurons and modulation of their firing rates (p. 255).

The maximum force a muscle could produce is therefore a matter of all the motor units being recruited, with the frequency of firing such that these units are in sustained tetanus.

However, other studies have suggested that sustained tetanus of all motor units cannot be achieved in human voluntary movement (Ikai and Steinhaus, 1961; Perrine and Edgerton, 1978; Caiozzo et al., 1981). For example, Perrine and Edgerton (1978) suggested that the plateauing at the low velocities, in the in vivo force-velocity relationship, was due to a neural tension limiting mechanism; this mechanism inhibits the sustained tetanus of all motor units. They compared the data points in the in vivo relationship with an in vitro relationship calculated from Hill's equation. Approximate calculations revealed that the regulator mechanism could be restricting the maximum voluntary tension level of the in vivo muscle to as little as 50% of its actual peak mechanical potential at zero speed.

This levelling-off phenomenon was observed by Caiozzo et al. (1981) who looked at the training induced effects in the in vivo force-velocity relationship in untrained subjects. Training at slow velocities had a significant effect on the levelling-off phenomenon, an effect which was not found in subjects trained at high velocities; the latters' relative improvement was the same across the whole in vivo relationship. The conclusions drawn from this experiment were that training at slow velocities had an effect on the neural tension limiting mechanisms, causing an enhancement of the motor neuron activation at slow velocities. Moreover, optimum motor neurone activation can be affected by psychological factors. For example, Ikai and Steinhaus (1961) were able to show that shouts, pistol shots, and hypnotic suggestion could enhance motor neuron activation and an increased production of force. They suggested that psychological, rather than physiological, factors determined the limits of human performance.

However, other studies have shown that there is no difference between force obtained in a maximum voluntary contraction and force obtained in the same muscles when stimulated electrically (Merton, 1954; Belanger and McComas, 1981). These studies suggest that the maximal force of a muscle can be produced in a maximum voluntary contraction. It must be pointed out, however, that these studies have used small muscle groups such as the thumb adductors.

Up to this point the regulation of force has been considered in terms of the numbers of motor units recruited, and of their frequency of firing. It must also be considered, however, that even a simple movement involves many muscles. To produce force the central nervous system must also organise and sychronise the firing, and frequency of firing, to obtain a motor pattern suitable to the movement (Fujiwara and Basmajian, 1975; Knutsson, 1982). The importance of this organisational function of the C.N.S., in terms of maximal force production, was shown by Knutsson (1982). In his study, he was able to show that the aberations from normal motor control, in terms of the organisation and sychronisation of muscles, caused below normal torque scores in patients with spastic paresis, as they performed maximal voluntary movements at constant angular velocities. (Patients with spastic paresis are those diagnosed with organisational dysfunction of the C.N.S..)

It could be concluded, therefore, that an important role of the C.N.S in force production is to synchronise and organise the firing and firing rate of the motor units of muscles involved in the movement pattern.

Given this role of the C.N.S., some researchers have concluded that in a maximal effort, where different speeds of movement are required, the force exerted will not be determined by the physiological limits of the muscle but by the neural pathways specific to the speed of movement (Smith, 1961; Whitley, and Smith, 1963; Knapik and Ramos, 1980).

Evidence for this comes from the interrelationships between maximal performances in limb movements loaded in various ways (isometric, isotonic, isokinetic); they suggest that the greater the difference between the tasks, in terms of the speed of movement, the greater the neurospecificity obtained (Whitley and Smith, 1963; Knapik and Ramos, 1980). The greatest individual differences are found between measures of isometric strength and measures of maximum limb speed moved by these muscles (strength in action). In general, the correlations between these two measures are low (Henry and Whitley, 1960; Whitley and Smith, 1963). Some correlations do not even differ significantly from zero (Clarke and Henry, 1961; Smith, 1961).

Consistently better correlations have been found in the intercorrelations between PT scores obtained at various constant velocities of movement (Fugl-Meyer et al., 1980; Knapik and Ramos, 1980), and in studies where different speeds of movement are obtained by loading the limb with weights (Whitley and Smith, 1963; Lambert, 1965). However, even in these studies there is still evidence to suggest that as the tasks become more dissimilar in terms of speed of movement the specificity increases. For example, Knapik and Ramos (1980) measured PT at the angular velocities of 0 deg/sec, 30 deg/sec, 90 deg/sec, and 180 deg/sec. They reported that the generality between the immediately adjacent velocities ranged from 31% to 81%. This generality decreased to 20% to 55% when the velocities immediately adjacent were compared. In explanation of this specificity between the torque at different isokinetic velocities Knapik and Ramos (1980) suggested the following:

> It may be that as the isokinetic velocities become further apart, the motor tasks become more dissimilar, requiring different patterns of neural recruitment and co-ordination (p. 66).

Clearly this indicates that even for the torque produced at a range of constant velocities the maximum torque exerted will be affected not only by the physiological limits of the muscle but also by the neural pathways which are specific to the velocity of the movement.

It could be concluded from these studies that in a maximal effort, where different speeds of movement are required, there will be individual differences in the force exerted. Furthermore, the greater the difference between the tasks, in terms of the speed of movement, the greater the individual differences. Given these results, these studies conclude that neural factors specific to the velocity of the task account for these individual differences.

However, Eckert (1965) pointed out that there may be factors, other than neurospecificity, to account for low correlations, especially for those between isometric strength and maximum limb speed. Eckert (1965) suggested that these low correlations might be due to the fact that an individual cannot attain the maximal limb speed, which would reflect the physiological limits of a muscle, in terms of force production, because of the anatomical limitations of the joint movement. The measurement of maximal limb speed would therefore not reflect the individual's maximum strength in action of an unloaded limb.

This was confirmed by Wilkie (1950) who measured the velocity curves of maximal limb movements loaded with various weights. Figure 5 shows that the velocity curve for the unloaded limb does not appear to have reached its maximum speed by the end of the movement. Similarly, Perrine and Edgerton (1978) suggested that the F-V relationships of muscles in vivo cannot be measured at the high shortening velocity region because of the inherent limitation of all in vivo F-V testing methods; the methods are limited in that they cannot allow the muscle enough time to develop full tension before an associated joint reaches the end of its

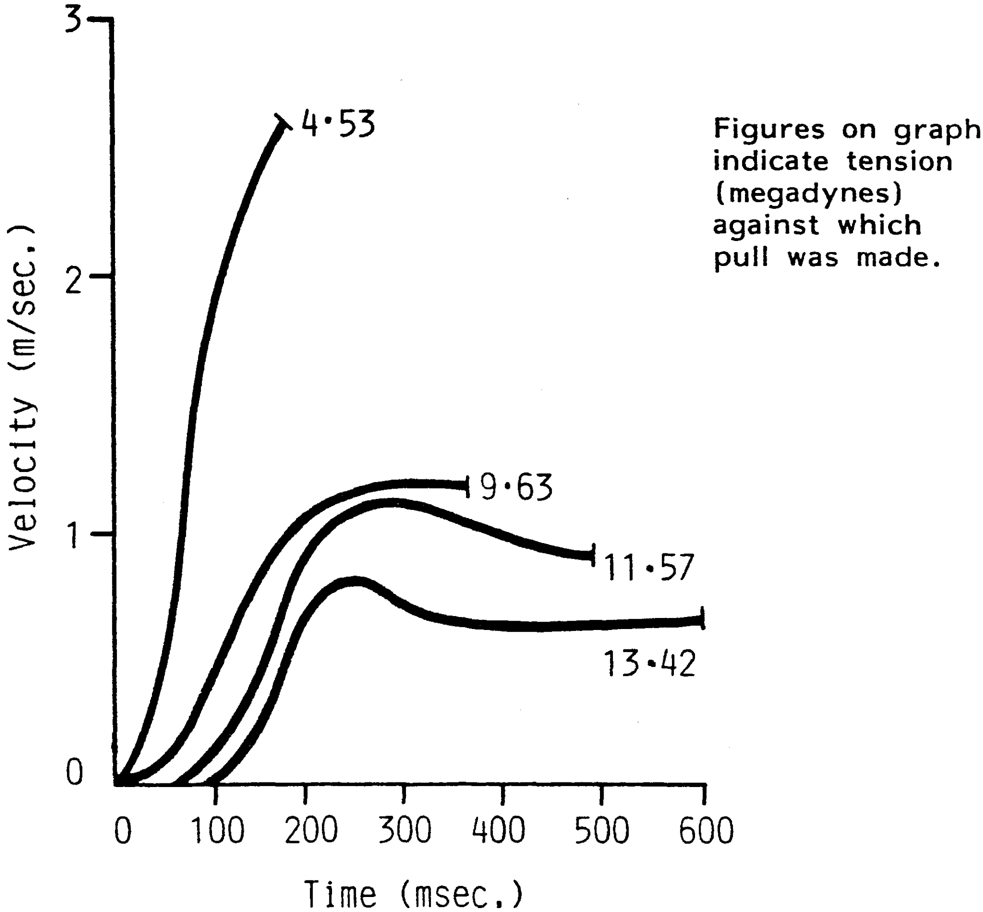


Figure 5 Velocity time curves (n = 1) for elbow flexion. The subject pulled with a maximal effort against a succession of weights. The bar at the end of each curve marks the end of the movement.

Note From "The Relation Between Force and Velocity in Human Muscle" by Wilkie, 1950, Journal of Physiology 110.

anatomical range of movement at high test speeds.

In conclusion, these studies suggest that force generation in limb movements is extremely complex; factors other than the physiological limits of the muscles could affect the scores. Asmussen (1973) has defined this complex process as follows:

> Muscular strength and power is the integrated expression of what the neuromuscular system can do under the existing conditions (p. 62).

Interpretation of a torque-velocity relationship, from voluntary movements, must, therefore, consider it as the relationship of the limb movement with its underlying neuromuscular mechanisms, and not focus exclusively on the muscles involved. Few studies of the F-V relationship have taken this into account. Indeed, the main emphasis of the studies was to compare the in vivo and in vitro curves. However, as was shown earlier, this approach has led to confusion in the understanding of the relationship between torque and velocity. Indeed, when comparisons were made between the in vitro and and T-V relationships, there were not only differences between the T-V and in vitro relationships but also differences between the T-V relationships themselves. It is perhaps not surprising that there are differences in the form of the T-V relationship, given the complexity of force generation in a limb movement. This is especially true when it is considered that the construction of these T-V relationships varied in terms of the subject populations' characteristics, of the muscle groups, of the measurement taken, of the velocity range, and of the testing devices used. Few studies have considered that these differences in design might be the cause of the differences in the form of the T-V relationships.

Clearly, there is a need to investigate the variations in the T-V relationships, rather than to continue to make comparisons with the in vitro relationship; studies must be designed to allow variation of the T-V relationship to be investigated. Perrine and Edgerton (1978), for example, stressed the importance of studying these variations:

> Further studies will be necessary, however, to determine the exact nature and significance of specific variations within the general form of the in vivo muscle force-velocity relationship associated with different muscle groups, joint angles, subject populations etc (p. 163).

One method of doing this has been developed by Fugl-Meyer et al. (1980), where the form of the relationship was investigated for several sub-groups of the total subject population tested (n = 135). Sub-groups were categorised on the following basis:

1. sex,
2. side: right or left side,
3. knee position: straight knee, and flexed knee,
4. age: subjects ranged in age from 20 to 60 years; they were split into two groups, below 50 and above 50.

Fugl-Meyer et al. (1980) demonstrated that in a semi-logarithmic plot (PT on the log scale) the PT scores for plantar flexion strength declined linearly, with increasing angular velocity. The authors concluded from their results that a negative exponential model accurately summarised the relationship between isokinetic strength and the velocity of angular motion, and that this model was suitable, regardless of subjects' age, sex, knee position, or the side at which they were tested. With a similar approach to Fugl-Meyer et al. (1980) Ingemann-Hansen and Halkjaer-Kristensen, (1979) were able to demonstrate that when the PT and velocity relationship was represented on a semi-logarithmic plot (with PT on the logarithmic scale) PT scores were shown to decline linearly, as the angular velocity increased. The equation of this line, using linear regression, was calculated to be Log PT = 2.269 + -1.04 (velocity 10^{-3}), and the probability for this regression function to be linear was reported to be significant ($p < 0.05$). Although this was the result reported for one subject, the authors reported that similar results were obtained for the rest of the subjects.

What is significant about these studies is that in both these studies the approach allowed the form of the relationship to be examined for different subject groups and individuals.

Other studies have used a different approach, in that they are designed to examine the effect of one factor on the T-V relationship. For example, several studies have used this approach successfully to study the effect of fibre type composition on the T-V relationship (Thorstenssen, 1976; Gregor et al., 1979; Coyle et al., 1981). Typically they compare the T-V relationship of a subject group with a high percentage of fast twitch fibres with the T-V relationship of a subject group with a relatively lower percentage of fast twitch fibres. Differences between the forms of these two relationships indicates the effect of fast twitch fibre on the torque generating capacities at different velocities.

Although these examples described above indicate the usefulness of investigating the variations in the T-V relationship there still needs to be more research in this area before a clearer understanding of the nature of the T-V relationship and factors that affect it are understood. Given this need the present study will describe the peak torque-velocity relationship for children, at a range of different age groups, and will then examine the effect of development on the relationships obtained.

Section 3

Factors affecting the Development of the Force Generating Capacities of Children

This next section will consider the factors that must be taken into account when investigating the development of isokinetic strength in children. Several studies have investigated factors that affect the development of strength; these factors include, age gender, changes in body size, and physical activity. However, as was shown in section one, the strength measurements used were, in the main, isometric tests or performance in gross motor tasks; little has been done to examine the factors that will affect the development of isokinetic strength.

There is, therefore, little evidence to suggest that the factors affecting the development of strength measured at a range of constant velocities will be any different from the factors affecting the development of strength measured isometrically or by performance in gross motor tasks.

To indicate the possible effects of such factors as age, gender, changes in body size, and physical activity on the development of isokinetic strength this section will, therefore, review the studies that have investigated the effect of these factors on the development of strength. Consideration will also be given to any evidence which would suggest that the development of strength is velocity specific.

2.3.1 Age

Many studies of the development of strength have used age to signify different stages of growth (Meredith, 1935; Jones, 1949; Metheny, 1941a, 1941b; Cullimbine et al., 1950; Torpey, 1960; Carron and Bailey, 1974; Montoye and Lamphiear, 1977). Meredith (1935) commented that the mean course for the development of strength in boys was as follows:

> a relatively slow constant growth below 12 years, a period of rapid increase between 12 to 16 years, and a phase above sixteen years indicating a decline in growth rate (p. 39).

The question, however, is whether this general pattern of growth in terms of age holds true for all measures of strength, irrespective both of the site measured and of the method of measurment. It would be difficult to justify such a conclusion from the evidence of the studies which have investigated the effect of age on strength in children. There are perhaps two major reasons for this:

1. limited measures, limited both in terms of method and of groups tested. Typically, the measurements used in children's studies have been confined to isometric methods of strength measurement, of which the most

commonly used is grip strength; only a small number of studies have investigated isokinetic strength;

2. variation in age range, there is a wide variation of the age groups studied. For example, Metheny (1941a) reports results for children aged between 2 to 6 years, while Carron and Bailey (1974) report results for children between 10 years and 15 years.

However, even despite differences in the method of measuring, the wide variation in sites measured, and the variation in age ranges investigated, there seems to be little doubt, from the evidence of these studies that as children get older they improve in strength. For example, Metheny (1941a) measured the grip strength of children aged 2 to 6 years and found that the increase in strength was significant year by year. The correlation between the increase in strength and age was reported to be +0.9. Meredith (1935) reported that in children aged 6 to 16 years boys increased in grip strength by 359% and girls by 260%. Jones (1949) reported the strength improvements in grip, pull, and thrust in a logitudinal study of children aged 11 years to age 17 years. Strength increases with age were evaluated in terms of standard deviation scale units: for each sex the difference between the raw score means at age 11 and at sucessive ages was divided by the standard deviation at age 11. Jones (1949) suggested that these standard deviation scale units provided a convenient method for comparing different functions, such as change in body size, to changes in strength, as well as the age changes in strength of boys and girls relative to their own initial status. Jones (1949) reported that at age 11 boys increased in strength by 7 standard deviation scale units and girls by 3.5 scale units. This was the result for grip strength, but similar results were reported for the other measures.

Although little work has been done with children using isokinetic measures it is possible from the work done to show that isokinetic strength increases in a variety of measures, and indeed at different velocities, as children get older. Alexander and Molnar (1973) and Molnar and Alexander (1973) in two pilot studies measured peak torque at an angular velocity of 30 deg/sec for elbow and knee flexors and extensors. Alexander and Molnar (1973) reported results for 36 boys and 34 girls aged 7 to 15 years, and Molnar and Alexander (1973) reported results for a further 50 boys and girls aged 7 to 15 years for the same movements. In both these studies it was reported that as age increased PT increased. The correlation between age and PT was reported to be 0.89 (for all measures).

Molnar and Alexander (1974) extended their study on isokinetic muscle strength in children to include PT measurements taken on the hip and shoulder flexors, extensors, and abductors. In this study they reported

PT scores at 30 deg/sec for 500 subjects aged between 5 and 17 years. Their results were similar to those of the other studies, in that PT increased as the chidren got older.

Gilliam et al. (1979b) obtained PT scores at more than one isokinetic velocity. They reported PT scores for 28 boys and 28 girls for knee and elbow extension and flexion performed at angular velocities of 30 deg/sec and 120 deg/sec. They reported that the correlations between age and PT scores, for each angular velocity, at each limb movement, ranged from 0.71 to 0.85. They also found that the velocity of movement had no significant effect on the magnitude of the correlation.

Although it could be suggested that, in general terms, strength increases with age, there are differences in the results; there are variations both in the age at which strength is reported to make its greatest gain and in the age at which the growth rate of strength declines. This can be most clearly illustrated in a table, devised by Espenchade and Eckert (1980), which includes the strength data collected from 115 boys and 101 girls, 7 to 12 years, in Wisconsin Elementary School. The mean strength scores for both boys and girls are shown for a variety of isometric strength measures: ankle extensor, knee extenors, wrist flexors, shoulder abductors, and hip extensors (Table 1).

TABLE 1

Isometric Strength Means for Various Muscle Groups (in pounds)

Age (years)	7	8	9	10	11	12
Ankle Extensor						
Boys	60	67.5	83.5	89.5	96 †	123.5
Girls	56.5	66.5	75.5†	96.5	101.5	102
Knee Extensor						
Boys	63.5	75	96.5	107.5	110.5†	151.5
Girls	64.5	76.5	83.5†	116.5	127.5	139.5
Hip Extensors						
Boys	40.5	46.5	58	59.5	65.5†	87.5
Girls	34.5	44.5	47	57.5	63.5	73
Elbow Flexors						
Boys	31.5	41.5	45	50.5	56.5†	67.5
Girls	31	35.5	41 †	50.5	50.5	56.5
Shoulder Abductors						
Boys	37	49	53	53.5	64 †	81
Girls	33.5	43.5	43.5†	55.5	56	59
Shoulder Medial Rotators						
Boys	20	25.5	27.5	28	31.5†	37.5
Girls	16.5	21	22.5	25.5	28.5	29
Wrist Flexors						
Boys	23	25.5	29.5	32.5	33 †	42
Girls	20.5	22	25	28.5	29.5†	39

† Start of period of greatest gain.

Note: From 'Motor Development', Espenschade and Eckert, 1980, University of California, C.E. Merrill, copyright Bell and Howell Company, 1980. p. 189.

These results suggest that the mean period of greatest gain varies considerably. For example, the period of greatest gains in strength for the girls, in four of the strength measures, was between 9 and 10 years, while boys made their greatest gains in strength, in seven of the strength measures, between 11 and 12 years. This study also shows variations in the onset of the greatest gain in the various muscle groupings. For example, boys and girls both make the greatest gain in wrist flexors between 11 and 12 years, whereas there is a difference of 2 years in the onset of gains in other muscle groupings for the sexes.

Similarly, Jones (1949) also found that the period of greatest gain varied depending on the area of the body at which strength was measured. For example, the period of most rapid gain for boys in grip strength was 13.5 to 15 years, but in pulling and thrusting strength it occurred a little later, between 13.5 to 16 years. Jones (1949) also showed that this was related very much to the maturity of the individual.

Carron and Bailey (1974), in a longitudinal study of boys aged 10 to 17 years, found that the largest increase in strength occured between the 10th and 11th year; this is younger than any of the other studies reported. They suggested, however, that the large increment between these two years might be a product of the test design; that is, in the 11th year subjects scored better because they were more familiar with the test.

Miyashita and Kanehisa (1979) reported PT scores for girls and boys aged 13 to 17 years in knee extension performed at a constant angular velocity of 210 deg/sec. They showed the rate of increase in isokinetic strength with age. They reported that PT scores increased linearly with age in boys from the age of 13 to 16 years, but found that there was no statistical difference in the PT scores between the age of 16 and 17 years. In girls there was only a significant increase in the PT scores between the ages of 13 and 14, and between the ages of 14 to 17 years the PT scores were reported to have remained constant.

It could be concluded from these studies that although strength increases with age there are variations both in the age at which strength is reported to make its greatest gain and in the age at which the growth rate of strength declines. Moreover, these variations will be affected by the area of the body in which strength is measured and by the gender of the individual.

Another important factor to consider in the effect of age on strength is that although as children get older they improve in strength, there is a wide range of scores within any one age group. For example, the study, mentioned earlier, by Alexander and Molnar (1973) reported that the correlation between age and PT scores was 0.89; this indicates a high positive relationship between the increase in PT and the increase in age. They also reported, however, that for any age group PT scores varied widely. These individual differences are to be expected; they reflect the fact that many factors, apart from growth, affect the strength of an individual. However, the variability of strength during the developmental years could also be a reflection of the fact that, within any age group, individuals will be at different stages in their development. This is highlighted by the results obtained by Jones (1949) concerning the changes in variability of strength scores for adolescents, from the ages of 11 to 17 years. He found that although the standard deviations of the strength scores increased in response to accelerating gains in the mean strength scores, the changes in standard deviations were not merely proportional to the growth of these mean scores. He found that during one phase of adolescence the variability increased more rapidly than did the group means. This was illustrated by the coefficients of variation (standard deviations expressed as a percent of the corresponding age means). Figure 6 shows the standard deviations for right grip strength, and Figure 7 shows their corresponding coefficients of variation. It would be expected that if the variabilty shown by the standard deviations in

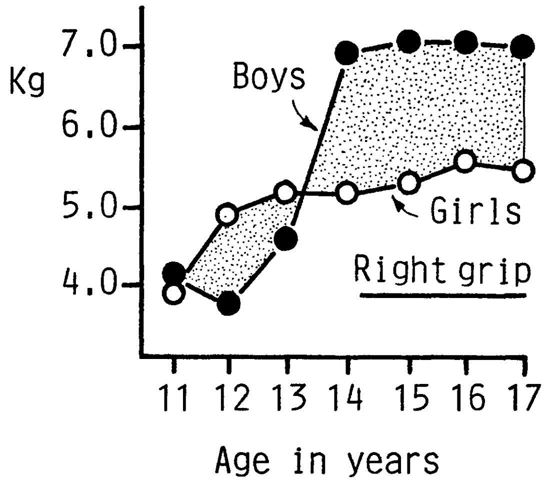


Figure 6 Standard deviation of strength scores by age.

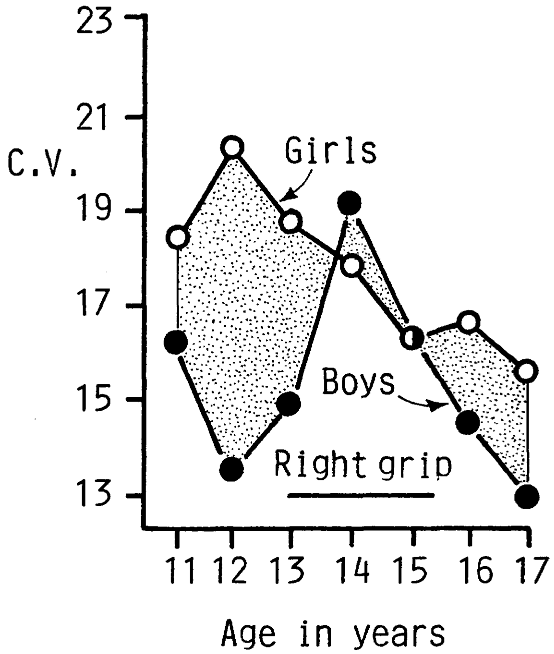


Figure 7 Coefficients of variation of strength scores by age.

Note Figures 6 and 7 are from "Motor Performance and Growth" by Jones, 1949, University of California Publications in Child Development.

Figure 6 was merely increasing in proportion to growth, the co-efficients of variation would remain constant. It can be seen from Figure 7, however, that the co-efficients of variation are not constant. Jones (1949) suggested that the co-efficients of variation obtained indicated cyclical changes in the relative variability which would be expected if the pubertal growth spurt appeared earlier in some individuals than in others. Its appearance in those first to mature would produce an increasing heterogeneity of scores, followed by a return toward more normal variability, as an increasing majority of cases completed their growth spurt.

This indicates that age is no more than a simple indicator of stage of development, and it would be expected that within any age group individuals will be at different stage of development. This is most clearly seen during adolescence, where there is the greatest variabilty in stages of devlopment with respect to age.

2.3.1a age and sex differences in strength

It is difficult to get a clear picture either of the age at which sex differences appear in strength or of the extent of these differences.

There have been studies which have found boys to be significantly stronger than girls, even at pre-school ages. It must be noted, however, that the majority of these studies have used grip strength as a representative measure. Metheny (1941a), for example, found that the mean grip strength of boys exceeded that of the girls in children aged 3 to 6 years. Indeed, even when the results were adjusted for differences in height the boys were still significantly stronger at age 5 ($p < 0.05$) and at age 6 ($p < 0.01$). In a review of several studies measuring the strength of children at pre-school and elementary stages, Metheny (1941b) reported that all the studies showed that the boys were on average stronger than the girls. All the studies she reviewed used grip strength. This conclusion is highlighted in the following statement Metheny (1941b):

> The existence of a sex difference in strength of grip has been implied by every investigator who has reported separate values for boys and girls (p. 125).

Indeed, the following excerpt is an example of the implied sex difference she found in the studies she reviewed:

> Boys surpass the girls in strength at all ages; even in the kindergarten the average boy is stronger in his left hand than the average girl is in her right hand (p. 125).

These studies would clearly indicate that sex differences in strength appear at a very early age. However, since only grip strength has been used to measure the strength of very young children this early appearance of a sex difference might only be true for grip strength. For example, Martin (1918), using the sum of 22 strength measures in children aged 5 to 18 years, found boys to be stronger than girls, except at the age of 5 years; this indicates that strength difference did not appear before the age of six. Similarly, Torpey (1960) found no sex differences in knee extensor strength in children of the first six grades. Asmussen (1980), although his results were expressed in relation to height, found that sex differences in children aged between 7 and 17 were more apparent in some strength measures than in others. Greater differences were noted in measures of strength from the upper body, such as the shoulder extensors, and finger flexors (grip strength), in comparison to measures of strength from the lower body, such as the knee extensors and hip flexors.

It could be concluded that the age when sex differences first appears varies and is affected by the site of the measurement.

The variability in sex differences for different measures of strength is perhaps highlighted in the strength data, referred to earlier, which were collected from the children in Madison Wisconsin Elementary School and cited by Espenschade and Ekert (1980) (see Table 1, p. 70). It is apparent from these results that there is a high degree of variability in the level of sex difference when the scores for each age and for each measure are analysed separately; in some cases the mean score of the girls is superior to that of the boys. For example, at age 8 the girls' mean score for knee extension is higher than the boys' mean score. The reverse is true, however, for the mean score at age 8 for the other six measurements. Espenchade and Eckert (1980) confirmed that there is wide variability in scores, with some girls being stronger than some boys, although, they suggested that boys on average have higher mean strength scores than girls.

This pattern is also demonstrated by Jones (1949). He calculated the percentage of boys surpassing the mean scores of the girls in pulling, thrusting, and in grip strength, for children aged 11 to 17. At the age of 12 the boys surpassed the girls' mean score by 40% in the thrust, by 55% in the pull, and by 75% in grip strength. After the age of 13 there was a rapid increase in these percentages described by Jones (1949) as follows:

> Sex distributions overlap so little after the age of 16, that practically no girl reaches the boys' means and practically no boys perform as low as the girls' average level (p. 41).

It would be expected that the pattern outlined by Jones (1949) and Espenschade and Eckert (1980) would also hold true for studies investigating sex differences in isokinetic strength. Miyashita and Kanieshia (1979) investigated the sex differences in the PT scores for knee extension at 210 deg/sec for girls and boys aged 13 to 17 years. They reported significant differences between girls' and boys' PT scores at each age, with boys having significantly higher scores ($p < 0.05$) than girls at each age. Similarly, Molnar and Alexander (1973) found that the mean scores of boys were higher than the mean scores of girls at the ages of 7 years, 12 years, and 15 years. It must be noted, however, that in this study the difference obtained was an observation, and not a result based on statistical analysis.

2.3.3 Body Size and Strength

Many studies have investigated body size and the development of strength. Two different approaches have been used in these studies to investigate this area. These are as follows:

1. studies investigating the extent to which changes in body size, particularly in muscle, account for the changes in strength;
2. studies investigating the actual relationship between different body size measures and strength.

This section will review studies involved in both types of investigations.

2.3.3(a) general body size and strength

During growth the dimensions of the body increase; this increase can be regarded in linear measurements, such as height, cross-sectional areas, such as muscle, or volumes, such as blood. It is a common belief that this increase in size, particularly in the the cross-sectional measurement of muscle, has much to do with the increase in strength. Indeed, studies have shown that the maximum voluntary isometric force which can be produced is proportional to the muscle's cross sectional area (Morris, 1948; Ikai and Fukunaga, 1968).

To examine the extent to which increases in strength are related to individual increases in size, and in particular muscle size, comparisons have been made between changes in strength and changes in body size. For example, Jones (1949) in a longitudinal study of isometric strength for children, from 11 years to 17 years, examined the increase in strength related to increases in body size. He compared the increase in body size measures to the increase in strength measures in terms of standard deviation scale units (for each sex the difference between the raw score means at age 11 and sucessive ages is divided by the standard deviation at age 11). Jones (1949) found that the strength scores improved beyond the scores of body size. For example, boys' right grip strength increased 7.61 standard deviation scale units, whereas, height increased 5.25 scale units.

Other studies have been more specific in their investigations; they have attempted to investigate the extent to which changes in muscle size account for changes in muscle strength (Asmussen and Heeboll-Nielsen, 1956; Carron and Bailey, 1974; Corlett, 1984). It must be noted, however, that in these studies changes in muscle size are not measured directly, but assumed from changes in body dimensions. This technique is based on dimensionality theory, which assumes that individuals are geometrically similar, and that the dimensions of an individual are proportional. Astrand and Rodahl (1977)explain this dimensionality theory as follows:

> If we take two geometrically similar cubes of different size, the relationship between the surface and the volume of the two cubes can easily be calculated when only the scale factor between the sides of the cubes is known. If this length scale is L:1, the surface ratio is L2:1, and the volume ratio L3:1 (p. 369).

When this principle is applied to humans, Astrand and Rodahl (1977), suggest, the dimensions of the body, in terms of its linear dimensions, cross-sectional areas, and volumes, will change dimensionally as a solid cube does:

1. changes in body length are linearly proportional to themselves, proportional to L1;
2. changes in area are proportional to the square of the changes in length, proportional to L2;
3. changes in volume are proportional to the cube of the changes in length, i.e. L3.

Based on these assumptions changes in the cross-sectional area of muscle can be represented by changes in simple body size measurements. For example, using height, changes in the cross-sectional area of muscle will be proportional to height squared. Since studies have shown that strength is proportional to the cross-sectional area of muscle it is hypothesised that strength can also be predicted from simple linear measurements. If actual strength measurements deviate from those predicted by changes in body size, this suggests that there is another factor, besides changes in muscle size, that accounts for the change in strength (Asmussen and Heeboll-Nielsen, 1956; Carron and Baily, 1974).

Using dimensionality theory Corlett (1984) was able to show that, for 240 Tswana children aged between 7 to 13 years, grip strength increased to a greater proportion than could be predicted from changes in body size. Similarly, Asmussen (1980), using 22 different strength measures, found that strength increased far more than would be expected from increases in linear dimensions. Asmussen (1980) pointed out that this increase varied according to the various muscle groups tested. Carron and Baily (1974), in a longitudinal study of boys, revealed that composite strength increased on average 22.7% per year. From linear dimension predictions, based on the dimensionality theory, it should have been 12.1%.

It could be concluded from the studies cited so far that strength does increase wth body size, but to a greater extent than would be expected if the increase was due to size alone. On the basis of their results, and working from their assumption that increases in body size indicated a proportional increase in muscle size, Asmussen and Heeboll-Nielsen (1956) stated that it was reasonable to assume the following:

> that the measured extra increase in strength is due to qualitative changes. These changes may be muscular, i.e.due to changes with the muscle fibres proper, or they may be nervous, due to an increased ability to mobilize muscles voluntarily (p. 600).

Asmussen and Heeboll-Nielsen (1956) also suggested that these qualitative changes were maturational, with muscle strength improving independently of growth in size. This point of view was also taken by Corlett (1984), who suggested that maturational factors, such as the ability to apply force more efficiently and appropriately could account for some of the improvement in performance.

Asmussen (1980) suggested that an important factor for this maturation was age. Using the strength and height data of children aged 7 to 17 years, he was able to show that age, independently of body size, affected strength. The strength scores were divided on the basis of height, with each height group divided into older and younger age groups (1.5 yr. differences approx.). Regressions were calculated for the mean strength-height relationship for both the older and younger age groups. These regression indicated that the older group was stronger. It was also shown that the younger subjects of the lowest height group had strength scores below the regression line which characterised the mean data for the strength-height relationship. Asmussen (1980) suggested that these results reflected the effects of the maturation of the central nervous system, independent of body size; the younger, smaller subjects were not able to reach the strength level expected for body size, and the older, taller subjects were stronger because the central nervous system had more time to mature.

2.3.3(b) general body size and sex differences in strength

Several studies have investigated the extent to which sex differences in strength are related to differences in muscle and body size (Martin, 1918; Rarick and Thompson, 1956; Asmussen and Heeboll-Nielsen, 1965; Montoye and Lamphiear, 1977; Gilliam at al., 1979b; Asmussen, 1980).

Rarick and Thompson (1956) looked at sex differences in the relationship between direct measures of leg muscle size and ankle extensor strength in 7 year-old children. The correlation between ankle extensor strength and muscle size of the leg was between 0.58 to 0.63 for boys and beeen 0.58 to 0.63 for boys and between 0.22 and 0.52 for girls. Not only were the boys stronger in ankle extensor strength but they also had a greater muscle size. When boys and girls were paired on the basis of muscle size the superiority of boys was not statistically significant, although on average the boys were 6 lbs stronger than the girls.

Similarly, Asmussen (1980), calculating changes in muscle size indirectly, using dimensionality theory, also investigated sex differences in strength related to differences in muscle size. He compared the mean height-to-strength data, for boys and girls aged 7 to 17 years, and found that boys tended to be stronger than girls of the same height at all ages. This difference was particularly apparent in strength measures of the upper body and trunk, but was not found in the lower body strength measures of children in the lower height groups. Although these two studies suggest that differences in muscle size do account for some of the differences in strength, it is clear that all differences cannot be explained by size.

Further support for this conclusion comes from studies investigating sex differences in strength, after sex differences in body size have been accounted for. For example, Montoye and Lamphiear (1977), in a study of grip strength in males and females aged 10 to 69 years, found that males were superior to females at every age, even when the results were expressed as a ratio of body weight. Similarly, Martin (1918) devised strength-to-weight ratios for boys and girls aged from five to eighteen years. He found that boys had higher ratios than girls from the age of six onwards.

Finally, and perhaps more relevant to the present study, are the results obtained by Gilliam et al.

(1979b) who investigated the sex differences in PT scores of children, aged seven to thirteen years, in knee and elbow extension and flexion, performed at constant angular velocities of 30 deg/sec and 120 deg/sec. The results were expressed independently of both body weight and body height. Significant sex differences ($p < 0.05$) were found for PT scores at 120 deg/sec, independent of height, in elbow flexion and for PT scores at 120 deg/sec, independent of weight, in knee extension and flexion. In all these measures, boys were stronger than girls. It should be noted that no significant differences were found for PT scores at 30 deg/sec, expressed independently of height and weight. This would indicate that although difference in body size accounted for the difference at 30 deg/sec, it did not account for the difference at 210 deg/sec. Clearly there is another factor affecting the sex difference at 210 deg/sec.

It could be concluded from these studies that differences in body size and muscle size only account for part of the sex differences in strength. Moreover, the extent to which differences in muscle size account for sex differences seems to be affected by both the site and the velocity at which strength is measured. This suggests that sex differences which cannot be explained by differences in muscle size might be due to qualitative differences in force production by muscles.

However, Ikai and Fukunaga (1968) not only reported that isometric force was proportional to cross-sectional area of muscle but also that the force output per square centimetre was the same for all subjects, regardless of sex or age. (In their study the population tested included children.) This indicates that the differences obtained are unlikely to be due to qualitative differences in the muscle tissue itself. Indeed, Rarick and Thompson (1956) suggested that the 6 lb difference obtained between boys and girls, in strength of muscles of the same size, was probably not due to differences in the quality of muscle tissue, but to differences between the sexes in their use of these muscles and to the consequent effect on force generation. This issue will be discussed in section 2.3.4..

2.3.3(c) the relationship between measures of body size and strength

So far the emphasis of the above studies has been on accounting for changes in strength, with changes in the general size, and particularly muscle size. To represent these changes in size, body size measures such as height were used. In these studies interest was not in the body size measures themselves or their effect on strength, but in their use as a means of representing a general change in the size and growth of the individual.

Many other studies, however, have investigated the actual relationship between the body size measures themselves and strength (Maglischo, 1968; Lamphiear and Montoye 1976; Slaughter, Lohman, and Boileau, 1982). Most of these studies attempted to discover the amount of variance that can be explained by a particular body measurement, or to find the best variable or combination of variables that will explain the greatest variation in strength scores. These studies will be now be considered.

Perhaps the first major point which needs to be highlighted from these studies is that there is considerable variability in the correlations between a strength task and different body size measurements, and that a number of these measurements combined are required to explain the variance in strength scores.

It would appear that in order to obtain the best correlation with various strength measurements no single body size measure is adequate. This point is highlighted in the studies by Clarke (1957) and Maglischo (1968). For example, Clarke (1957), using sixteen strength measures and 10 anthropometric measures, found a correlation of 0.64 between body weight and trunk flexion strength, whereas for height this correlation was only 0.27. In knee extension strength the best correlation was for hip width 0.62, whereas, with sitting height it was only 0.29.

Other studies have found that a combination of anthropometric measures, in a regression analysis, expresses the best relationship with strength (Clarke, 1957; Maglischo, 1968; Lamphiear and Montoye 1976). For example, Lamphiear and Montoye (1976), in a multiple regression analysis selected five size variables to show the best relationship between body size and strength in children.

Finally, some studies have found that measures suitable at one age level might show a lower correlation at another age level (Jones, 1949; Cearley, 1957; Carron and Bailey, 1974). For example, Maglischo (1968) intercorrelated twelve anthropometric measures and three derived indices with 25 cable tensiometer tests. The highest multiple correlations with composite strength for three age levels were as follows:

1. 0.822 using height, cube root weight, arm girth divided by thigh girth, at elementary level;
2. 0.784 using chest girth, standing height and shoulder width, at junior high school level;
3. 0.607 using arm girth, shoulder width divided by hip width, at senior high school level.

These studies suggest not only that children are not geometrically similar in their growth, but also that variation in body proportions does not allow the relationship between body size and strength to be shown by one measure. In fact, Corrlett (1984) suggested that the geometric models, based on the dimensionality theory, were not adequate because of this fact and were only useful precisely because they forced examination of their underlying assumptions.

These assumptions have been investigated in the study by Marshall et al. (1978). Based on the geometric model, these studies have looked at the changes in body size in terms of one measure relative to another. Marshall et al. (1978) reported the mean exponent (b) values for girth lengths, and skinfolds on a yearly basis for boys 7-17 years. These results show the relative positive or negative allometric growth for different body size measures. For example, perfect geometric growth between height and weight would be shown by an exponent value of 3. However, Marshall et al. (1978) reported that below the age of 14, weight showed negative allometry, suggesting that height increased beyond the expected increase in weight. At the age of 14, weight and percentage body fat changed to positive allometry. This indicates that the increase in weight was due to an increased proportion of body fat. At the age of 16 weight and lean body mass both showed positive allometry with percentage body fat showing negative allometry. This would indicate that the increase in weight was due to an increased proportion of muscle mass. In their conclusion about the variability of growth, in terms of girth lengths and skinfolds, Marshall et al. (1978) drew attention to the implications of their results for future studies:

> Utilization, or at least note of present results would be wise in any attempt to dissociate differential structure from functional change (p. 9).

That variability can occur in the growth of body tissues such as bone muscle and fat has also been shown, using longitudinal data to follow growth patterns (Meredith and Boynton, 1937; Reynolds, 1944; Malina and Johnston, 1967). For example, Malina and Johnston (1967), looked at the significance of age, sex, and maturational differences in the upper arm composition of children aged 6 years to 16 years. Malina and Johnston (1967) reported that there were no sex or age differences in the muscle and bone ratios, but found that the muscle to fat ratio more than doubled for boys, while it remained constant for girls. This change was due to a reduction in the adipose tissue in the boys. This study highlights the markedly different upper arm composition of boys and girls; this would not have been shown by the measurement of girths.

The second major factor which should be highlighted, from the results of studies examining the relationship between body size and strength, is the wide variation in the magnitudes of the relationships. For example, Jones (1949) reported a correlation of 0.33 between measured strength and body height in children 17.5 years of age, whereas Molnar and Alexander (1973) reported a correlation of 0.918 between body height and PT scores obtained in a knee extension task performed at 30 deg/sec in children aged from 7 to 15 years.

However, as was indicated by studies cited earlier (Asmussen and Heeboll-Nielsen, 1956; Corlett, 1984), children's strength increases firstly because they are getting bigger, and, secondly, because of maturational factors. The interpretation of the relationship between body size variables and strength, therefore, demands the recognition that measures of body size are also commonly used as measures of growth and maturation (Krogman, 1948; Espenchade and Eckert, 1980). The relationship between height and strength will therefore be affected by the homeogeneity of the population in terms of stage of development. Clearly, using data from a wide age range, or during a growth spurt period such as adolescence will decrease this homeogeneity and increase the magnitude of the correlation between body size and strength.

Jones (1949) was able to emphasise these points in the results of his study. A correlation co-efficient of 0.65 was found between strength and height. It was stressed, however, that this was for a grade group with an age range of two years, which covered a period of accelerated growth around 14 years. When the correlation was obtained for subjects aged 17.5 years it was reduced to 0.33. Jones (1949) suggested that the lower correlation was due to the fact that the group was more homeogeneous. This was because the age was held constant and the subjects had reached maturity. Similarly, Carron and Bailey (1974), measuring strength in a longitudinal study of boys aged 10 to 17 years, found that the magnitude of the correlations with height and weight varied year by year. They found that the magnitude increased and decreased in the shape of an inverted U. It was suggested that this was to do with the homeogegeneity of the group, where correlations were greatest during the period of greatest change: the adolescent growth spurt.

It could be concluded from this section that the magnitude of correlation between measures of size and strength do not simply reflect the influence of size on strength but also the effects of maturation.

This conclusion is perhaps not surprising, since the most commonly used indices of maturity are an individual's morphological characteristics, such as height and weight. Indeed, studies which have investigated the relationship between more sophisticated measures of an individual's maturity and strength not related to body size have found that they provide little to explain the variance in strength (Clarke and Harrison 1962; Carron and Bailey 1974). For example, Rarick and Oyster (1964) measured skeletal age to see whether this measure gave more information on the relationship between growth and strength, not measured by the common indices of maturity, height and weight. They found that the skeletal age added little, if anything, to the relationship between strength and growth. They did find, however, that the skeletally maturer subjects were stronger than those who were skeletally immature. By the same token, however, the more mature individuals also tended to be the ones who were taller and heavier.

2.3.4 Physical Activity and Strength

Several investigators believe that the level of physical activity and type of physical activity children engage in during growth and development will have an effect on their strength and motor performance scores (Muller, 1970; Conger et al., 1982; Heeboll-Nielsen, 1982; Corlett, 1984).

Muller (1970) studied the influence of training and physical activity on muscle strength. He proposed that the state of training of a muscle be expressed as a percentage of its limiting strength, which is the maximum strength that can be achieved by maximum exercise. Specifically related to children's strength Muller (1970) suggested that growth and development increased children's limiting strength, but that level of activity affected their relative strength. In children, stage of development, in terms of limiting strength, is a barrier to their impovement in relative strength. Muller (1970) suggested that it was possible to decrease in relative strength due to inactivity, while increasing in limiting strength due to growth. By comparing initial strength levels to the strength achieved in response to maximum exercise (strength training where subjects improved to their maximum) Muller (1970) was able to calculate the relative strength for 88 children aged 11 to 16 years. He reported that average initial strength was 78%, with only 11 children having an initial relative strength above 90% of their limiting strength. He concluded that limiting strength had not been reached in these children by their daily physical activity and school physical education classes.

Heeboll-Nielson (1982) compared the strength of Danish children in 1956 to Danish children in 1981. He expressed the results of the strength measures relative to height and found that when differences in body size were accounted for children in 1956 were on average 9% stronger than the children measured in 1981. He suggested that a less active lifestyle and a 50% decrease of physical education class time in the cirriculum since 1956 could possibly account for the decreased strength in children. Conger et al. (1982) compared the C.A.H.P.E.R. fitness test scores obtained in 1960 with the results obtained in 1980.

Significantly better performances ($p < 0.001$) were obtained in the 1980 children's scores for a one minute sit-up test, standing long jump, and a flexed arm hang (for females). One of the explanations given for this improvement was as follows:

> Children were now physically superior and capable of superior performance due to increased emphasis on physical activity programs in school and community settings (p. 11).

Lower levels of physical activity and the engagement in different types of physical activities are thought to be factors that could account for sex differences in strength and gross performance in children and adults (Rarick and Thompson, 1956; Andres et al., 1981; Rees and Andres, 1981). It is suggested that males and females engage in different levels and types of physical activity because of social stereotyping (Andres et al., 1981; Rees and Andres, 1981). With respect to stereotyping, Rees and Andres (1981) showed that children, regardless of gender, believe boys to be stronger than girls.

It is thought that there is little physiological basis, in terms of muscle size or quality of the muscle before puberty in boys, for any sex difference in strength in children (Ikai and Funkaga 1968; Marshall, 1979). However, studies have found that boys are significantly stronger than girls, even when differences in body size, and muscle have been accounted for (Rarick and Thompson, 1956; Montoye and Lamphier, 1977; Asmussen, 1980).

Studies using adults have found that when differences in body size have been corrected for, sex differences have been reduced (Wilmore, 1974; Hoffman, Stauffer, and Jackson, 1979; Morrow and Hosler, 1980). Wilmore (1974) also found that when lower body strength is expressed relative to weight males and females have similar levels of strength. This was not true for upper body strength, where men were stronger than women in strength expressed per unit of lean weight. Similar results were also reported by Hoffman et al. (1979) who found that when strength was expressed relative to lean body weight and height, sex differences in strength were due to upper body strength and not to lower body strength. These studies suggest that this difference between upper and lower body strength provides evidence that sex differences are partly due to dissimilarity of use. They hypothesise that males and females are similar in lower body strength when differences in body size are accounted for, because these muscles are used in similar activities by both sexes (running, walking).

This trend, for sex differences to be more apparent for upper body strength than for lower body strength is also noted in studies reporting sex differences in strength in children. For example, Asmussen (1980) reported that sex differences in children at any height was almost non-existent in lower body strength, but more apparent in upper body and trunk strength. It could be inferred that sex differences in children are caused by dissimilarities of use. Indeed, Rarick and Thompson (1956) suggested that the 6 lb difference in leg extensor strength between boys and girls of equal leg muscle size was probably due to differences in levels of physical activity between the sexes. This suggestion is expressed in the following statement by Rarick and Thompson (1956):

> It would, therefore, seem that the tendency shown by the boys to be slightly stronger per unit of muscle area than girls may be due to qualitative differences in the muscle tissue of the sexes. Such differences at this age level are more likely the result of differences in physical activity than of constitutional sex differences (p. 331).

It could be concluded from this section that a source of variance in strength scores amongst children and between girls and boys will be levels of physical activity and the type of physical activity engaged in.

2.3.5 The Velocity Specific Nature of the Development of Strength

Growth of the body in terms of size, the maturation of the central nervous system, and state of training, are all factors which might affect the development of an individual's torque generating capacities in voluntary limb movement. One might expect that the relative influence of these factors would be the same, irrespective of the angular velocity of the limb movement at which peak torque was obtained. However, in the studies cited above it was shown that an individual's capacity, in terms of maximum torque production, can be specific to the speed of movement: individual's who are strongest at one velocity may not be the strongest at another velocity (Henry and Whitley, 1960; Whitley and Smith, 1963; Knapik and Ramos, 1980). Indeed, Gillian et al. (1979b), who obtained PT scores at 30 deg/sec and 120 deg/sec in children aged 7 to 13 years, found that sex differences were relatively greater at 120 deg/sec in comparison to 30 deg/sec. Significant sex differences were found in PT scores, independent of both height and weight, at 120 deg/sec, though not found in PT scores at 30 deg/sec. This indicated that boys were able to produce relatively greater torque at higher velocities than the girls. Gillian et al. (1979b) also reported that the magnitude of sex difference increased as the children grew taller and heavier. This indicates that this sex difference is affected by development.

A similar type of sex difference has also been found in a study by Anderson et al. (1979) who tested college men and women in one isometric and three isokinetic knee extension tasks 60, 180 and 300 deg/sec. When strength scores were expressed in Nm and Nm/kg men were stronger in all tests. However, when the results were expressed in Nm/LBW no difference between the sexes was found for the isometric and 60 deg/sec conditions. At isokinetic speeds of 180 deg/sec and 300 deg/sec men exerted a greater percentage ($P < 0.01$) of their maximum isometric torque than did women. If both studies are considered together, therefore, it would appear that the sex difference in the ability to produce greater relative force at high speeds becomes apparent during development and becomes more established during adulthood.

In view of this, a pertinent question to raise is whether a child's development of maximal torque production at different velocities of movement is constant or develops at different rates. The folowing statement by Asmussen (1973) suggests the possibility that strength development could be velocity specific:

> Growth may influence various parts of the neuromuscular system differently, asynchronously, and strength in one situation may therfore be different from strength in another situation because the co-operation of these various parts may be different in the two situations (p. 64).

Little is known about the factors which affect the rate of development of children's force-generating capacities at different velocities of movement. Perhaps the major reason for this can be found in the following statement made by Bosco (1985) in a monograph on strength and explosive power in man:

> Due to the complexity of the neuromuscular system it is often difficult to identify the essential components and their relative contributions to the production of force and speed (p. 69).

However, one of the components of the neuromuscular system that has been identified and is thought to influence force production at different velocities of movement is the quality of an individual's muscle, in terms of its fibre type distribution. Indeed, Anderson et al. (1979) suggested that the velocity-specific nature of the sex difference for PT scores at the higher velocities, independent of height and weight, was probably due to differences in fibre type or fibre type recruitment.

The next section will examine the studies which have investigated fibre type distribution and its effect on force and speed production.

2.3.6 Fibre Type

The purpose of this section is to review the studies which have investigated the effect of the quality of an individual's muscle in terms of fast-twitch fibre type composition on force and speed production. The purpose of reviewing these studies is to ascertain the extent to which children's maximum torque-generating capacities, at a range of velocities, will be affected by the percentage of fast-twitch fibres in their muscles.

Several studies have found that the percentage of fast-twitch fibre will affect force production. For example, Thorstensson (1976) obtained PT (Nm.kg/bw) measures of maximum voluntary efforts in a knee extension task at a range of constant angular velocities, including 0 deg/sec (isometric), using a Cybex II for subject populations with a percentage fast-twitch fibre composition greater than 60%, and a subject population with a percentage fast-twitch composition less than 50% (n=10). He reported that the peak torque velocity curves obtained for these two subject groups diverged in terms of PT production as the velocity increased. This is shown in Figure 2 (p. 45). This figure shows that the subject group with the percentage of fast-twitch fibres greater than 60% tended to have higher PT scores at each of the velocities, compared to the subject group with a percentage of fast-twitch fibres less than 50%. This difference, however, was only significant ($p < 0.05$) at 180 deg/sec. These results have been confirmed in two other studies by Thorstensson et al. (1976 and 1977).

Thorstensson (1976) suggested that these results demonstrated the importance of fast-twitch fibres in movements demanding high tension at high velocities. It was also suggested that the lack of significance at low velocities was possibly due to the fact that at these velocities other factors, such as muscle size, were of more importance.

Other studies have also confirmed the results obtained by Thorstensson. For example, Gregor et al. (1979) obtained PT scores in a knee extension task at velocities of 0, 96, 192, and 280 deg/sec, using a Cybex II, n = 22 female athletes. Subjects were divided into two groups on the basis of their percentage distribution of slow twitch and fast twitch fibres (ST group less than 50% FT, FT group greater than 50% FT). In all cases subjects with a slow twitch fibre composition less than 50% tended to have higher torque scores. These differences were significant at 96 deg/sec ($p < 0.05$), 192 deg/sec ($p < 0.01$), and 280 deg/sec ($P < 0.025$). No significant differences were found at 0 deg/sec. When torque values were expressed per kilogramme of body weight a significant difference was found only at 192 deg/sec ($p < 0.05$). Coyle et al. (1979) obtained PT scores in a leg extension task at the following constant angular velocities: 57, 115, 200, 287, and 400 deg/sec. All PT scores were expressed as a percentage of the subjects' PT score obtained at 57 deg/sec. Twenty-one males were tested. When subjects were divided into two groups, on the basis of their percentage distribution of slow twitch and fast twitch fibres (ST group less than 50% FT, FT group greater than 50% FT), it was found that the predominantly fast twitch group was able to produce 11%, 16%, 23%, and 47%, significantly greater percentage torque than the slow twitch group at the velocities of 115, 200, 287, and 400 deg/sec respectively.

The studies reported so far would seem to support the view that the quality of an individual's muscle, in terms of its percentage of fast-twitch fibres, influences its capacity to develop maximum force, particularly at high velocities.

Based on the evidence of the above studies it could be inferred that the percentage of fast-twitch fibres in children's muscles might affect the torque they produce, particularly at high velocities. This assumes, of course, that the quality of children's muscles and adults' muscles are the same. To investigate this, Komi et al. (1977) looked at the significance of the genetic component in determining the inter-individual variation observed in muscle fibre composition using 31 pairs of female and male monozygous and dizygous twins. The data revealed that, unlike the dizygous twins monozygous twins had essentially identical muscle fibre compositions. Similarly, a study by Bell et al. (1980) investigated the muscle fibre types and morphometric profiles of skeletal muscle (vastus lateralis) in six year-old children. The researchers concluded that the fibre distribution pattern and ultrastructure of skeletal muscle in six year-old children was no different from that of normal adults. It should be noted that Bell et al. (1980) not only investigated the similarity between children and adults in terms of their percentage of FT and ST fibre type distribution but also investigated a more detailed classification which included the division of FT fibre into subtypes; fast twitch glycolytic known as FG or IIb fibres, and FT oxidative known as FOG or IIa fibres. The difference between the IIa and IIb fibres is related to their glycolytic and oxidative potential; type IIb fibres have a lower oxidative and higher glycolytic capacity than type IIa fibres which have enzymes for both metabolic pathways. It has been shown that it is possible with training to convert the type IIa fibre to type IIb fibre and vice versa (Henriksson and Reitman, 1976); no such effect has been found for the conversion of ST into FT fibres or vice versa. It could be suggested that growth might be another factor that could influence this conversion. Indeed, it might be the case that pre-puberty there is a predominance of either type IIa or type IIb fibres. However, the fact that Bell et al. (1980) was able to show that the distribution of type IIa and type IIb fibres was no different between children and adults gives evidence against this possibility. Indeed, the results of these studies by Komi et al. (1976) and Bell et al. (1980) would suggest not only that the distribution of fibre types within a muscle is controlled genetically but also that this distribution is not affected by development.

Two conclusions could be drawn from this, regarding the extent to which children's maximum torque-generating capacities at a range of velocities will be affected by the percentage of fast-twitch fibres in their muscles. These are as follows:

1. Since fibre distributions are the same for adults, it would be expected that individuals with a higher percentage of fast-twitch fibres might obtain higher scores, especially at the high velocities.

2. Since fibre distribution is not affected by development, this phenomenon would not be affected by age; the variability would be expected to remain relatively constant across all ages.

Only two studies have investigated the relationship between fibre type distribution and performance tasks involving high tension at high velocities in children: Miyashita and Kanehisa (1979) and Kanehisa and Miyashita (1980). Neither study, however, measured fibre distribution directly; both assumed, on the basis of the results reported by Thorstensson (1976), that a high peak torque score obtained at a maximal effort, at a fast contraction velocity, would reflect the effect of a higher percentage fast-twitch fibre distribution. The results of both studies are reported below.

Myashita and Kanehisa (1979), in a study of 569 boys and girls aged 13 to 17 years of age, found a significant relationship between the PT (210 deg/sec) of

TABLE 2

Correlations Between Running Speed and Peak Torque

Age		13	14	15	16	17	Total
Boys	n	55	53	54	51	50	269
	r	0.573***	0.557***	0.513***	0.256	0.188	0.688***
	r^2	0.328	0.310	0.263	0.066	0.035	0.473
Girls	n	61	58	55	52	55	281
	r	0.361**	0.251	0.281*	0.304*	0.312*	0.373**
	r^2	0.131	0.063	0.079	0.092	0.097	0.139

* Significant at 0.05
** Significant at 0.01
*** Significant at 0.001

Note: From 'Dynamic Peak Torque Related to Age, Sex, and Performance', Miyashita and Kanehisa, 1979, Research Quarterly, 50, 2, p. 250.

knee extensors and the mean speed, in metres per second, of a 50 metre maximal run (boys' $r = 0.688$; ($P < 0.001$), and girls' $r = 0.373$; ($P < 0.01$)). Significant relationships were also found when correlations were obtained for these subjects categorised by age. These are shown in Table 2. Significant correlations, using 35 swimmers aged between 11 years and 21 years were also obtained between peak torque scores (210 deg/sec) of arm pull and the best recorded time in the 100 metres freestyle swimming (boys $r = 0.728$; $p < 0.001$), and (girls $r = 0.515$; $p < 0.05$)). The authors reported that they had expected to obtain relationships between PT 210 deg/sec for these two motor tasks. In addition, although significant correlations were obtained, for both males and females, the authors could not explain the tendency for females to have lower correlations.

In the study by Kanehisa and Myashita (1980) an attempt was made to classify 569 children aged between 13 to 17 years into sprint or endurance types. In order to do this , performance scores (which were converted into t scores) were obtained on the following tests:

1) 50-metre dash

2) 5-minute run

3) PT score from a knee extension task obtained at a constant velocity of 210 degrees/sec.

Subjects were classified into fast-twitch and slow-twitch fibre types using the following procedure:

1. fast-twitch fibre types: subjects whose t scores of PT per unit of body height were 55 or over were classified as having more than 50% fast-twitch fibres,

2. slow-twitch fibre types: conversely those whose t scores were 45 or under were classified as having more than 50% of slow-twitch fibres.

Using this classification system 25.8% of the boys and 27.9% of the girls were classified as fast-twitch types and 25.8% of the boys and 22.7% of the girls were classified as slow-twitch types.

When the relationships between fibre type and performance t scores on the 5-minute run, and 50-metre dash were examined, it was reported that the slow-twitch fibre type boys and girls tended to have higher T scores on the 5-minute run than on the 50-metre dash, whereas the fast-twitch fibre types had higher t scores in the 50-metre dash than in the 5-minute run. Correlations of the significance of these relationships were not reported. The researchers did report, however, that 30% of the subjects showed the reverse tendency.

A stricter classification procedure identified subjects as endurance types and sprint types as follows:

1. endurance types: t scores of 45 or below, for PT and 50-metre dash, and t scores for the 5-minute run of 55 or over.

2. sprint types: if they had t scores of 45 or

under on the 5-minute run, and t scores of 55 or above for PT and 50-metres dash.

Using this classification system only 3 sprint type boys and seven endurance type girls could be identified out of the 569 children tested. The authors reported that they could offer no explanations for the apparent sex differences in the classification. They did suggest, surprisingly perhaps, that this classification system might aid the school teacher in providing exercise programmes suited to the physiological profile (in terms of fibre type composition) of children.

It could be concluded from these two studies that, first of all, there are associations between PT scores at 180 and 210 deg/sec and performance in motor tasks demanding high tension at fast speeds, and, secondly, these associations appear to be stronger in males than in females. Moreover, since both these studies assume that a high score at 180 or 210 deg/sec is indicative of a subject with a high percentage of fast-twitch fibres, it is also concluded that the better performance in tasks demanding high tension at fast speeds is related to a higher percentage of fast-twitch fibres.

Based on the above conclusions two observations on the relationship between the percentage of fast-twitch fibre and performance could be made:

1. Although it was concluded that males showed a better relationship between percentage fast-twitch fibre and performance in tasks demanding high tension and speed than females, this sex difference cannot be explained as differences in fibre type distributions, since females are thought to have the same percentage of fast-twitch fibres as males.

2. Although it was concluded that there was a significant relationship between fibre distribution and performance, the results indicate that as a factor affecting performance it only accounts for a small proportion of variance, particularly at some ages. For example, although, from Table 2 it can be seen that many of the relationships, found by Myashita and Kanehisa (1979), (relationships between the PT (210 deg/sec) of knee extensors and the performance in a 50-metre maximal run), were significant, they only accounted for between 47% and 14% of the variability in performance.

These observations highlight the fact that the effect of fibre type distribution is not clear; there are many questions still to be answered. Indeed, many studies question the validity of the basic assumption, made by Kanehisa and Miyashita (1980) and Miyashita and Kanehisa (1979), that relatively higher PT scores will be obtained in maximal efforts at fast velocities by individuals with a higher percentage of fast-twitch fibre distributions. In other words, researchers have either found no significant correlations between the percentage fast-twitch fibre composition and performance in motor tasks which involve high tension and or speed (Campbell et al., 1979; Ingemann-Hansen and Halkjaer-Kristensen 1979; Clarkson et al, 1982), or they have found significant relationships for one population and the reverse or absence of significant relationships for another subject group (Inbar, Kaiser, and Tesch, 1981, Jacobs and Tesch, 1981; Karlsson and Jacobs, 1981; Komi and Karlsson, 1978, 1979).

Two main explanations in these studies account for the conflicting results.

The first explanation is that the percentage fibre composition in a muscle is not a particularly significant factor for explaining the variance in performance scores obtained in motor tasks involving high tension and/or speed. For example, Campbell et al. (1979) found no significant relationships between the percentage fast-twitch distribution (22 females), either positive or negative, and performance scores obtained in the following tests:

1. 20 sec anaerobic power test with low KP and high KP,
2. sargent jump,
3. VO2 max test.

In contrast to the results reported by Thorstenssen

(1976), Ingemann-Hansen and Halkjaer-Kristensen (1979) reported that they could not demonstrate that in a PT-V relationship there is a significant correlation between PT at the higher velocities and fast-twitch fibre composition. In their study they obtained PT scores in knee extension at a range of constant angular velocities (30 deg/sec to 360 deg/sec) in 15 football players. They found that PT decreased linearly with increasing angular velocity in a semilogarithmic scale. Linear regression was used to calculate intercept and slope values from individual data, plotted on a semilogarithmic system (Log PT = Va + b, where a was the slope, b the intercept, and V was velocity). Correlations between the variables of slope and fast-twitch fibre composition were not significant. Similarly, Clarkson et al. (1982), obtained PT scores using an isokinetic device at velocities of zero deg/sec, 30 deg/sec, 180 deg/sec, and 240 deg/sec for eight males. No significant correlations were found between PT (expressed relative to MVC or per kilogramme of body weight) and the percentage distribution of fast-twitch fibres. However, in their discussion of the lack of significant relationships, Campbell et al. (1979) made the following qualifications:

> Significant correlations are usually exceptions to the data, or have not been confirmed in other studies. Such correlations may therefore be type I errors and rationalisations of such relationships may not be warranted (p. 264).

One of the rationalisations referred to was that made by Thorstensson et al. (1977), who suggested that subjects with a higher percentage of fast-twitch fibres would have a greater performance capacity in tasks involving high tension at high velocities. However, Thorstensson et al. (1977) did point out that although a significant relationship was found between PT 180 deg/sec and the percentage distribution of fast-twitch fibres, fibre distribution alone could not account for the higher PT (180 deg/sec) scores obtained for sprinters in comparison to the other athletes and sedentary subjects. Campbell et al. (1979) also suggested that the significant correlations in studies such as Thorstensson et al. (1977) have not been confirmed; however, it must be noted that the Campbell et al. (1979) study was published in 1979, and, since then other studies have confirmed the results reported by Thorstensson et al. (1977), studies such as Coyle et al. (1979) and Gregor et al. (1979).

It could be concluded from these results that the effect of percentage of fast-twitch fibres for many motor tasks might be relatively unimportant.

The second explanation for the conflicting results of studies in this area is that the relationships obtained between fast-twitch fibre distribution and performance scores, in tasks involving high tension and speed, may be specific to the subject population tested.

For example, studies have found that in comparable groups of males and females, differences were found between the sexes, with respect to the relationships between fibre type distribution and exercise performance variables. Karlsson and Jacobs (1981), in a study of the exercise performance of 38 males and 22 females obtained the following results:

1. females, in muscle strength and power, were 60% to 80% of the male level, even when corrections were made for body size;
2. females required almost twice as much time to develop 70% of the maximal leg force of the males;
3. females demonstrated lower levels of activity of the enzymes responsible for muscle contractility and glycogenic activity.

These differences were found, in spite of the fact that the females displayed a higher percentage of fast-twitch fibre type distribution compared to the males. The results of this study were similar to the results of their earlier investigations (Komi and Karlsson, 1978; Komi and Karlsson, 1979). They interpreted their results as follows:

> Observations suggest that sexually mediated differences in neuromotoric control may exist affecting muscle force production, speed, and the accepted relationships between muscle fibre types and exercise performance (p. 110).

The results reported by Jacobs and Tesch (1981) would support the above conclusions of Karlsson and Jacobs

(1981). Jacobs and Tesch (1981) obtained the following results for the females in their study:

1. negative relationships between percentage fast-twitch muscle fibre area and a) post exercise muscle lactate and b) peak power;

2. insignificant relationships between muscle lactate and peak power.

In contrast, when these results were compared with the same tests and variables examined on males, as reported by Bar-Or et al. (1980), the males showed the reverse of the results for the females. Jacobs and Tesch (1981), who observed this reversal, made the following comment:

> Where a significantly positive relationship was evident for the males, a statistically insignificant or negative relationship was demonstrated by the females (p. 130).

In discussing these results Jacobs and Tesch (1981) suggest that sex differences in relationships between fibre types and exercise performance might explain the conflicting results obtained in some studies. For example, they first of all suggested that the non-significant relationships in the study by Campbell et al. (1979) might be due to the fact that the subjects were females, and, secondly, they suggested that unexplained sex differences, found by Myashita and Kanieshia (1979), in the strength of the correlation between PT 210 deg/sec and speed of a 50-metre run are the result of sex differences in the accepted relationships between fibre type and exercise performance. Moreover, Anderson et al. (1979), in their attempt to explain why the sex difference in torque, independent of lean body weight, increased and became significant, with males being stronger as velocity increased, suggested that this sex difference might be related to fibre type or muscle fibre recruitment.

It could be concluded from these studies that while it is thought there are no sex differences in fibre type distributions there may be sex differences in the accepted relationships between these fibre types and performance. In terms of force production, this sex difference would appear to give males an advantage over females at high velocities.

One of the purposes of the present study is to investigate sex differences in PT scores at a range of velocities. Sex differences in the accepted relationships between FT fibre types and force production at high speeds might be a factor which will cause sex differences in the PT produced at high velocities.

2.3.7 The Test as a Factor Affecting PT Scores

The purpose of this third section has been to review the research concerning the factors that will affect the development of isokinetic strength in children; so far the factors which have been reviewed are: age, gender, body size, level of activity, and fibre type composition. It would be expected that some, or all, of these factors will affect the variance in PT scores obtained for children at a range of velocities. Indeed, Molnar and Alexander (1974) tested children aged 7 to 15 years at a velocity of 30 deg/sec in various limb movements. It was found that sex, age, height, weight, and leg dominance, in a multivariate regression analysis, could account for 50% to 70% of the variance in obtained scores. They suggested that the remaining variation might be the result of variation in level of activity, constitutional, or other unknown influences. However, as Molnar and Alexander (1979) pointed out in the following statement, the test itself must be considered as a possible source of variance.

> A pertinent question to raise is whether inaccuracies of measurement as a result of technical defficiencies, physiological and psychological variables play a significant role in the remaining variance (p. 220).

In the present study the intention is to obtain PT scores at 4 constant velocities using a Cybex II. It must be considered, therefore, that this test will be a possible source of variance in the PT scores. To be able to evaluate the possible effect of this test on the PT scores this review will consider the research relevant to the following: the ability of the Cybex II to give valid and reliable PT scores, and the ability of the subjects to give reliable PT scores representing their maximum voluntary effort.

2.3.6(a) reliability and validity of Cybex II

An important procedure for studies measuring strength, irrespective of the method used, is first of all to establish that the equipment gives valid and reliable measures.

To date the procedures recommended by manufacturers for calibrating the Cybex II to check its reliability and validity are based on the principle that torque is a force which acts about an axis of rotation; it is the product of the force and its perpendicular distance from the axis of rotation. The validity of torque measurements can therefore be checked by dropping a known weight from a known lever length, where the obtained peak torque should equal the calculated torque: weight X lever length.

The manufacturers of Cybex II, Lummex Inc., claim that a properly calibrated machine will accurately measure peak torque to plus or minus 1.5 ftlbs, when the 30 ftlb full-scale deflection mode is used, and plus or minus 2.5 ftlbs with the 180 ftlb full-scale deflection mode. In addition, the manufacturers also claim that a calibrated machine will only deviate by 1 ftlb for repeated measures across time, when the 30 ftlb or the 180 ftlb full-scale deflection mode is used.

It should be noted that this calibration procedure can only be performed at 30 deg/sec. Nevertheless, the manufacturers state that the reliability and validity determined using the calibration procedures at 30 deg/sec will determine the reliability and validity of the scores at the other velocities. However, as will be shown later in this review, recent research would question the accuracy of this statement.

The procedures outlined by the manufacturers have been used to check the reliability and the validity of the Cybex II devices used in the majority of previous studies (Moffroid et al., 1969; Thorstensson, 1976; Knapik and Ramos, 1980; Scudder, 1980). All these studies report that the Cybex II gives reliable and valid measurements of torque. For example, Moffroid et al. (1969) made a detailed study of the reliabilty and validity of the Cybex II. Their conclusions were as follows:

> The measurements made by the isokinetic device and recorded by a pen recorder (torque, work, power, range of motion, and speed) have been shown, thus far, to be reliable and valid (p. 746).

Similar conclusions were drawn from the calibration procedures of the other studies.

However, although Thorstensson (1976) concluded that "torque registration showed high reliability and validity," he also reported that velocity was not constant during the whole arc of motion. Furthermore, he attributed inconsistencies in velocity to the initial phase in the arc, where there was a time-lag before the pre-set angular velocity was reached.

The effect of this time-lag, and its implications for obtaining valid torque measurements, is an area that has only recently been investigated (Murray et al., 1982a; Murray, Harrisson and Wood, 1982b; Sapega et al., 1982 Murray and Harison, 1986).

In an ongoing study of the reliability and validity of the Cybex II, Murray et al. (1982a) suggested, from initial observations, that the ability of the servo-mechanism of the Cybex II, to control limb movements at a constant velocity throughout a movement and give accurate registrations of torque, had perhaps been overestimated.

The manufacturers themselves suggest that the time-lag is caused by approximately 2 degrees of mechanical free play in the Cybex II. The effect of this free play is that, for brief instants, the limb may accelerate beyond the pre-set velocity; the result of this is an impulse load, as the servo-mechanism decelerates the limb. The main effect is at the beginning of the movement, where it causes an initial spike or a peak on the chart recording. This is referred to as "overshoot". This overshoot can also occur at other points during the movement, although to a smaller degree. It is shown by oscillations in the chart recording (Murray et al., 1982a; Sapega et al., 1982).

Sapega et al. (1982) have described the overshoot effect as follows:

> The prominent initial torque spikes and secondary oscillations that often appear in Cybex torque records do not represent intermittent surges of muscular contractile force, but rather the forces associated with the initial deceleration and subsequent velocity fluctuations of an initially over speeding limb-lever system (p. 375).

The clearest examples both of the servo-mechanism's response to accelerations and decelerations of the limb, and of its effect on torque registration, can be found in the undamped chart recordings of a torque curve (Murray et al., 1982b; Sapega et al, 1982).

The damping facility on the Cybex II has the effect of smoothing out the curve, correcting the artifacts (Cybex II Handbook). However, studies have questioned the effect of this damping on the process of obtaining accurate torque registrations (Murray et al., 1982a; Murray and Harrisson, 1986; Sapega et al., 1982). In fact, Murray et al. (1982b) were able to show that the ability of this damping system to give valid artifact-free torque cuvres varied for different velocity settings. In other words, the magnitude of the inaccuracies was velocity-specific. This indicates that there is some doubt about the assumption that the calibration at low velocities is also valid across the whole velocity range. Sapega et al. (1982) suggested that this indicated the need for further research in the use of the damping system, particularly at high velocities:

> Investigators using the Cybex should cite the damping setting used in recording their data when reporting their results. Further investigation into the accuracy of overshoot correction by torque signal damping is needed, particularly in high speed testing (p. 375).

Clearly the studies by Murray et al. (1982a), Speaga et al. (1982), and Murray and Harrison (1986) indicate that the Cybex has limitations, particularly in the ability of the servo-mechanism to control velocity at the start of the movement. However, although these researchers have pointed out the limitations of the Cybex they do not quantify the consequences of these limitations for actual subject testing; their evaluation of the Cybex was based mainly on the mechanical loading of the system rather that on subject testing. Indeed Murray and Harrison (1986) recognised this fact when they wrote:

> Present inferences are based solely upon a mechanical loading model. A further appraisal, which utilizes muscle loading, is needed (p.623).

Although this indicates the need for greater research in this area the manufacturers themselves have investigated the implications of the limitations of the Cybex for actual subject testing. As a result they have issued guidelines which should be followed to prevent inaccuracies in the validity of the torque measurements during testing. These guidelines recommend the following during testing. These guidelines recommend the following two procedures to ensure valid results:

1. investigators should observe the recommended damping setting,

2. peak torque scores should not be taken if they occur within the first or last eighth of a second of the torque curve (1/8 second is approximately three small units along the baseline).

The latter recommendation ensures that peak torque measures are taken in what is referred to as the artifact-free part of the torque curve, that is, the part of the curve where the effects of the initial overshoot have passed.

To ensure valid results in the present study the standardised calibration procedures, which have not only been recommended by the manufacturers, but also used in the majority of studies to date, have been used. In addition to these procedures guidelines issued by the manufacturers for preventing the inaccuracies which can occur in torque registration as a result of the overshoot phenomenon have also been followed.

2.3.6(b) subject reliability of PT scores

The second possible source of error in the measurement of PT in the present study concerns the subjects' ability to produce reliable PT scores representative of their maximum effort. Indeed to obtain such measures it must be considered that technical and psychological factors are potential sources of error which might affect this reliability. The effect of these factors has been estimated in two ways: examining the occurrence of best scores in the trials and retests and examining the amount of variation between the trials and retests. This section will consider these studies and the information they provide that will be of use in the present study.

(i) the occurrence of best score

For strength testing, researchers have investigated the occurrence of the best score in the trials and in the retests in order to find out whether or not there are any factors affecting the subjects' ability to produce their best score (Johnston and Siegel, 1978; Molnar and Alexander, 1979; Murray et al., 1980). For example, if as a result of this type of examination it was shown that the best scores more frequently occurred in the retest it would indicate there was a factor preventing the subjects from giving their best score in the first test. Furthermore, it would also suggest that in future testing two tests are required to obtain reliable scores. In the present study this type of information would be important, particularly when designing the method; it would be ideal to get an indication from previous research of the factors that might affect the occurrence of best scores.

In providing this information the study by Molnar and Alexander (1979) is relevant to the present study, in that the occurrence of best PT scores was examined both in successive trials and between an initial and repeated test for peak torque scores obtained at 30 deg/sec, using the Cybex II, in children aged between 7 and 15 years. They reported that there were no systematic trends, in terms of the increase or decrease, in the scores for successive trials of the test. Nor were there any consistencies in the direction of the deviations between initial and repeated tests, carried out by the same or by different examiners; that is, the frequency at which higher maximal scores were obtained on the initial or the repeated test were nearly equal, 48.6% and 51.4% respectively. Molnar and Alexander (1979) suggested that these results indicated that fatigue, training, or learning did not affect the results.

These results might indicate that in the present study, at least for testing at 30 deg/sec, these factors would not affect the results. It could also be concluded that one test is sufficient to obtain the best score.

However, although these conclusions could be drawn from Molnar and Alexander's (1979) study, they would not be supported by the results of other studies; other studies have shown that factors such as learning and familiarisation with the task can affect the reliability of the scores. For example, Carron and Bailey (1974), in a longitudinal study of the development in strength of boys from age 10 to age 17, found that the largest increase in strength occurred between the 10th and 11th year. They noted, however, that this large increase may reflect the influence of factors other than a simple strength increase; that is, the subjects at age 11 had adjusted to, and become familiar with, the apparatus, the test environment, and with the isometric test itself. This would suggest, therefore, that the first test was not sufficient to obtain subjects' best score and that familiarisation did affect the subjects' ability to produce a reliable score.

Although these results by Carron and Bailey (1974) contradict the results of Molnar and Alexander (1979), this contradiction might be a result of fact that different methods of testing were used in the two studies; it may be that isometric tests are more affected by familiarisation and learning than are isokinetic tests. In fact, a study by Murray et al. (1980), comparing the reliability of isometric and isokinetic tests suggested that, not only was isokinetic testing affected by learning, but this effect was also greater than any effects that occurred in isometric tests. More specifically, Murray et al. (1980) investigated the difference in the torque obtained in knee extension in repeated measures, during three trials and two testing weeks, using both isometric and isokinetic techniques. The following results were reported for the isokinetic test:

1. there was no significant difference between the best score obtained from the two testing weeks, although the torque scores tended to be higher in the second week;

2. torque scores were significantly higher in the second of the two consecutive trials in 5 out of the 6 knee angles tested.

Murray et al (1980) pointed out that the opposite results, with respect to points 1 and 2 above, were found for the torque produced when these same muscle groups and joint angles were tested isometrically, instead of isokinetically. It was this difference that led Murray et al. (1980) to suggest that, within a given testing session, motor learning played a more important role in the isokinetic test than in the isometric test. Murray et al. (1980) further suggested that this was possibly because the experience of a constant speed of movement was new to the subjects.

Further evidence that factors such as learning and familiarisation with the task can affect the occurrence of best performance in isokinetic tesing is seen in the results reported by Johnson and Siegel (1978). They investigated the reliability of peak torque scores obtained in knee extension at 180 deg/sec, using a Cybex II isokinetic dynamometer; three warm-up trials were given, followed by six maximal recorded trials. When checking the assumption of the randomness of trials Johnston and Siegel found a significant linear trend ($p < 0.01$). Further analysis revealed that this trend was due to the first three trials. This trend clearly indicated that there was a factor preventing the subjects from producing their best effort in the first three trials. Although Johnston and Siegel (1978) did not suggest a reason for this trend, they did suggest that to obtain reliable scores, future studies should include these three maximal trials as part of the warm-up.

It could be concluded, therfore, that although Molnar and Alexander (1979) found no trends in the occurrence of best PT scores to suggest that factors such as learning, training, or fatigue were affecting the subjects' ability to produce their maximal scores, other studies did find trends that would indicate the influence of such factors on the reliability of the scores. Indeed, Murray et al. (1980) suggested that, in comparison to the more commonly used isometric test, there was greater evidence of motor learning affecting the reliability of the scores. The conflicting evidence from these results indicates that there is little definite information that could be used in the present study, particularly for establishing a sound measurement schedule. Johnston and Siegel (1978) highlighted the need for such information in the following statement:

> Although a number of authors have addressed the fundamental question of how many trials over how many days are required to obtain a true measure of a subject's ability to perform a particular task, a considerable amount of work remains to be done in establishing sound measurement schedules for different parameters and populations (p. 88).

Indeed, it could be concluded that one of the important aspects of this study is that it will provide this information, information important not only for establishing that subjects in the present study were able to produce PT scores that represented their maximal effort within the trials and retests given, but also important for the information it provides for future testing in this area. More specifically, it will provide information concerning the ability of specific age groups, 5, 8, 11, and 14, to produce maximal efforts in knee extension at four constant velocities within the trials and retests given.

(ii) magnitude of variation

Although the occurrence of best scores in repeated measures gives an indication of any general factors affecting reliability, by investigating the amount of variation between these repeated measures researchers have been able to obtain a more quantitative assessment of reliability; high variability indicates low reliability. Indeed, to be able to assess the reliability of the PT scores in the present study it would be ideal from previous research to get an indication of the amount of variation that would be acceptable. This type of information would allow the reliability of the PT scores to be assessed by comparison with an established baseline score. However, few of the studies that do quantify this variability are relevant to the subject population and task performed in the present study.

The exception to this is the study by Molnar and Alexander (1979). As was shown above, this study investigated the reliability of the peak torque scores obtained at 30 deg/sec, using the Cybex II, in children aged between 7 and 15 years. The results of their investigation, concerning the variablity between repeated measures, showed a mean score deviation of 5.3% to 5.8% within the trials. This was called intratest variation; that is, the maximum deviation of the three trials computed as a percentage of the highest score of the three trials. When the test was repeated, seven to ten days later, the mean deviation, using the highest scores of the two weeks, ranged from 7.9% to 9.8%; this was called intertest variation. Molnar and Alexander (1979) suggested that calculating the magnitude of variation gave an indication of the following:

> Intratest and intertest variability reflect the many aspects of psychological ambience that occur in a testing situation and that are created by the interaction between particuluar subjects and examiners. In addition they can be considered as an indication of the consistency in the technical conduct of measurements by the individual examiner (p. 220).

Furthermore, they concluded from their results that, since the variations were slight, technical and psychological factors did not affect the results to any extent and could be attributed to the fluctuations in the uniformity of any human performance.

Since the subject population and testing device used by Molnar and Alexander (1979) show similarities to those to be used in the present study it could be suggested that their results provide a baseline score that would allow for the assesment of the reliability of PT scores in the present study. However, in Molnar and Alexander's (1979) study the reliability results were only obtained at 30 deg/sec. In the present study, by contrast, PT will be obtained at four constant velocities. It is possible that the magnitude of variation would be affected by velocity. A study by Thorstensson (1976), however, indicated that velocity had little effect of the reliability of scores. More specifically, this study assessed the reliability of 25 subjects' ability to produce peak torque at six constant angular velocities (0 to 180 deg/sec), using the Cybex

II. The co-efficients of variation were reported to be 2.1% to 4.7% in consecutive attempts, and 4.1% to 6.5% in repeated tests, with velocity having little effect on the co-efficients. Although Thorstensson (1976) concluded that velocity had little effect on the reliability, it must be noted that his study differs from the present study in two respects; firstly, the velocity range used was only 0 deg/sec to 180 deg/sec, whereas in the present study it is from 30 deg/sec to 300 deg/sec, and, secondly, the subjects were adults, whereas, in the present study the subjects are children aged 5 to 14 years. It might be suggested that these differences in the age of the subject population and in the velocities tested might be factors affecting the variability, and that they should be investigated in the present study. Indeed, in terms of the age of the subjects, Molnar and Alexander (1979) did find a tendency, although not significant, for the deviations to be greatest for those with the lower absolute scores; this represented the younger subjects.

It could be concluded from this section that there is very little information from previous research that would indicate what magnitude of variation to expect for the subject population and task to be performed in the present study. The exception to this was the study by Molnar and Alexander (1979) who reported the mean variation between PT scores over trials and repeated tests for a similar subject group at 30 deg/sec. However, since little is known about the effect of velocity on the magnitude of variation, for children of different ages, it is important that the present study investigates this. This information is important, not only, for establishing the reliability of the PT scores in the present study, but also because it will add to the information obtained from Molnar and Alexander's (1979) study concerning the reliability of measuring PT in children with a Cybex II. More specifically, the present study will describe the variation in best PT scores obtained out of four trials, occurring between initial and repeated tests, for subjects aged 5, 8, 11 and 14 in a maximal voluntary knee extension task performed at four constant velocities (300, 210, 120, and 30 deg/sec) using a Cybex II.

CHAPTER THREE

METHOD

This study was undertaken to investigate the development of children's torque generating capacities in maximal voluntary limb movements performed at a range of velocities. To be able to obtain meaningful information from this investigation the answers to five specific questions were sought:

1. What was the relationship between peak torque and velocity for the subjects of each age group?
2. What effect does age have on the peak torque scores obtained at each velocity?
3. Are there any sex differences in (a) peak torque scores? (b) body size measures?
4. To what extent do parameters of growth, i.e. age, hip to ankle length, hip to knee length, knee to ankle length, thigh circumference, height, weight, and cybex lever length, explain the variation in peak torque scores?
5. Is it possible to obtain PT scores representative of a subject's maximum voluntary effort?

To answer these question a design was implemented which used boys and girls of four age groups, in a repeated test, to obtain measurements of PT in left leg knee extension at four angular velocities, and measurements of body size. The design also included a calibration test of the Cybex, the equipment used to measure PT.

The methods used to carry out this design will be detailed below in the following sections:

section 1- subjects, measurements, and equipment,

section 2- testing procedures,

section 3- the calibration test.

Section 1

Subjects, Measurements, and Equipment

3.1.1 Subjects

121 subjects were involved in this study. Their age range was between 5 years and 15 years. The numbers of the subjects, in their respective age and gender groups, are listed in Table 3.

The subjects were selected from neighbouring Primary and Secondary schools and from the Summer Sports School held in the Department of Physical Education and Recreation at Glasgow University.

To obtain children from the selected schools the headteachers were contacted and the test was explained. They were asked to distribute letters to the parents of eligible children. The letter explained the purpose and requirements of the test. Parents who agreed to let their children participate in the test returned the permission slips; these recorded the child's name, address, telephone number, and date of birth. The parents were then contacted directly, any questions they had were answered, and arrangements were made for the test. The parents of eligible children attending the Summer Sports School were contacted directly.

TABLE 3

Age and Sex of Subjects

Age (years, months)	Sex	Number
5 yrs. - 5 yrs. 6 mths.	F	14
	M	15
8 yrs. - 8 yrs. 6 mths.	F	15
	M	16
11 yrs. - 11 yrs. 6 mths.	F	15
	M	16
14 yrs. - 14 yrs. 6 mths.	F	15
	M	15

Note: Seven subjects did not complete the test.
These were:
Females - 2 aged 5, 2 aged 8
Males - 1 aged 5, 1 aged 8, 1 aged 14.

Subjects were asked to wear light sports clothing for the test. All tests were carried out in the Physical Education and Recreation Department of Glasgow University. Transport was available to and from the test, if required.

3.1.2 Measurements

There were two types of measurements taken: measurements of PT and mesurements of body size.

The measurement of PT involved the subject performing left leg knee extension in a standardised testing position at 4 pre-set velocities: 300 deg/sec, 210 deg/sec, 120 deg/sec, and 30 deg/sec. At each velocity the subjects were required to perform seven efforts, three submaximal efforts followed by four maximal efforts. The torque produced in the four maximal efforts was recorded.

There were six measurements of body size taken: standing height, weight, hip to ankle length, hip to knee length, knee to ankle length, thigh circumference.

Both the PT measurements and the measurements of body size were repeated one week later.

There were seven subjects who did not do the second test; 114 subjects completed both tests.

3.1.3 Equipment

The equipment used to measure PT will be described in this section. The equipment used for each body size measurement will be described along with their respective testing procedures.

To be able to perform voluntary limb movements at a pre-set velocity and to record the torque produced throughout the range of movement an isokinetic device is needed. The isokinetic device used in this study was the Cybex II Isokinetic Dynamometer (Lummex Inc.), as illustrated in Plate 1.

The isokinetic method allows for the measurement of the maximum torque throughout the whole range of a movement. This is possible because isokinetic devices, such as the Cybex II, control the moving limb to a constant pre-set velocity. More specifically during the voluntary limb movement the lever arm of the Cybex, which is attached to the limb being tested, moves freely without resistance until it attains a pre-set operating speed. Once in motion the lever arm is mechanically prevented from surpassing this speed. It does this by a hydraulic feedback system which keeps acceleration to zero; the amount of loading is determined by the efforts of the subject. If a maximal effort is given, then maximal loading is maintained at all points in the range of movement, with the resulting torque being recorded.

The Cybex also incorporates a device which can record the torque produced during one effort. Plate 2 shows a typical example of a recording of the torque produced during a voluntary knee extension limb movement performed on a Cybex. This Plate also indicates where the peak torque (PT) values are for each torque curve; PT is the maximum torque value obtained in the curve. To measure the PT in foot-pounds (ft.lbs) the vertical units from the baseline to this highest point are counted. Each vertical unit represents (x) number of ftlbs depending on the scale chosen. The Cybex recorder used in this study has three possible scales:

30 ft.lbs scale: 1 vertical unit = 1ft.lbs and a full scale deflection of 30 ft.lbs.

180 ft.lbs scale: 1 vertical unit = 6 ft.lbs and a full scale deflection of 180 ft.lbs.

360 ft.lb scale: 1 vertical unit = 18 ft.lbs and a full scale deflection of 180 ft.lbs.

In this study only the 30 and 180 ft.lbs scales were used; the torque scores were not high enough to require the use of the 360 ft.lbs scale.

Plate 1. Cybex II being used to test knee extension

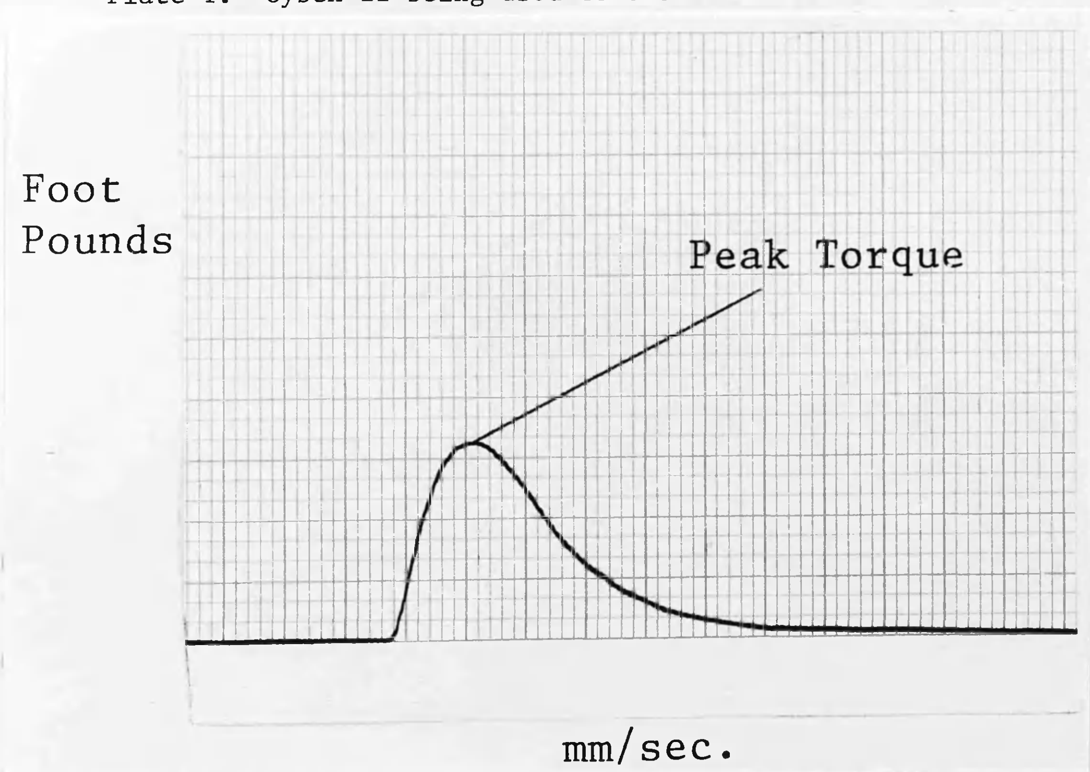


Plate 2. Torque recording obtained from knee extension task

Note: Peak Torque = number of boxes from torque baseline to highest point in torque curve.

Section 2

Testing Procedures

The purpose of this section is to describe the exact procedures used to carry out this test. Included will be a description of the collection of the subjects, the testing protocol for the measurement of PT, the testing protocol for the measurement of body size, and the testing protocol for the retest. A summary of the complete test for one subject is given on page 153.

3.2.1 Collection of Subjects

Subjects were collected and brought to the testing centre at the Department of Physical Education and Recreation at Glasgow University. Parents or guardians of the subjects were given the option of attending; this was considered important for younger subjects, or for subjects apprehensive about the test. On arrival at the testing centre the subjects were asked to change into their sports clothes.

3.2.2 Testing Protocol for Measurement of PT

3.2.2(a) testing position

It was, firstly, necessary to make sure that the subjects assumed a standardised testing position, and that this position could be repeated exactly for the retest. Plate 3 shows the correct positioning of a subject on the Cybex for left leg knee extension. To achieve this position for the subjects in this study the following procedures were adopted:

1. Subjects were positioned on the right-hand chair, sitting as far back as possible, with their back supported, and with their lower legs hanging freely over the edge of the chair. In this position the left thigh was stabilised using the thigh strap provided on the Cybex. For small subjects to be able to achieve this positioning several adaptions were made (Plates 4 and 5):

    a) For smaller children, sitting as far back as possible meant that their lower legs could not hang freely over the edge of the chair. Back spacers were used to overcome this.

    b) Subjects' legs are usually placed at either side of the middle bracket of the chair, with only one leg being stabilised by the thigh strap. Since this was not possible for smaller children, both legs were placed and stabilised between the middle and left bracket.

Plate 3. Standardised testing position - knee extension (subject aged 11)

Plate 4. 5 year-old subject sitting on Cybex II, showing the problems of achieving testing position

Plate 5. Modifications made for 5 year-olds to achieve testing position

2. In this correct sitting position the dynamometer of the Cybex was adjusted so that the centre of the subject's knee joint was in line with the axis of rotation of the dynamometer, that is with the collect lock. The lever arm was then adjusted to suit the length of the subject's lower leg and attached with the shin pad just above the subject's dorsi-flexed foot.

3. The next step in obtaining the standardised testing position was to standardise a starting postion for the leg before each of the knee extension trials. This position was obtained using the following procedures:

a) the Cybex was set to a velocity between 120 deg/sec to 180 deg/sec;

b) the subject were then asked to fold their arms, close their eyes and relax their leg;

c) the tester then lifted the left leg to the extended position and then let it go; this free-hanging position, the point where the leg came to rest, was used as the starting position;

d) this position was marked by fixing the angle dial on the collect lock to zero; this allowed the subject to return to the starting postion by refering to the zero mark on the collect lock.

5. The final step was to make the subjects aware of the testing postion, the position they must assume before each knee extension trial. They were told to check that

their leg was in the correct starting position (the point at which the leg corresponds to the zero on the angle dial), that their arms were folded, and that they were sitting straight.

2.2(b) measurement of testing position

To be able to obtain this testing position in the retest, each subject's testing position was measured using the following procedures:

1. The number of back spacers used was noted. If one or both legs had been stabilised, this was also recorded.

2. Hip and knee angles were taken using the following procedures:

a) Hip Angle.

The centre of the manual angle goniometer was placed on the greater trochanter of the left femur, with one arm of the goniometer being placed in line with the outside edge of the acromial process of the left shoulder blade. This can be felt as a ridge just above the shoulder joint. The other goniometer arm was placed in line with the lateral epicondyle at the left knee joint. With the goniometer set in this position the angle shown was recorded.

b) Knee angle.

The centre of the goniometer was placed on the lateral epicondyle at the left knee joint, with one arm of the goniometer placed in line with the lateral malleolus of the left ankle joint. The other goniometer arm was placed in line with the greater trochanter of the left hip joint. With the goniometer set in this position the angle shown was recorded.

3. The length of the lever arm, in centimetres to the nearest millimetre, was taken from the base of the lever arm to the mid-point of the centre axis (collect lock) on the dynamometer.

2.2(c) knee extension trials

After the measurement of the testing position was completed the next part of the procedure involved the subject performing three warm-up, followed by four maximal knee extension trials for each of the four velocities. The first velocity to be tested was 300 deg/sec. The procedures for testing at this velocity were as follows:

1. The speed selector of the Cybex was set to 300 deg/sec.

2. Subjects were asked to perform three warm-up trials. They were encouraged to proceed as follows:

a) get the "feeling" of the task by making the first trial easy, the second a moderate effort, and the third as hard and as fast as possible;

b) practice getting into the testing position before and after each effort.

3. After the completion of the warm-up trials, the subjects were asked to rest (approx. 30 secs.).

4. Subjects were asked to get into the "testing position", ready for the maximum effort trials. For younger subjects the leg was positioned by the tester.

5. Subjects were instructed that after the command "Are You Ready? GO!" they had to kick their leg into the extended position "as hard and as fast as possible".

6. The following procedures were then followed by the tester:

a) the scale was set on the Cybex Recorder to 30 ft lb or 180ft lb,

b) the stylus was adjusted to make sure that the torque line was recording on the Cybex's base line,

c) the velocity setting was checked,

d) the paper speed was turned from 0 to 25 mm/sec,

e) the testing position of the subjects was checked,

f) the command "Are You Ready? Go!" was given.

7. After the subjects had completed the knee extension task and returned the leg to the testing position they were given a verbal appraisal of performance. Typical phrases used were:

"That was super, see if you can get an even better score";

"That was a much better score";

"That wasn't as good as the last one";

"That was your best score yet, let's see if you can go even higher."

The purpose of the appraisal was to keep motivation high by giving as much encouragement as possible.

After this maximum effort trial the subjects were required to rest for approximately 30 seconds. Three more trials were given at the first velocity, i.e. 300 deg/sec, using the same procedures as outlined above.

After the four maximum trials were completed at 300 deg/sec, the procedures for both the warm-up and the maximum trials, as outlined above, were repeated for 210 deg/sec, followed by 120 deg/sec, and finally 30 deg/sec.

3.2.3 Measurement of Body Size

After the test measuring PT had been completed six measurements of body size were taken. The equipment and the procedures used for each measurement will be described below.

2.3(a) standing height

Height was measured using a Weylux (model 424) height and weight measuring scale (Plate 6). The subjects were asked to stretch upwards as far as possible, making sure that their heels were on the scale base, and that their eyes were focused straight ahead. To make sure that they were in the correct position the following steps were taken:

a) gentle traction was given on the head, behind the ears, to aid subjects in stretching to their fullest extent;

b) the head position was checked to make sure that they were looking straight ahead;

c) care was taken to make sure that the subjects kept their heels on the scale base while being measured.

Once the subjects were in the correct position the tester placed the head-bar gently on the subject's head. Readings were taken to the nearest 0.5 of a centimetre.

3.2.3(b) weight

Weight was measured using a Weylux (model 424) height and weight measuring scale. For measuring weight the Weylux model has a beam balance scale. The subjects were weighed bare-footed in light sports clothes, to the nearest tenth of a kilogramme (Plate 6)

3.2.3(c) hip to ankle length

With the subjects standing, feet slightly apart, the measurements were taken with a wax cloth tape from the greater trochanter at the left hip joint to the lateral malleous at the left ankle joint. The measurements were taken to the nearest millimetre (Plate 7).

3.2.3(d) hip to knee length

With the subjects standing, feet slightly apart, the measurements were taken, with a wax cloth tape measure, from the greater trochanter at the left hip joint to the lateral epicondyle at the left knee joint. The recordings were taken to the nearest millimetre (Plate 8).

3.2.3(e) knee to ankle length

Knee to ankle length was not directly measured, but was calculated by subtracting the hip to knee value from the hip to ankle value.

3.2.4(f) thigh circumference

With the subjects standing, measurements were taken with a wax cloth tape placed round the left thigh horizontally, with the top edge just under the fold of the buttock. The measurements were taken to the nearest millimetre (Plate 9).

Plate 6. Measurement of height and weight

Plate 7. Measurement of hip to ankle length

Plate 8. Measurement of hip to knee length

Plate 9. Measurement of thigh circumference

3.2.4 Retest

The design of this study required that subjects were retested in both the PT measurements using the Cybex and the body size measurements. Arrangements were made for the subjects to return for a second test not less than four days and not more than ten days after the first test. If subjects failed to be tested a second time within this time limit their first week's results were not used. This occurred for seven subjects.

3.2.4(a) retest procedure

Efforts were made to ensure that the retest procedures were identical to those of the first test:

1. The most important method of replicating the procedures for the Cybex test was to ensure that the subjects assumed the same "Testing Position":
   a) Cybex lever length was the same as it was in the first week,
   b) the same number of back spacers was used,
   c) adjustment of the subject's sitting position established the same starting for the leg as recorded in week 1.
2. The measurements of height, weight, hip to ankle length, hip to knee length, and thigh circumference were taken by the same procedures as in the first test.

Subjects retested in both the PT measurements, and body size measurements had completed all the tests required by the study.

3.2.5 Summary of Testing Procedures

1. Subject positioned on Cybex II

2. Measurement made of this testing Position

3.a) 300 deg/sec: familiarisation trials x 3

(30 sec rest)

maximum recorded trials x 4

(30 sec rest after each trial)

b) 210 deg/sec: familiarisation trials x 3

(30 sec rest)

maximum recorded trials x 4

(30 sec rest after each trial)

c) 120 deg/sec: familiarisation trials x 3

(30 sec rest)

maximum recorded trials x 4

(30 sec rest after each trial)

d) 30 deg/sec: familiarisation trials x 3

(30 sec rest)

maximum recorded trials x 4

(30 sec rest after each trial)

4. Five measures of body size taken: height, weight, hip to ankle length, hip to knee length, and thigh circumference.

5. Subject repeated whole test one week later.

Section 3

Calibration

In this study PT measurements were obtained using a Cybex II. It was important, therefore, to ensure that the Cybex II used in this study was giving both valid and reliable measurements of PT throughout the testing period. This was checked using the calibration test. The theoretical bases of this test was outlined in the review, page 119.

3.3.1 Calibration Procedures

The procedures used in this study to calibrate the Cybex were as follows:

1. Two disc weights were measured to find their exact weight. Their weights were:
   a) 20.15 lbs
   b) 20.24 lbs.
2. These two weights were attached to the base of the Cybex II lever arm. The length of the Cybex II lever arm was 18 inches. This arrangement is shown in Plate 10.
3. The Cybex damping scale was set to mode 3, as recommended by the manufacturers.
4. Full scale deflection mode was set to 180 ft lbs. (The Cybex manufacturers suggest that the calibration could be done using any of the full-scale deflection modes, 30, 180 or 360 ft lbs).

5. The speed selector was set to 30 deg/sec, as recommended by the manufacturers.

6. The paper speed was turned from "off" position to 25 mm/sec.

7. The lever arm with the weights attached was raised to a fully vertical position and then released (plate 11). It then dropped through an angle range of 180 degrees at a velocity of 30 deg/sec. After the lever had come to rest, the paper speed was turned off.

This procedure was repeated five times. After each trial it was necessary to check that the speed selector was still registering 30 deg/sec, and that the lever length was still exactly 1.5 ft.

The Cybex 11 used in this study was calibrated six times during the nine-month testing period. Six trials were performed in each of the calibration tests. The first calibration was performed after the pilot study (see appendix G), which was just prior to the start of testing for the main study. The Cybex was then calibrated at two-month intervals, with a final calibration at the end of the study.

In addition to the calibration trials the validity of the PT measurements made by the Cybex II were also checked by investigating whether any of the PT scores obtained from the subjects occurred in the first or last eight of a second.

Plate 10. Calibration of Cybex II

Plate 11. Lever arm dropped through 180 degrees

3.3.2 Conclusion

At the beginning of this chapter five sub-problems of the study were outlined. The three sections outlined in this chapter were designed to answer these questions. In chapter four the results, including the analysis of data, will be reported.

CHAPTER FOUR

RESULTS

The results obtained are reported in five specific sections:

1. the reliability of the PT and body size measurements,
2. the relationship between PT and velocity for the subjects of each age group,
3. the effect of age on the peak torque scores at each velocity,
4. the variation in peak torque scores for this subject population, using several parameters: age, height, weight, hip to ankle length, hip to knee length, knee to ankle length, thigh circumference, and Cybex lever length.
5. the sex differences between a) the mean peak torque scores and b) body size measures.

Section 1

Reliability of Measurements

Important for any study is to ensure that the measurements taken were reliable. In the present study two types of measurements were taken PT scores and body size measurements. The purpose of this section is to report on the reliability of these measurements.

Reliability of PT Scores

Two aspects were investigated to establish the reliability of the PT scores:

1. to assess whether the Cybex II gave valid and reliable measurements of PT during the testing period,
2. to assess the reliability of subjects in producing PT.

4.1.1 Cybex II: Validity and Reliability

The purpose of the calibration trials, as outlined in the method section, was to investigate whether the Cybex II Isokinetic Dynamometer used in this study was giving valid and reliable measurements of peak torque.

4.1.1(a) validity of peak torque measurements

Using this calibration technique accurate measures of peak torque would be indicated if the peak torque values obtained from the calibration trials equalled the theoretical value of peak torque for the calibration trials of 60.5 ft lbs (weight x lever length).

Figure 8 shows both these values: the theoretical value of peak torque and the peak torque obtained from the calibration trials. A comparison between these values produces the following results in this figure:

1. The majority of the obtained values of PT are lower than the theoretical value with only 3 exceptions. This suggests that the Cybex device used in the study underestimated peak torque.

2. There is little difference between the theoretical value and the obtained values of PT. The mean and standard deviation of the difference was found to be 0.57 ft lbs and 0.34 ft lbs respectively, representing a mean error of 0.56%.

It is concluded that although there was a tendency for the calibration trials to underestimate the theoretical value of PT, the small error obtained indicated that the Cybex II Isokinetic Dynamometer used in this study gave valid measurements of peak torque over the testing period.

This conclusion is based on the standardised testing procedures outlined by the manufacturers. However, in addition to the standardised procedures two addtional procedures recommended by the manufacturers were also followed. More specifically, the first procedure involved using the recommended damping setting. As was shown in the method this was carried out at the recommended damping setting of two. The second procedure recommended that PT scores should not be taken if they occured in the first eighth or last eighth of a second. All PT scores obtained from all trials over the two testing weeks were examined and were found to fulfill these criteria. It is concluded therefore that in following these additional procedures the validity of the PT scores is given further confirmation.

4.1.1(b) reliability of peak torque measurements

The reliability of measuring peak torque was investigated by looking at the variation that occurred amongst the peak torque scores obtained from all the calibration trials, that is, all the results obtained over the nine-month testing period.

The peak torque scores produced in each of the calibration trials are shown in figure 8. The mean and standard deviation of the obtained PT scores were found to be 59.95 ft lbs and 0.38 ft lbs respectively. The co-efficient of variation was 0.63%.

It is concluded that since the trials were obtained throughout the nine-month testing period, the small co-efficient of variation indicates that the Cybex used in this study gave reliable measurements of peak torque during the testing period.

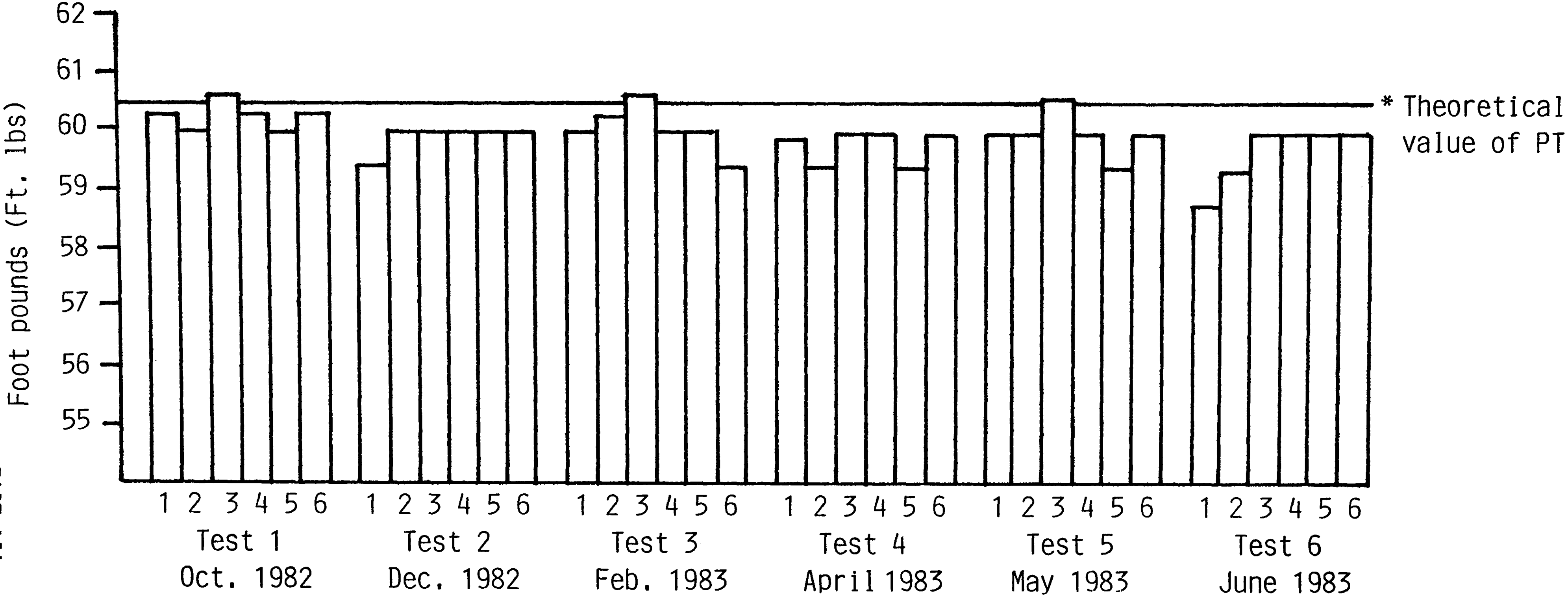


Figure 8 A comparison between obtained calibration values (n = 36) and the theoretical PT value.

Note Theoretical value of PT = 60.5 ft-lbs.

4.1.2 Subject Reliability of Peak Torque Scores

One of the purposes of this study was to obtain scores representative of the maximum peak torque attainable, for four age groups of children, in a maximal voluntary knee extension task at four constant velocities.

To obtain PT scores, 4 trials were given at each velocity, with the whole test being repeated one week later. PT for each subject at each velocity was the highest PT score obtained over the two tests. The mean standard deviation and the range of the PT scores obtained for boys and girls for each velocity and for each age group, are reported in appendix A (Tables A-1 to A-4).

Before the PT scores could be used in further investigations of this study it was necessary to investigate the reliability of this measurement.

4.1.2(a) the determination of reliability

The reliability of these PT scores was determined by investigating the variation between the best PT scores of test 1 and test 2; the differences between the PT scores of each of the two weeks were expressed in proportional terms for each subject: week 2 minus week 1, divided by week 1. Using these proportional differences the following calculations were made:

1. mean and standard deviation of the proportional difference, for each age at each velocity, and for all subjects at each velocity;

2. ninety-five percent confidence intervals for the average proportional difference, for each age group at each velocity, and for all subjects at each velocity.

These calculations were used to determine the magnitude of variation, and to assess whether week of testing had an effect on the production of best PT scores. Consideration was also given, in both these aspects, to the possibility that age and velocity might affect the results.

4.1.2(b) the magnitude of variation

Figure 9 shows the mean proportional differences for each age group at each velocity. There is considerable variation across the ages and velocities in the magnitude of the differences obtained. This is highlighted by the range of the differences obtained, which is from 0.3% to 17%.

Figure 9 also shows the mean proportional differences for all subjects at each velocity. In terms of the magnitude of differences it can be seen that across velocity the differences ranged from 1.5% to 6.5%. This is a narrower range in comparison to the range noted above, when differences were examined for each age at each velocity.

There seem to be no trends occuring with age and velocity in the magnitude of variation. The exception to this is at 300 deg/sec where the magnitude of variation decreases as age increases.

4.1.2(c) significance of week of testing.

Figure 9 shows that the majority of the means are negative. This indicates a bias towards better scores being produced in week 1. Exceptions to this are obtained almost exclusively at 300 deg/sec, where children aged 5, 8 and 11 have means which indicate a bias towards better scores being produced in week 2.

Figure 10 shows the 95% confidence intervals produced for the average proportional difference for each age group at each velocity. These intervals indicate that the bias towards better PT scores being produced in week 1 or week 2, as shown by the mean values, is in the majority of cases not significant.

However, if the mean values, using all subjects at each velocity, are examined a trend is apparent. It would appear that as velocity decreases the bias towards better PT scores being produced in week 1 increases. Significant differences are obtained ($P < 0.05$) at 30 and 120 deg/sec in favour of better PT scores occurring in week 1 and at 300 degress/sec, a significant difference ($P < 0.05$) in favour of better PT scores being obtained in week 2.

The purpose of this section was to investigate the reliabilty of the PT scores obtained for subjects aged 5, 8, 11 and 14 years, at velocities 300, 210, 120 and 30 deg/sec. The results reported describe this reliability in terms of the magnitude of variation and the significance of the week of testing for each velocity, at each age.

In both these aspects consideration was also given to the possibility that age and velocity might affect the results. In this respect, two effects were noted:

1) It was apparent that velocity affected whether best PT scores were produced in week 1 or week 2; as velocity decreased, the bias toward better PT scores being produced in week 1 increased. Only at 300 deg/sec was there a bias towards better PT scores being produced in week 2.

2. It was also apparent that at 300 deg/sec the age of the subject affected the magnitude of variation of PT scores over the two weeks; as the age of the groups increased the magnitude of the variation decreased.

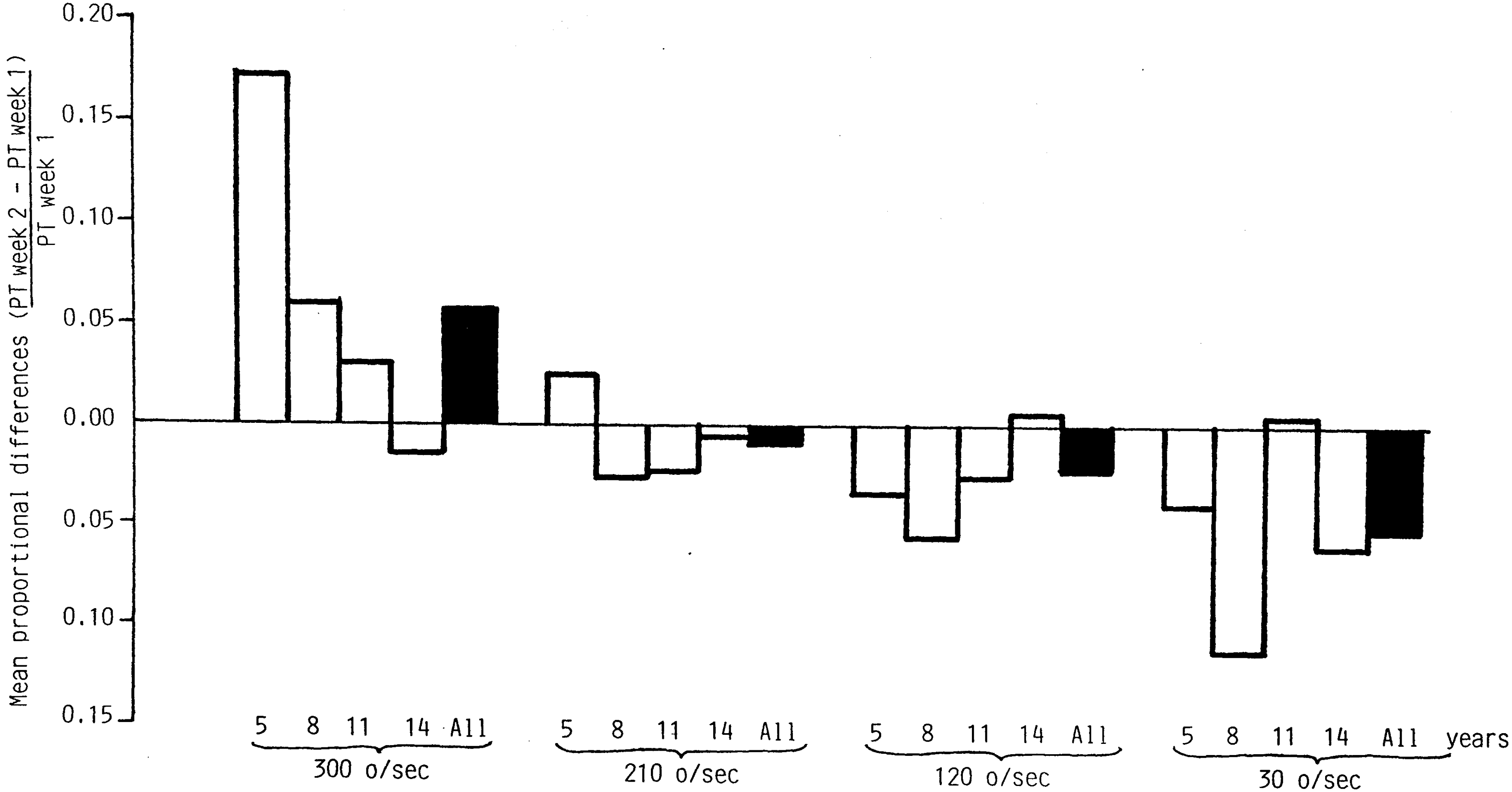


Figure 9 Mean scores of the proportional differences between PT scores of week 1 minus PT scores of week 2, obtained for 4 age groups at 4 isokinetic velocities.

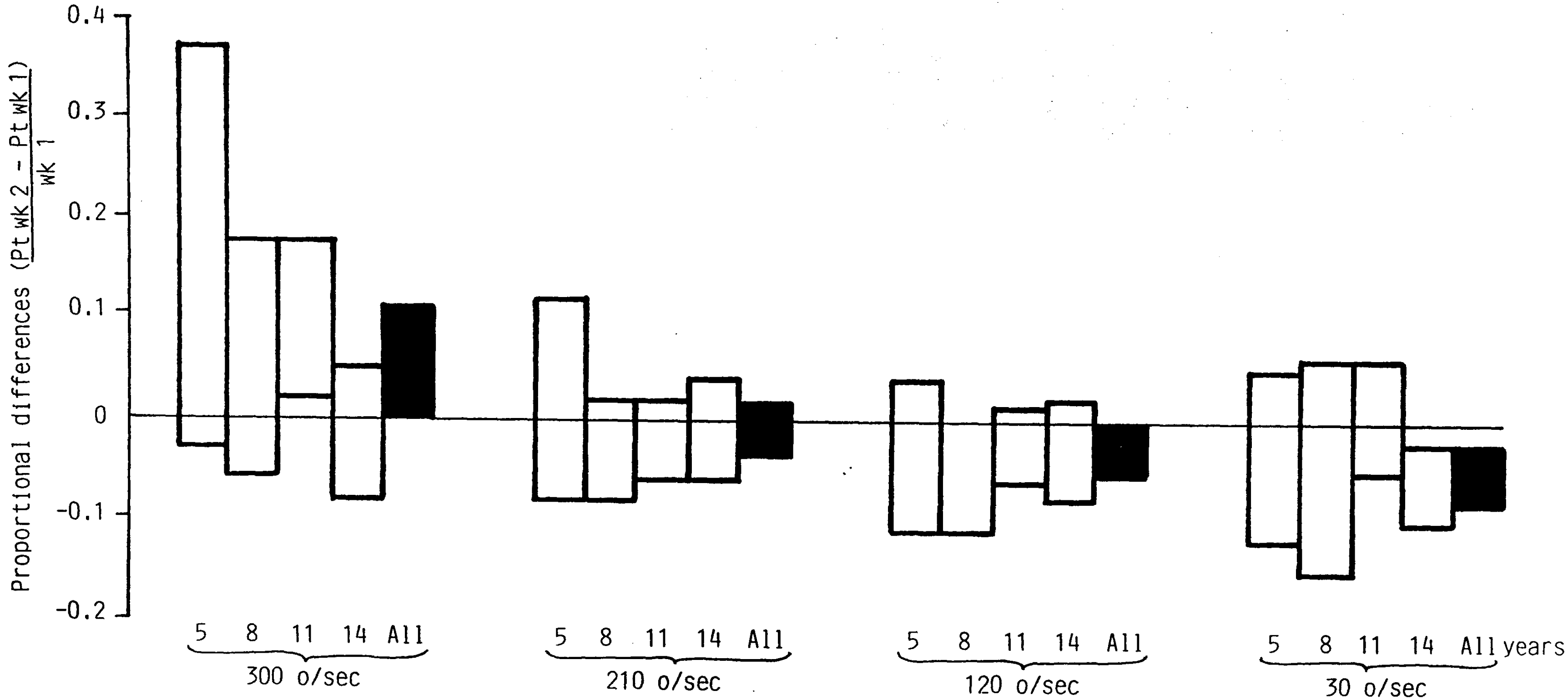


Figure 10 95% confidence intervals of the proportional differences between PT scores of test 1 minus test 2, obtained for 4 age groups at 4 isokinetic velocities.

4.1.3 Reliability of Body and Limb Size Measurements

Six body and limb size measurements were taken:

1. height
2. weight
3. hip to ankle length
4. hip to knee length
5. knee to ankle length
6. thigh circumference.

All the measurements listed above were taken in both testing weeks.

The reliability of these measurements was determined by statistical comparisons of measurements taken in the first week and repeated in the second week.

Differences between scores at the two tests were calculated by subtracting week 1 scores from week 2 scores. The mean and standard deviations of these differences are reported in Appendix B, Table B-1.

Using this data, 95% confidence intervals for the population mean differences were calculated for each measurement. With these 95% confidence intervals, reported in Table B-1, it is possible to ascertain whether or not there were any significant differences between the weeks. A significant difference ($p < 0.05$) would be indicated if the interval did not contain zero.

Table B-1 shows that all of the intervals contain zero; this indicates that there were no significant differences between the weeks for any of the measurements. It was concluded, therefore, that the body and limb size measurements were reliable.

The average of scores obtained over the two tests was used as the representative score in each of the measurements. Means and standard deviations for boys and girls of each age group for each of the measurements are reported in Appendix B (Tables B-2 to B-7). The means and standard deviations calculated for the Cybex lever lengths are also reported in appendix B (Table B-8). These mean values are also shown in Figures 11 and 12; they show the characteristics of the subject population in terms of their body and limb size measurements.

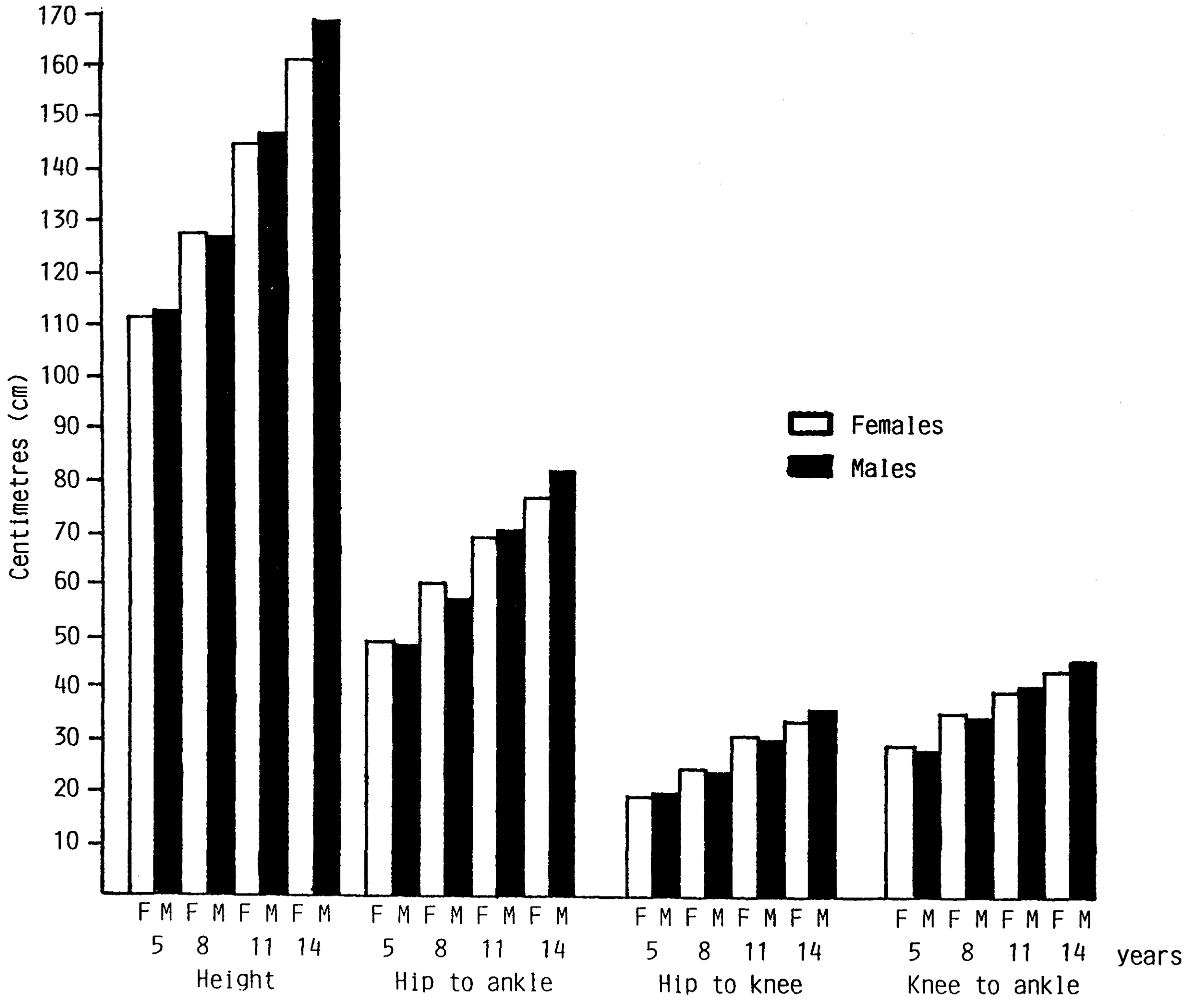


Figure 11 Mean values of five different body size measurements (linear dimension) for 4 age groups of children.

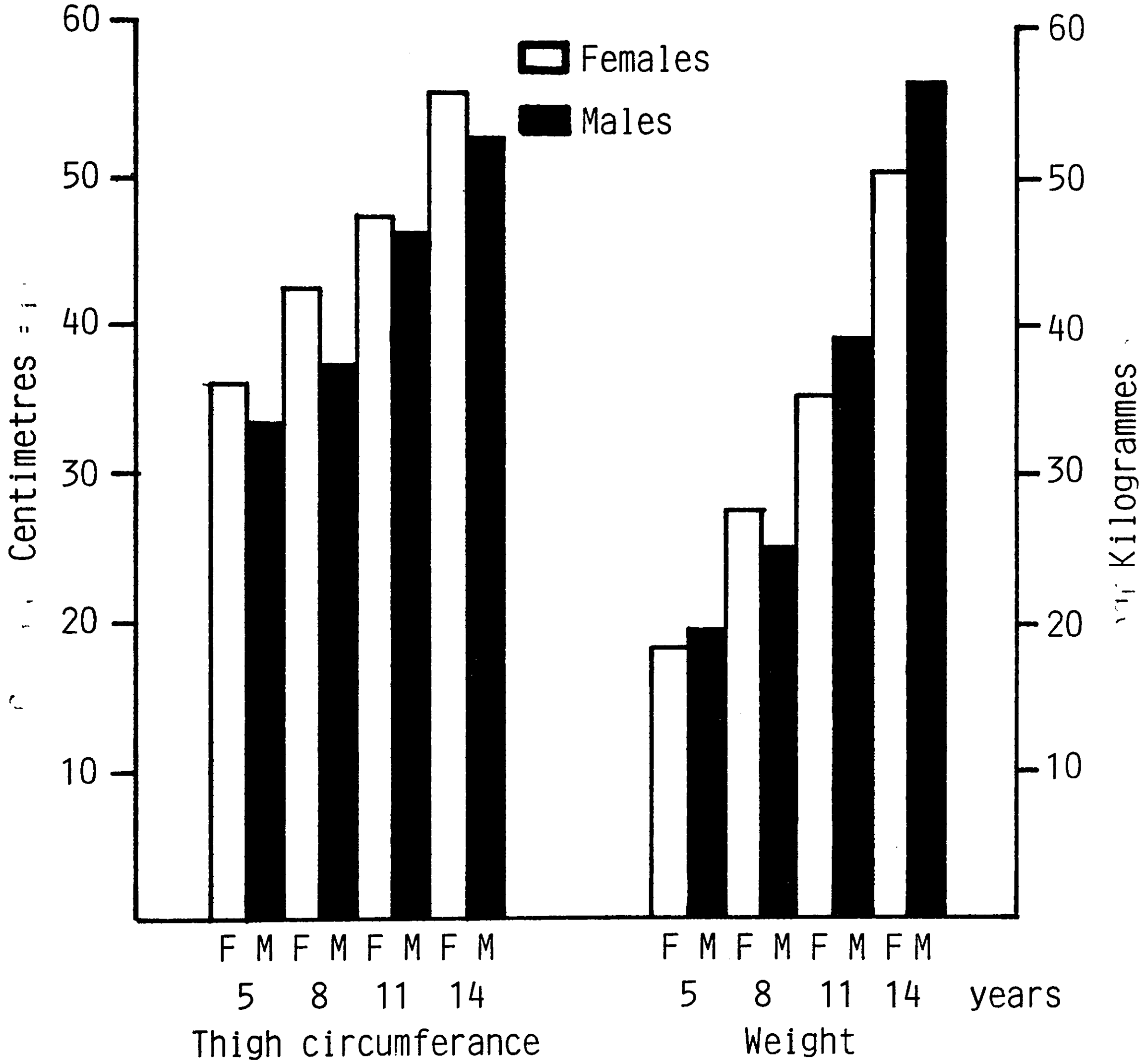


Figure 12 Mean values of two different body size measurements (mass) for 4 age groups of children.

Section 2

The Relationship Between PT and Velocity

One of the purposes of this study was to describe the relationship obtained between the PT scores and velocity for each age and gender group. In this study peak torque scores were obtained for boys and girls, aged 5, 8, 11, and 14 years at velocities of 300 deg/sec, 210 deg/sec, 120 deg/sec, and 30 deg/sec.

To describe this relationship three aspects were considered: the relationship between PT scores and velocity; the exponential trend; and the relationship between PT and velocity, described as a mathematical equation.

4.2.1 The Relationship Between PT and Velocity

Figure 13 shows the relationship between PT and velocity for boys and girls aged 5, 8, 11, and 14 years. The mean PT scores at velocities 300 deg/sec, 210 deg/sec, 120 deg/sec, and 30 deg/sec obtained for boys and girls at each age group, were used to construct these relationships (8 relationships in total).

All 8 relationships show a similar trend; as the velocity decreases mean PT scores increase, not at a uniform rate but at an accelerating one.

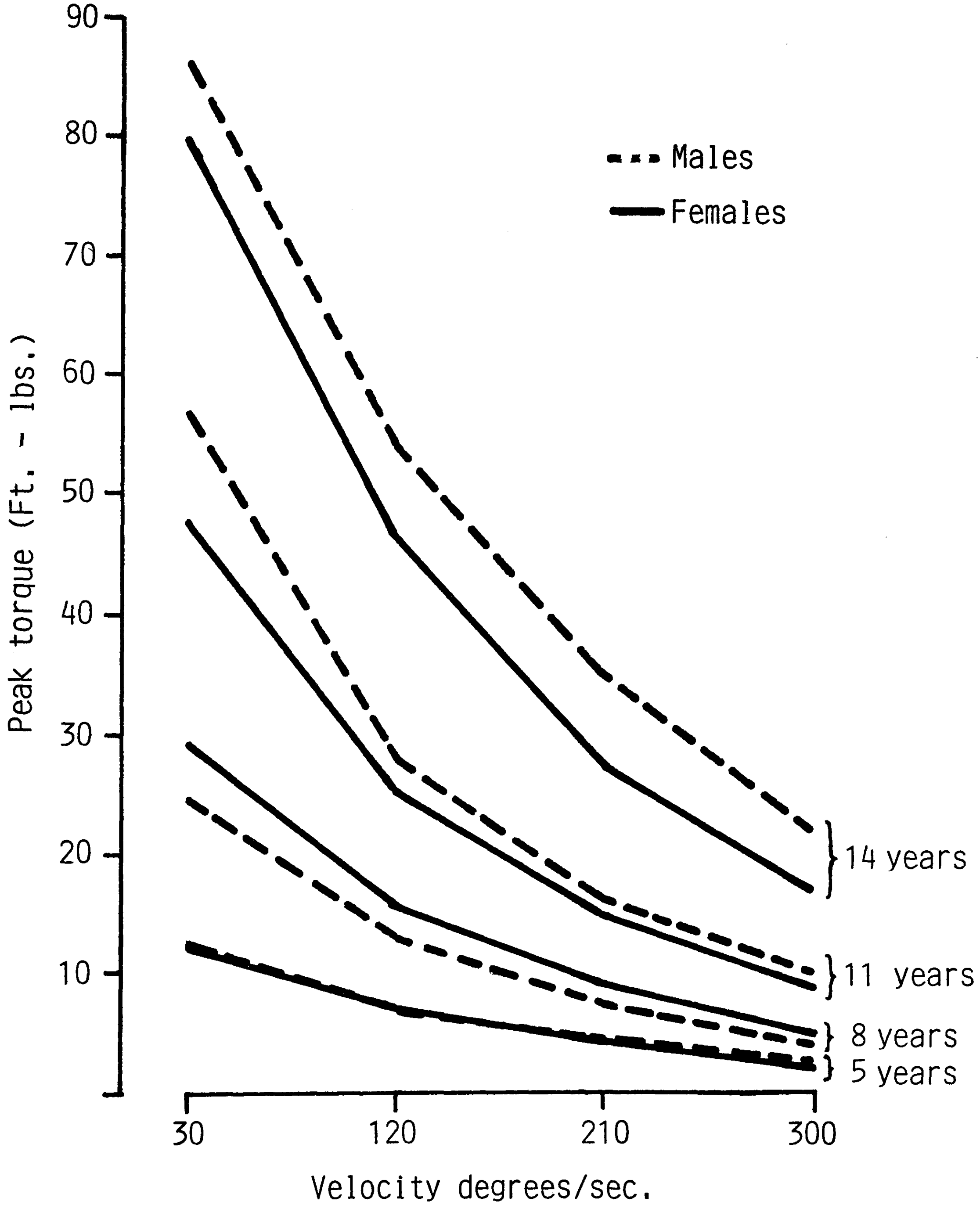


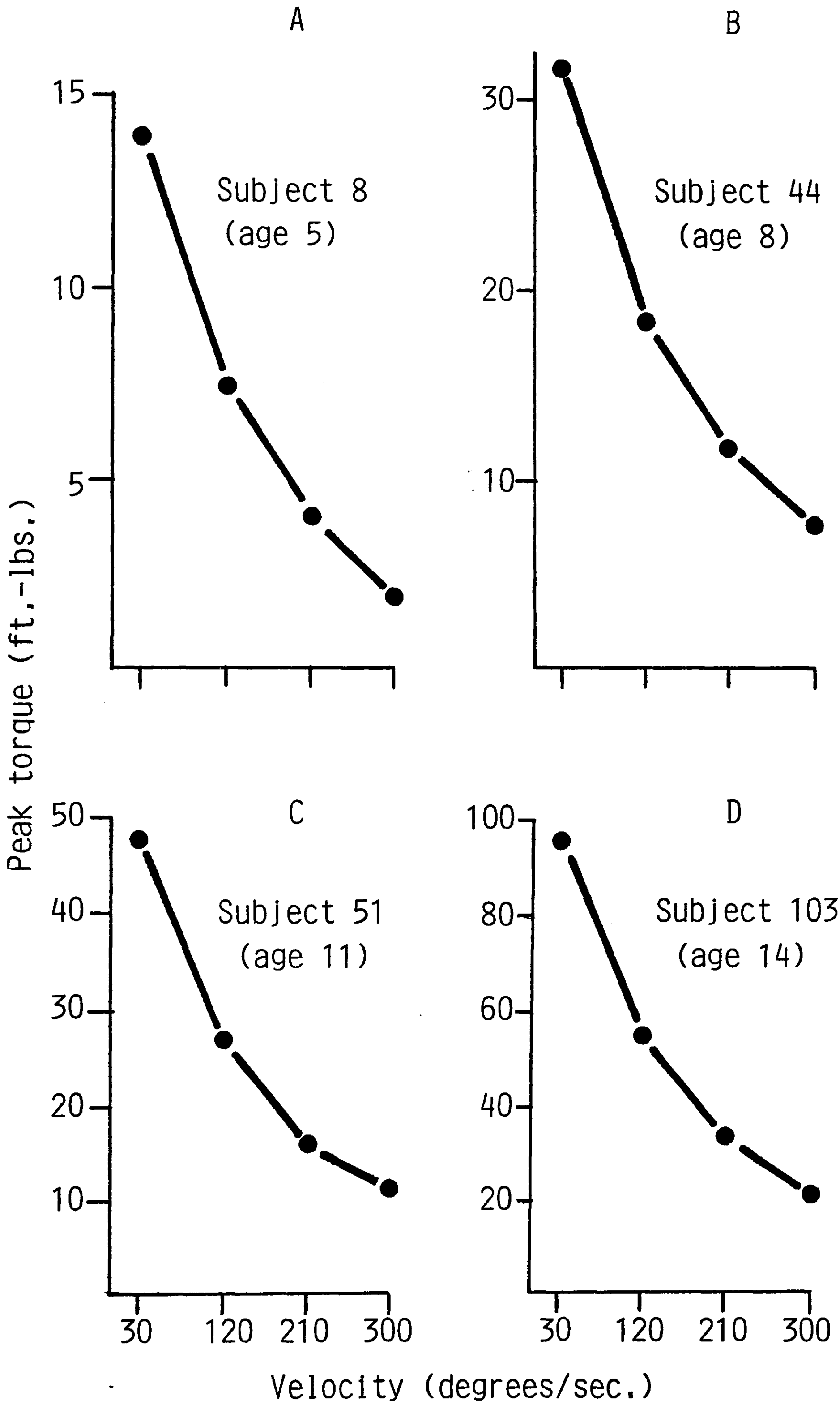
Figure 13 The relationship between PT and velocity for children of 4 different ages.

To check that this trend was not an effect of the process of computing the mean values, trends between PT and velocity were investigated for individual subjects; Figure 14 (a, b, c, d) are plots of velocity and PT scores, using the results of randomly chosen subjects; one from each age group. These plots show trends consistent with the population means described above; it is inferred that the trends obtained in Figure 13 were not merely the result of computing mean values.

4.2.2 Exponential Trend

The trend, obtained from individual and population mean plots, suggested that the relationship between PT and velocity for each subject might be exponential.

This was investigated by transforming all PT scores to Log PT and examining the relationship obtained between Log PT and velocity for each subject; an exponential relationship would be indicated if the trend was linear. Figure 15 (a, b, c, d) shows the plots between Log PT and velocity for the same subjects as used in Figure 14 (a to d).



<u>Figure 14</u> Relationship between PT and velocity

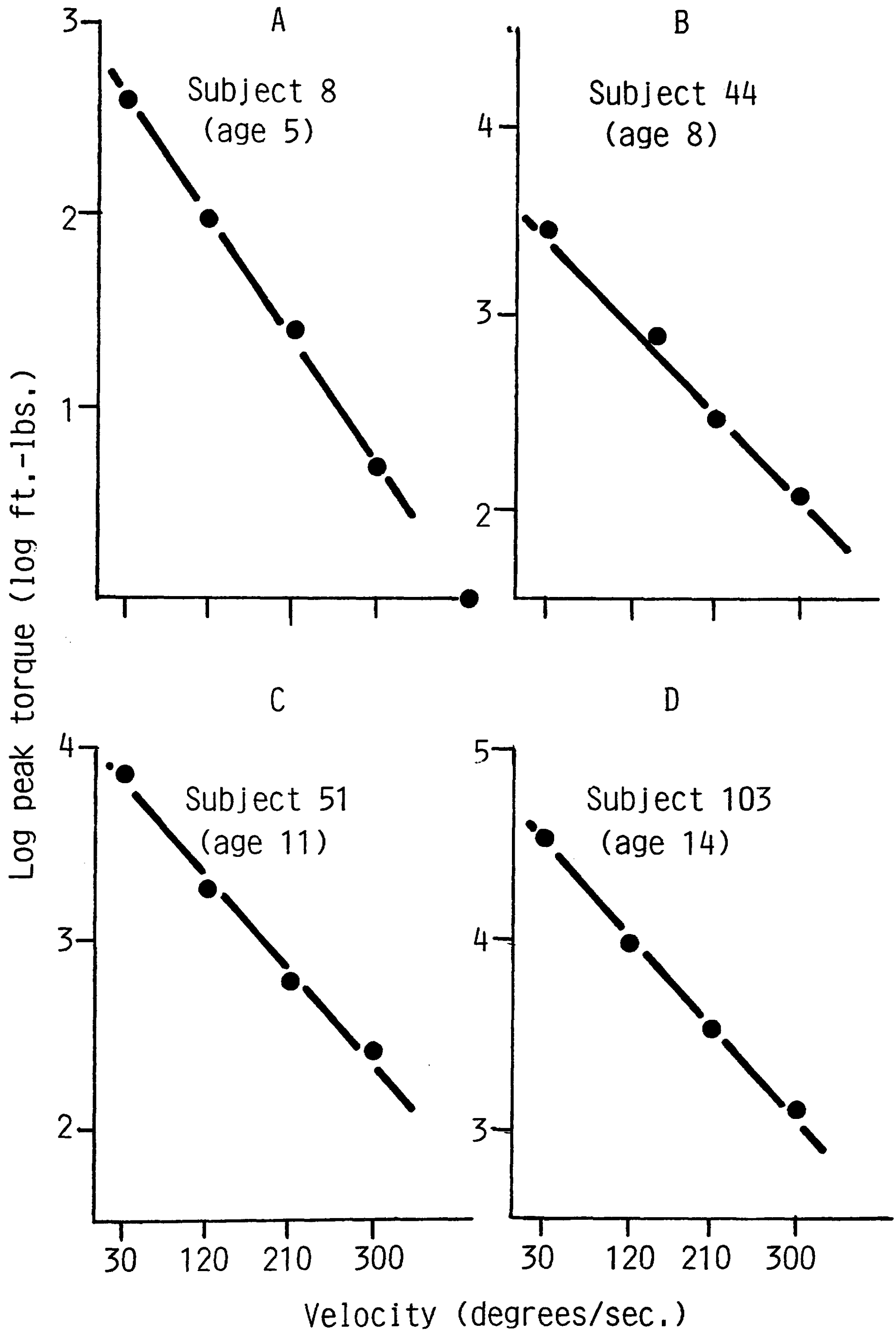


Figure 15 Relationship between log PT and velocity

Note For figures 15a-c best fitting straight line calculated by linear regression

The effect of this transformation for these subjects was that, in comparison to the relationships between PT and velocity, the relationships between Log PT and velocity showed a trend which was more linear. This increased linearity is also shown in the plots between Log PT and velocity, using the population mean values for each age and gender group (Figures 16 and 17).

To examine the strength of the linear relationship between Log PT and velocity for each subject, Pearson's Product Moment Correlation was used. All subjects' correlation co-efficients lie within -0.96 to -0.99, and all were found to be significantly linear ($P < 0.01$).

These results indicate that, for all subjects, there is a significant negative linear relationship between Log PT and velocity. It can be inferred that the relationship between PT scores and velocity could be described as exponential: a negative exponential decrease in PT scores as the velocity of angular motion increases. This description is the same for all subjects, irrespective of age and gender.

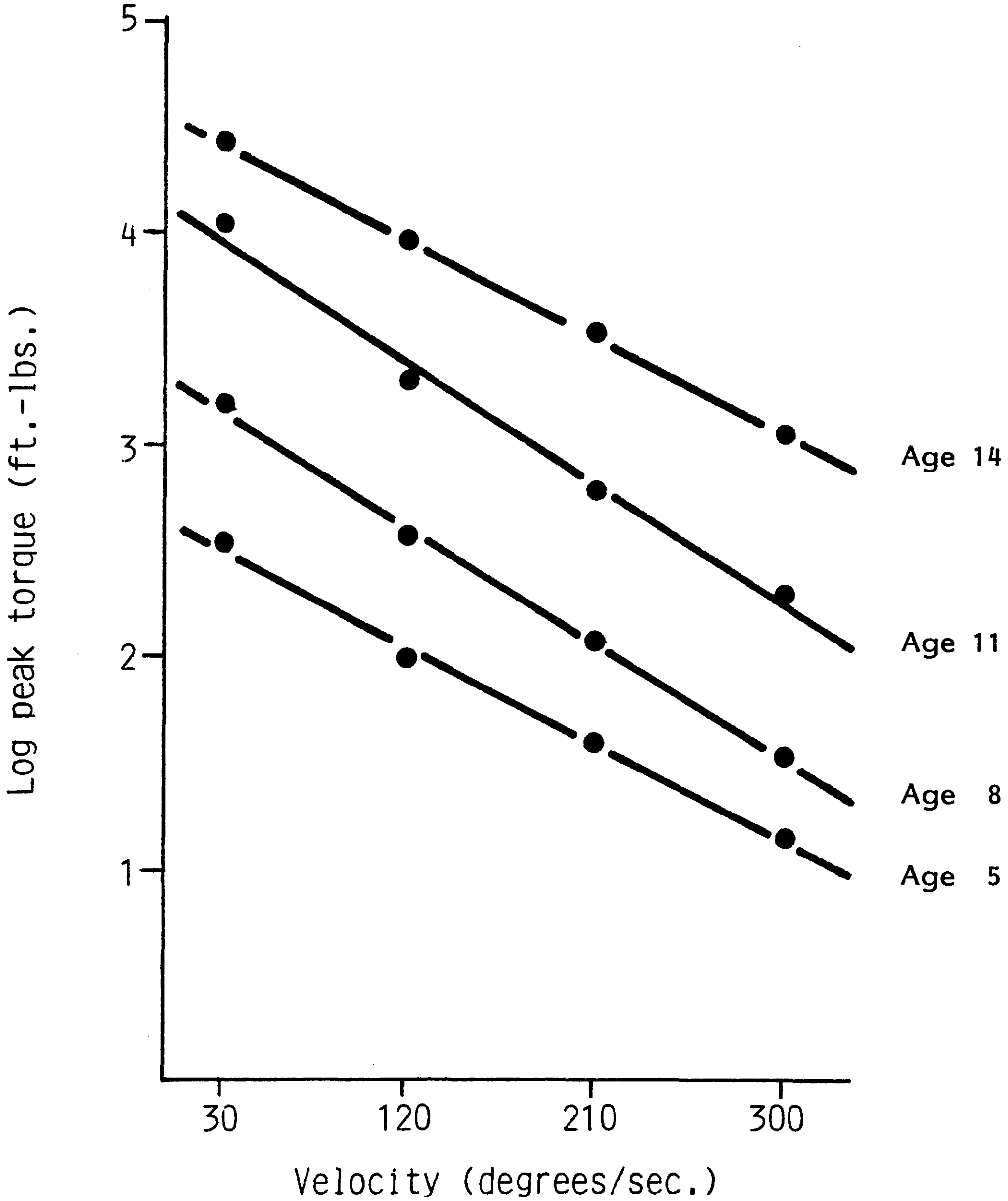


Figure 16 Relationship between mean log PT scores and velocity for 4 age groups of boys

Note Best fitting straight line calculated using linear regression

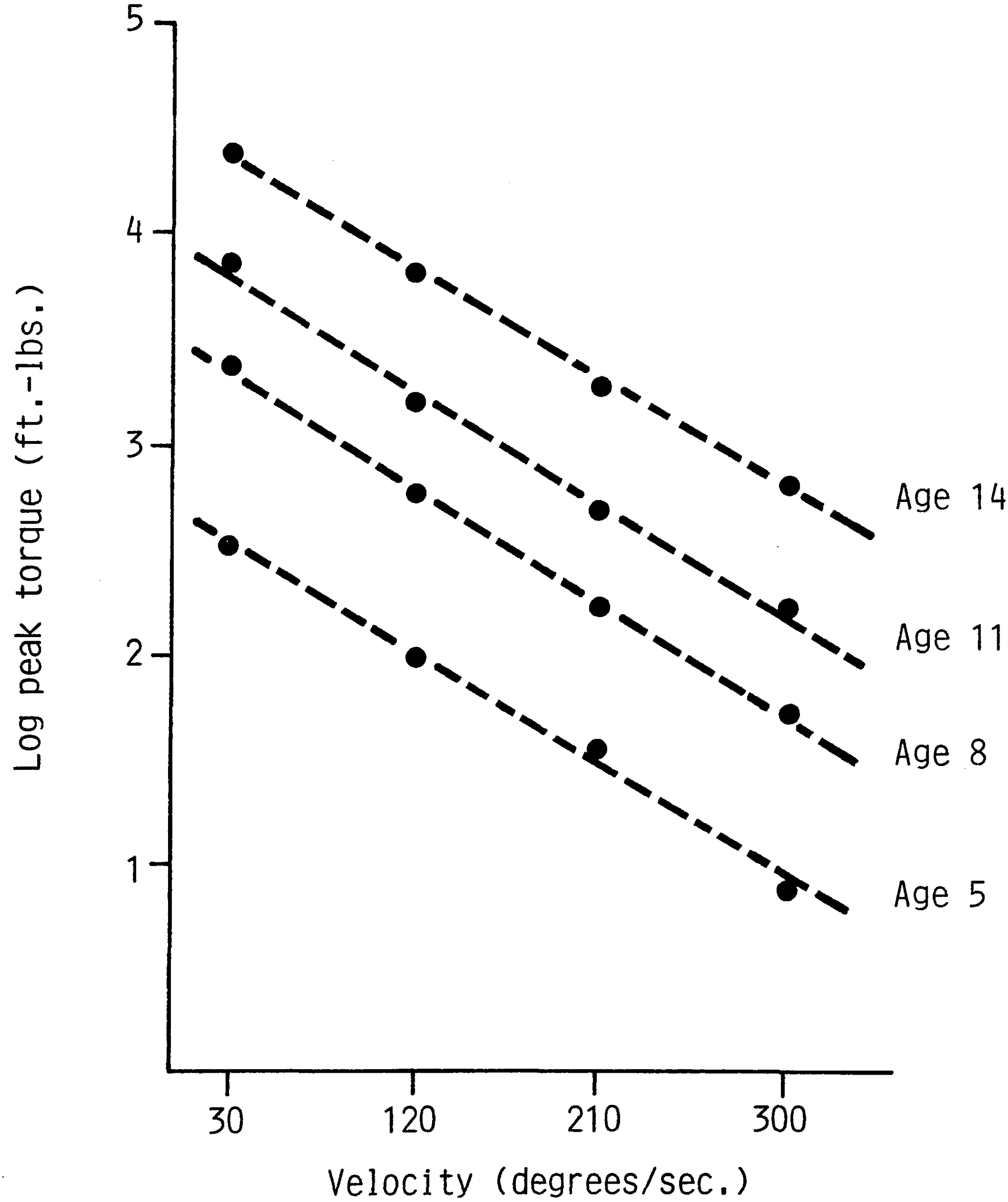


Figure 17 Relationship between mean log PT scores and for 4 age groups of girls.

Note Best fitting straight line calculated using linear regression

4.2.3 The Relationship Between PT and Velocity Described as a Mathematical Equation

The strength of the linear relationship obtained between log PT and velocity meant that it was possible, with the mathematical equation of a straight line, to describe each subject's relationship.

Linear regression was used to find the straight line most appropriate to each subject's Log PT velocity relationship. The equation used was as follows:

$$\text{Log PT} = a + b \times \text{velocity}.$$

In this equation a and b are constants for intercept and slope respectively.

Obtaining values for intercept and slope means that the relationship between PT and velocity for each subject can be described as two data points in the following equation:

$$\text{Log PT} = \text{Intercept} + \text{Slope Velocity}$$

$$\text{PT} = \text{Exponent (Intercept} + \text{Slope Velocity)}$$

Values for intercept and slope were found for each subject's regression of Log PT on velocity. The mean values for intercept and slope for boys and girls of each age group are reported in Appendix C (Tables C-1 and C-2). These values can be used to represent the mean relationship between PT and velocity for each age and gender group. Figure 18 shows the mean log PT velocity relationship calculated for the mean intercept and slope values for each age and gender group.

In conclusion, the main purpose of this section was to describe the relationship between PT scores and velocity. It was found that the relationship was the same for all subjects, irrespective of age and gender; that is, there was a negative exponential decrease in PT scores as the velocity of angular motion increased. Furthermore, it was found that the intercept and slope values calculated (for each subject) from the regressionof Log PT on velocity, when used in the equation Log PT + Slope x velocity, were highly accurate representations of each subject's obtained PT velocity relationship.

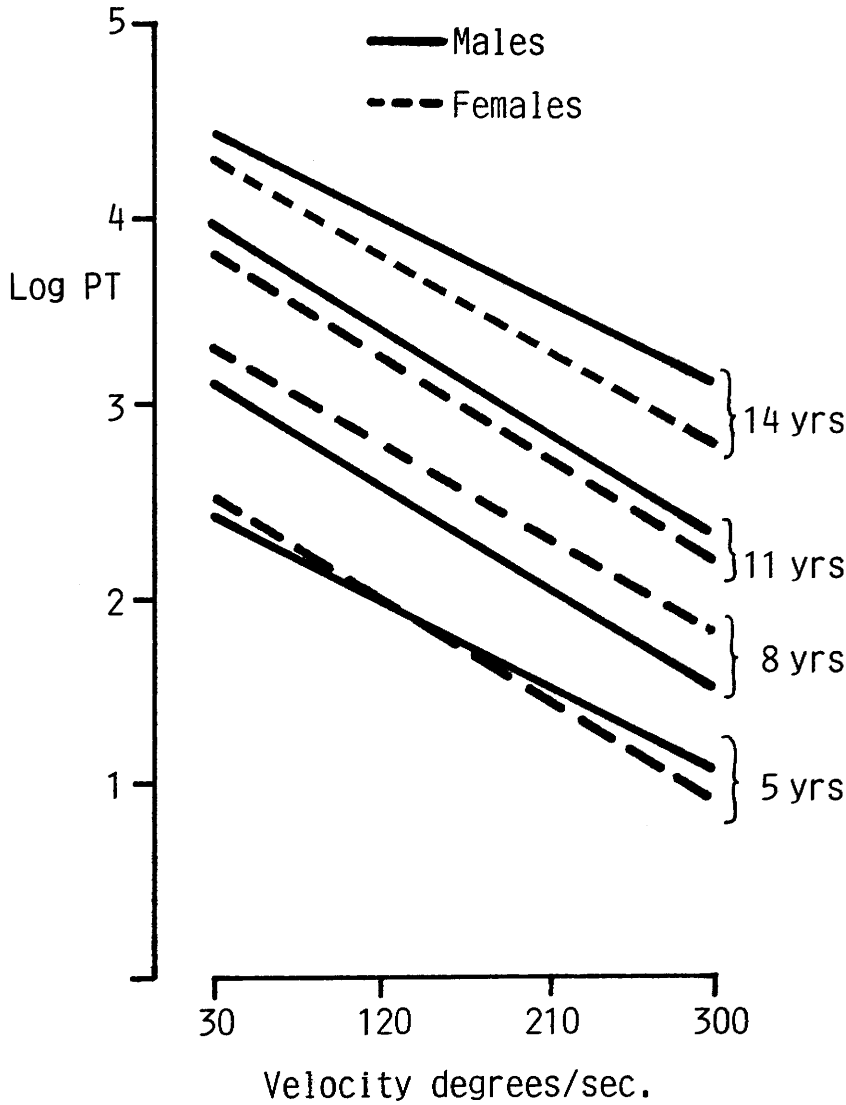


Figure 18 Mean Log PT - velocity relationship for girls and boys of four age groups, constructed using mean intercept and slope values.

Note Mean intercept and slope values were calculated from each subjects linear regression of Log PT on velocity.

Section 3

Effect of Age on PT Scores at Each Velocity

One of the purposes of this study was to investigate the effect of age on the mean PT scores obtained at four velocities: 300 deg/sec, 210 deg/sec, 120 deg/sec, and 30 deg/sec. To investigate this, the analysis considered the following: the use of intercept and slopes; the difference between male intercepts; the difference between male slopes; the difference between female intercepts; the difference between female slopes.

4.3.1 The Use of Intercepts and Slopes

To investigate whether age had any significant effect on the mean PT scores obtained at the four velocities, the mean intercept and slope values for boys and girls, in each age group, were used in the statistical analysis (Appendix C, Tables C-1 and C-2).

It was shown in the last section that mean intercepts and slopes would accurately explain the mean relationships occurring between PT and velocity for boys and girls of each age group; use of these values would allow the effects of age to be examined across the whole PT velocity relationship, and not just at individual velocities.

Intercepts show the point at which the regression line crosses the x axis, and therefore represent a summary of the PT scores for the four velocities. An examination of mean intercepts for each age group can determine whether or not there is any difference in the PT produced between the age groups.

Slopes indicate the rate of decay of PT, as velocity increases, and therefore show the relative amounts of PT obtained across all velocities for each age group. The steeper the slope, the faster the decay in PT as velocity increases. An examination of mean slopes for each age group can determine whether or not there is a difference in the relative PT produced across velocities.

Analysis of variance was used to discover if there were any differences between the mean intercepts and mean slopes obtained for the 4 age groups of males and females. Separate analyses were conducted for intercepts and slopes. Where significant differences were obtained, 95% confidence intervals were used, as a follow-up test, to investigate the differences between the means.

4.3.2 The Differences Between Mean Male Intercepts

Table D-1 (Appendix D) is an ANOVA summary table for the main effect of age on mean male intercept values. The analysis revealed a significant main effect for age $F(3,55) = 155.8$, $p < 0.001$.

As a follow up test (to investigate these differences further) 95% confidence intervals were calculated for the mean intercepts of males aged 5, 8, 11, and 14. Comparisons between these intervals would show the following significant differences:

Age 5	Age 8	Age 11	Age 14
(2.5, 2.8)	(3.1, 3.4)	(4.0, 4.3)	(4.4, 4.7)

This indicates that there are significant differences between all four male age groups in the amount of PT produced, with the 14 yr-olds producing the greatest scores, followed by the 11 yr-olds, 8 yr-olds, and finally the 5 yr-olds.

4.3.3 The Differences Between Mean Male Slopes

Table D-2 is an ANOVA summary table for the main effect of age on mean male slope values. The analysis revealed a significant main effect for age $F(3,55) = 8.9$, $p < 0.01$.

To investigate these differences 95% confidence intervals were calculated. Comparison between these intervals reveals the following significant differences:

Slopes expressed 10^{-3}

Age 14	Age 5	Age 8	Age 11
(-4.5, -5.4)	(-4.7, -5.7)	(-5.6, -6.5)	(5.8, 6.7)

The higher score in the slopes indicates a steeper gradient, which means that PT decreases at a faster rate as velocity increases. The 11 yr-olds had the highest slope value, followed by the 8 yr-olds, 5 yr-olds, and finally the 14 yr-olds. The 11 year olds' slope value was significantly different from the values obtained for the 5 and 14 yr-olds, but not those of the 8 yr-olds. The 8 yr-olds' slope value was only significantly different from the 14 yr-olds'. The 5 yr-olds' slope value was significantly different from the 8 and 11 yr-olds' but not from the 14 yr-olds'. Finally, the 14 yr-olds' slope value was significantly different from the mean slope values of the 8 and 11 yr-olds', but not from the five yr-olds'.

It could be concluded from these results, investigating the differences between intercepts and slopes for boys, not only that PT scores significantly increase with age, but also that the relative increase for each velocity is specific.

4.3.4 The Difference Between Mean Female Intercepts

Table D-3 is an ANOVA summary table for the main effect of age on mean female intercept values. The analysis revealed a significant main effect for age $F(3,51) = 190.56$, $p < 0.001$.

To investigate these differences 95% confidence intervals were calculated. Comparison between these intervals reveals the following significant differences:

Age 5	Age 8	Age 11	Age 14
(2.6, 2.8)	(3.4, 3.6)	(3.9, 4.1)	(4.4, 4.6)

These results would indicate that there are significant differences between all the four female age groups in the amount of PT produced. The 14 yr-olds produce the greatest scores, followed by the 11 yr-olds, 8 yr-olds and finally the 5 yr-olds.

4.3.6 The Difference Between Mean Female Slopes.

Table D-4 is an ANOVA summary table for the main effect of age on mean female slope values. The analysis revealed that there was no significant main effect for age $F(3,51) = 2.79$.

This would suggest that age has no effect on the relative PT produced across velocity.

It could be concluded from these results, investigating the differences between intercepts and slopes for females, that PT scores significantly increase with age, and that the relative increase for each velocity is constant.

Section 4

Variation in PT Scores

The purpose of this next section is to describe the variation in PT scores for this subject population, using several parameters: age, height, weight, hip to ankle length, hip to knee length, knee to ankle length, thigh circumference, and Cybex lever length.

Several steps were taken in describing this variation: the relationship between PT and body size variables; the relationship between body size variables; the use of step-wise regression; variation in intercepts for females only; variation in intercepts for males only; variation in intercepts for males and females.

4.4.1 Relationship Between PT Scores and Body Size Variables

Pearson's Product Moment Correlation was used to examine the strength of the relationships between PT scores and the above parameters at each velocity. Table E-1 (Appendix E) shows the correlations between PT scores and the 8 variables, using the data obtained from all 114 subjects. Table E-2 shows the correlations using the data obtained from the 55 female subjects. Table E-3 shows the correlations using the data obtained from the 59 male subjects.

These tables show that all the correlations lie within the range of 0.83 to 0.94. These values were all found to be significantly different from zero ($P < 0.001$) and explain between 69% and 88% of the variation in PT. This indicates that all 8 variables will each explain a high proportion of the variation in the PT scores for this subject population.

4.4.2 Relationship Between Body Size Variables

The relationships between the 8 variables were also examined using Pearson's Product Moment correlation.

The correlations obtained are shown in Table E-4 (Appendix E), and all lie between 0.81 and 0.95. These values were all found to be significantly different from zero ($P < 0.001$) and explain between 66% and 90% of the variation between the variables. This would indicate that there is a large common source of variance between these 8 variables and would also suggest that each of these variables might account for the same variation in PT scores.

4.4.3 Step-wise Regression

When there are several independent variables which can be used to explain the variation in a dependent variable, it is useful to examine whether all explanatory variables are needed, and to consider which variable or combination of variables would best explain this variation.

In order to select the variables which best explained the variation in PT scores, step-wise regression was used. In this analysis, instead of using PT scores at each velocity, the intercept values calculated from the regression of log PT on velocity were used. Intercept values calculated for each subject represent a summary of the amount of PT produced at all four velocities. The extremely strong relationship between PT and velocity meant that it was possible to use this summary value, rather than the PT, at each velocity.

The justification for using intercept, rather than PT scores at each velocity can be highlighted by observing the correlations in tables E-1 to E-3. The magnitude of the correlations between PT and each variable are similar when compared across velocity. This was to be expected, since it has already been shown that there is a highly significant relationship between PT and velocity. This similarity is therefore a reflection of the relationship between PT and velocity.

In view of this, when investigating the best variable or combination of variables to explain the variation in PT scores, it was concluded justifiable to use intercept values calculated for each individual, since they represent a summary of the PT produced at the four velocities for each individual.

Step-wise regressions were calculated for dependent variable intercept values with eight independent variables: age, height, weight, thigh circumference, hip to ankle length, hip to knee length, Cybex lever length, knee to ankle length. This was done using data obtained for dependent and independent variables as follows: females subjects (n = 55); male subjects (n = 59); male and female subjects (N = 114). The results of each of these analyses are reported below.

4.4.4 Female Subjects (n = 55)

Table E-5 indicates that for female subjects, age and Cybex lever length were the variables which explained the highest variation in female intercepts, with an r^2 of 93.24%. It can be seen, however, that age alone has an r^2 of 90%, suggesting that age alone will explain 90% of the variation in the female intercepts.

4.4.5 Male Subjects (n = 59)

Table E-6 indicates that four independent variables explained the highest variation in male intercepts: hip to ankle length, age, hip to knee length, and Cybex lever length. Together they explained 94.18% of the variation of the male subjects' intercept scores.

It can also be seen, however, that most of this variation can be explained by hip to ankle length, which had an r^2value of 91.23%. This suggests that hip to ankle length will alone explain 91.18% of the variation in the males' intercept scores.

4.4.6 Male and Female Subjects (N = 114)

Table E-7 indicates that five independent variables explained the highest variation in the intercepts for all subjects: hip to ankle length, age, Cybex lever length, thigh circumference, and hip to knee length. Together these variables explained 93.82% of the variation in the intercept values. As in the other cases, the majority of the variation could be explained by one variable, with hip to ankle length alone explaining 89.01% of the variation in the intercept scores using all subject data.

Section 5

Sex Differences in PT Scores and Body Size

One of the purposes of this study was to investigate, for subjects aged 5, 8, 11 and 14 years, whether or not there were any sex differences in the mean PT scores obtained at 4 velocities: 300 deg/sec, 210 deg/sec, 120 deg/sec and 30 deg/sec. The mean PT scores for boys and girls of these age groups, at each of the four velocities, are shown in Tables 1 to 4 in Appendix A.

To determine the sex differences, this data was analysed using three procedures: a) *t*-tests, b) proportional differences, and c) Hotelling's *t*-test. The analyses were similar for each age group.

The results obtained from the various analyses, however, will be reported for each age group separately: sex differences for PT and body size at age 5, sex differences at age 8, sex differences at age 11, sex differences at age 14.

4.5.1 Data Analyses

It was said above that three statistical procedures were used to investigate sex differences: a) *t*-tests, b) proportional differences and c) Hotelling's *t*-test. Each of these procedures is described below.

4.5.1(a) *t* -tests

The first test investigated whether the difference between the mean PT scores of males and females, at each age and at each velocity, was significant. This was done using *t*-tests. To obtain the most robust *t* statistic the flow chart for the use of *t*-tests shown in Appendix F, figure F-1 was used.

6.1(b) proportional differences

In this study interest was not confined to whether or not there were significant sex differences at each velocity, but extended to the effect of velocity on the magnitude of these sex differences. Using absolute differences was not an appropriate method of investigating this, since absolute scores themselves are affected by velocity.

Variations in the magnitude of difference occurring across velocity were investigated by calculating the proportional differences (mean male PT minus mean female PT, divided by mean male PT), expressed as a percentage. Figure 19 shows these proportional differences, between the PT scores of the girls and boys, aged 5, 8, 11, and 14 years, at velocities 300, 210, 120, and 30 deg/sec. In this figure the boxes show the percentage difference. Where the percentage differences were a result of the boys having higher scores, the boxes are shown above the zero line, and where the percentage difference was a result of females being higher, the boxes are shown below the zero line.

4.5.1(c) Hotelling's *t* -test

The magnitude of sex differences across velocity indicated that at ages 11 and 14 the sex differences were affecting the whole PT-velocity relationship.

The significance of the sex differences in the PT-velocity relationships for the 8 and 14 yr-olds was investigated using their mean intercept and slope values; these mean values have been shown to be highly accurate representations the mean PT-velocity relationships. The problem for this analysis was to take each age group separately, and to test whether or not the distribution of slope and intercept jointly had the same population average for males and females. The appropriate test for this was the Hotelling's *t*-test. This is a multivariate form of the conventional *t*-test, and was necessary because the effect of gender was being examined for two variables. Conventional *t*-tests are only appropriate in a univariate analysis.

In the Hotelling's *t*-test the observed *t* value has to be compared to the F(2, n1+n2-2) distribution, where n1 = number of females and n2 = number of males. Where significant differences were indicated, follow-up *t*-tests were used to investigate where these differences occurred: at intercepts, slopes or both.

4.5.2 Sex Differences in Body Size

In addition to investigating the sex differences in the PT scores the sex differences in body size were also investigated. The body size measurements were height, weight, thigh circumference, hip to ankle length, hip to knee length, and knee to ankle length. The sex difference for Cybex lever length was also investigated. The mean body size measurements for boys and girls for each age group are shown in Tables B-2 to B-8 in Appendix B

The analysis used to determine the signifcance of these differences was the *t* test described above in section 4.5.1(a). These results will be reported for each age group separately along with the results obtained for the sex differences for the PT scores for each age.

4.5.3 Sex Differences at Age 5

Figure 19 shows that the proportional percentage differences between males and females at age five were small. The exception to this was the result at 300 degrees/sec which was 19.8%. This difference was much larger in comparison to the other velocities at this age. The *t*-tests revealed, however, that there were no significant sex differences between the mean PT scores at any of the velocities.

In terms of the body size measurements and Cybex lever length there were no significant sex differences at this age.

4.5.4 Sex Differences at Age 8

Figure 19 shows that all the percentage differences at age 8 are below the zero line. This indicates that the percentage differences were a result of the females having higher mean PT scores than the males. In percentage terms, this difference ranged between 18.4% and 22.4% across the four velocities. The *t*-tests investigating sex differences between the means revealed that the differences were not significant at any of the velocities.

In terms of the body size measurements and Cybex lever length there was only one significant sex difference; girls had significantly greater thigh circumference $t(27) = 3.17$ ($p < 0.01$)

4.5.5 Sex Differences at Age 11

Figure 19 shows that all the percentage differences at age 11 are above the zero line. This indicates that the percentage differences were a result of the males having higher mean PT scores than the females. However, the *t*-tests investigating the sex differences between the mean PT scores, indicated that the only significant difference was at 30 degrees/sec: $t(29) = 2.65$ ($p < 0.05$).

Figure 19 also shows that the magnitude of the percentage differences is affected by velocity; the percentage difference between the males and females increases as the velocity decreases. This increase is from 6.5% at 300 deg/sec to 16.1% at 30 deg/sec. This indicates a sex difference in the relationship between PT and velocity at this age.

To test whether this difference was significant, Hotelling's *t*-test was used. The observed *t* was found to be 2.49. This value has to be compared with the $F(2, n1+n2-2)$ distribution, where n1 = number of females and n2 = number of males; $F(2, 29)$. The observed *t* (2.49) was lower than the *t* value required for significance at the 5% level (3.33). This indicates that there was no significant difference between the male and female PT-velocity relationships.

In terms of the sex differences in the body size measurements and Cybex lever length there was only one significant sex difference; boys had a signifcantly greater Cybex lever length than the girls: t (29) = 2.52 ($p < 0.05$).

4.5.6 Sex Differences at Age 14

Figure 19 shows that all the percentage differences at age 14, are above the zero line. This indicates that the percentage differences were a result of the males having higher mean PT scores than the females; the percentage differences ranged from 7.1% at 30 deg/sec to 22.4% at 300 deg/sec.

The t-tests investigating the sex differences between the mean PT scores indicated significant differences at the following velocities: 300 deg/sec, $t(27) = 2.91$ $p < 0.01$; 210 deg/sec, $t(27) = 3.15$ $p < 0.01$; and 120 deg/sec, $t(27) = 2.18$ $p < 0.05$. The difference between the male and female PT scores at 30 deg/sec, $t(27) = 1.25$, was not significant.

Figure 19 also shows that the magnitude of the percentage differences is affected by velocity; that is, the percentage difference between the males and females increases as the velocity increases. This indicates a sex difference in the relationship between PT and velocity at this age.

To test whether this trend was significant Hotelling's *t*-test was used. The observed *t* value was found to be 5.39. This value has to be compared with the F(2, n1+n2-2) distribution, where n1 = number of females and n2 = number of males; $F(2, 27)$. The observed *t* (5.39) was above the *t* value required for significance at the 5% level (3.35). This indicates that there was a significant difference ($p < 0.05$) between the male and female PT-velocity relationships.

Since a significant difference was found, follow-up *t*-tests were used to investigate where these differences occurred; in intercepts, slopes or both.

The difference between the mean intercepts of the males and females was not significant, but the difference between the mean slopes of the males and females was significant: $t(27) = 3.06$ ($P < 0.01$).

This would indicate that at 14 years the sex difference was due to a significant difference in the slope values. As described above, the slope values indicate the rate of decay in PT as velocity increases. A significant difference between the slope values would suggest that the sex difference becomes greater and therefore significant ($P < 0.01$), as the velocity increases.

In terms of the sex difference in the body size measurements and Cybex lever length the following four significant differences were found, in all these cases boys had greater scores than the girls:

(i) hip to ankle length $\underline{t}(27) = 3.55$ ($p < 0.01$);

(ii) height $\underline{t}(27) = 2.87$, ($p < 0.01$);

(iii) hip to knee length $\underline{t}(27) = 2.90$, ($p < 0.01$);

(iv) Cybex lever length $\underline{t}(27) = 4.22$, ($p < 0.001$);

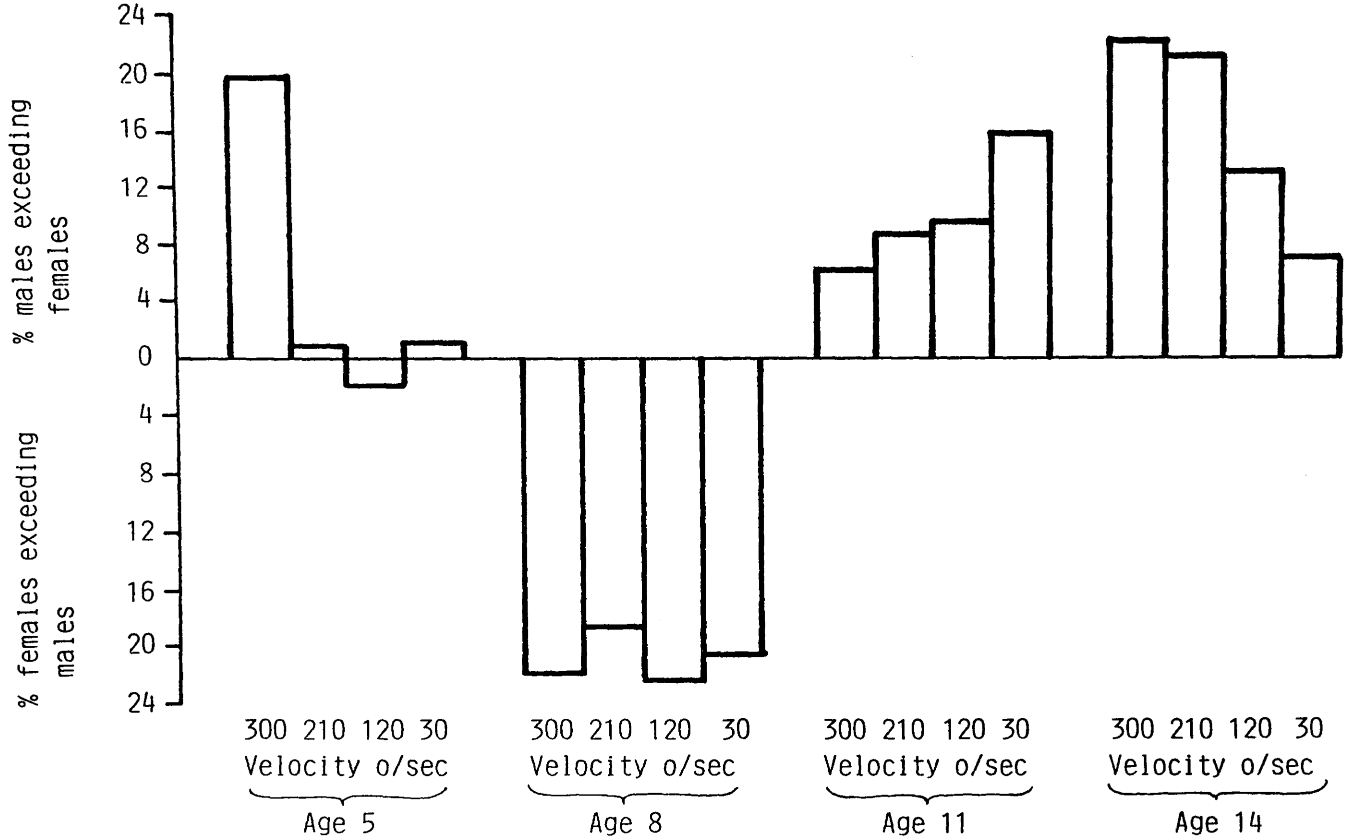


Figure 19 Proportional sex differences expressed as a percentage obtained for the PT scores of 4 age groups of children at 4 velocities.

Note Proportional sex differences were calculated in the following way: mean male PT minus mean female PT divided by the mean male PT score.

CHAPTER FIVE

DISCUSSION

This study was undertaken to investigate the development of children's torque generating capacities in maximal voluntary limb movements performed at a range of velocities. In order to obtain meaningful information from this investigation the answers to five specific questions were sought. The study was designed to provide answers to these sub-problems, the results of which have been reported in chapter four, sections 1 to 5.

The purpose of the present chapter is to discuss these results. The results will be discussed in the following order: the relationship between PT and velocity, the effect of age on PT scores, the variation in PT scores, sex differences in PT scores and the reliability of the PT scores.

Section 1

Relationship Between PT and Velocity

Two features of the relationship between PT scores and velocity will be discussed: the form of the relationship and the interpretation of the relationship.

5.1.1 form of the relationship

In the present study it was found that, irrespective of age and gender, the form of the relationship was the same for each of the 114 subjects; there was a negative exponential decrease in PT as the isokinetic velocity of angular motion increased. Furthermore, it was found that the intercept and slope values calculated (for each subject) from the regressions of Log PT on velocity, when used in the equation Log PT + Slope x velocity, were highly accurate representations of each subject's obtained PT-V relationship.

These results clearly defined the form of the relationship between PT and velocity for each of the 114 subjects. Furthermore, this clear definition meant that it was possible to identify any similarities and differences in the form of the relationship, particularly for the different age and gender groups.

Few studies have used this approach when studying the form of the PT-V relationship. Indeed, as was shown in the review of literature, the majority of studies have constructed the T-V relationships using a variety of subject populations, of movements, of velocity ranges, of measurments and even of testing equipment, with the sole purpose of comparing the form of the relationship to the form of the in vitro F-V relationship of muscle.

However, the review suggested that this emphasis has led to conflicting results and general confusion about the T-V relationship. This confusion arises from the fact that while some studies are able to report a similarity between the form of the T-V relationship and the form of the in vitro F-V relationship (Komi, 1973a; Jorgenssen, 1976; Thorestensson, 1976), others have not been able to do so (Perrine and Edgerton, 1978; Gregor et al., 1979; Caiozzo et al., 1981). Furthermore, if comparisons are made between the T-V relationships, it was shown that there were many differences. These differences are not surprising, when one considers the complexity of torque production in voluntary movement. Indeed, it is conceivable that these differences are related to many other differences in the construction of these relationships: the construction of T-V relationships vary in terms of subject populations, movements, measurements (angle-specific or PT), velocity ranges, and testing devices. However, since the emphasis of the studies has simply been to compare the T-V to the in vitro F-V relationships, little has been done to examine specifically the form of the T-V relationship and the factors which cause variations in its form.

This emphasis indicated the necessity for the approach used in the present study, where an attempt was made to investigate the form of the T-V relationship for a subject population (n=114) which varied in age and gender. Indeed, the results of the present study indicated the value of this approach, since it was possible to define clearly the relationship between T-V for each of the 114 subjects. Furthermore, this clear definition allowed comparisons to be made amongst the relationships. More specifically, as a result of this comparison, it could be stated that the form of the relationship was consistent for all 114 subjects, irrespective of their age and gender.

The exponential model used in this study to describe the relationship is not unique to this study. In fact, the review of literature showed that two studies were able to describe their relationships in the same way (Ingemann-Hansen and Halkjaer-Kristensen, 1979; Fugl-Meyer et al., 1980). These studies were highlighted in the review because they were two of the few studies which had used the same approach as the present study; that is, they investigated the consistency of the PT-V relationship within their subject population.

The fact that these two studies were able to describe the relationship between PT-V with the same negative exponential model as in the present study is significant for several reasons.

1. It shows that this description of PT-V relationship was not unique to the subject population in the present study (male and females age 5, 8, 11, and 14 years). For example, Fugl-Meyer et al. (1980), were able to show this negative exponential model for male and female subjects aged 20 to 60 years. Similarly, Ingemann-Hansen and Halkjaer-Kristensen (1979) also found this negative exponential model adequately described the PT-V relationship obtained for 15 football players.

2. It also shows that this negative exponential model was not unique to the device (Cybex II) used in the present study. For example, Ingemann-Hansen and Halkjaer-Kristensen (1979) used this same model for a PT-V relationship obtained on a different device, a modified Orthroton system.

3. Finally, it shows that this negative exponential model was not unique to the movement (knee extension) used in the present study. For example, Fugl-Meyer et al. (1980) showed that it adequately described the PT-V relationship for plantar flexion.

It could be concluded, then, that the form of the relationship for each of the 114 subjects in the present study is consistent with the form of the relationships reported in two other studies (Ingemann-Hansen and Halkjaer-Kristensen, 1979; Fugl-Meyer et al., 1980). Furthermore, the consistency with these studies was shown, in spite of the fact that their PT-V relationships were constructed using different subject populations, movements and testing devices.

It must be noted, however, that what remains unclear, in the results reported by Fugl-Meyer et al. (1980), is the basis on which the authors justified their conclusion that a negative exponential model summarised the relationship of their subjects. Inspection of the results suggests that the mean PT values for the respective sub-groups were plotted, on a logarithmic scale at each velocity, with a hand-drawn line fitted through the data points. This being the case, the model and conclusions drawn by Fugl-meyer et al. (1980) are not based on statistical analysis but simply on the fact that the relationship between log PT and velocity appears to be linear.

In the present study, by contrast, this conclusion, that a negative exponential model accurately summarised the relationship between PT and velocity, was based on statistical evidence; the strength of the linear relationships between Log PT and velocity were examined for each subject, using product moment correlation. Each subject's correlation was very high (range 0.996 to 0.999, n = 114) and significantly linear ($p < 0.01$). This confirms the procedure and result of Ingemann-Hansen and Halkjaer-Kristensen (1979), where the accuracy of the negative exponential model was also checked. Ingemann-Hansen and Halkjaer-Kristensen (1979) showed that, for each subject (n = 15), the linearity of the relationship between Log PT and velocity was significant ($p < 0.05$).

The fact that the present study concluded, on the basis of statistical evidence, that the relationships between PT and velocity were the same for each of the 114 subjects makes these results and conclusions more credible than if the similarity had been based on subjective assessment.

Subjective assessment has been used in the majority of studies as a method of comparing relationships. However, as was pointed out in the review of literature, this method has led to errors. This was shown to be particularly true for studies comparing the T-V relationships with the in vitro F-V relationship. For example, many studies reported that the form of the T-V relationship was similar to the in vitro relationship, they based this conclusion on the subjective assessment that the curves looked similar. However, when these relationships were examined in more detail, in a study by Murray, et al. (1982b) (reviewed in pp. 48-50), it was shown that the forms of the relationship were actually very different .

The present study also reports that each subject's PT-V relationship can be described as a mathematical equation of a straight line; intercept and slope values calculated (for each subject) from the regressions of Log PT on velocity, when used in the equation Log PT + Slope x velocity, could be used to represent each subject's obtained PT velocity relationship.

The major advantage of describing the relationship in this way was that it was an extremely convienent method for further analysis of the relationship. Indeed, a primary purpose of this study was to investigate the development of torque-generating capacities acoss the four velocities, not simply to look at the effect of development on the amount of torque produced, but also at any velocity-specific effect that occurred. The ability to summarise the PT velocity relationship by intercept and slopes was particularly convenient for this purpose, since they summarised in two values exactly the information required in this study:

1. Intercepts in this study represents a summary of the amount of PT produced at all four velocities. Although it is a value derived from PT scores at the four velocities, it is not in itself a value

concerned with the torque produced at any specific velocity.

2. The slopes calculated in this study represent the rate of decay of torque with increasing velocity. The faster the rate of decay, the poorer the ability to produce torque at the higher velocities, relative to the intercept value. Differences in slope values give an indication of the velocity-specific nature of torque generation.

This summarising of the PT-Velocity relationship by the calculation of intercept and slope values was also used in the study by Ingemann-Hansen and Halkjaer-Kristensen (1979). As in the present study, Ingemann-Hansen and Halkjaer-Kristensen (1979) confirmed that the value of using such calculations is that it is a convenient method for further analysing the relationship. For example, while in the present study the analysis was concened with investigating the developmental factors affecting the relationship, Ingemann-Hansen and Halkjaer-Kristensen (1979) were concerned with investigating the effect of fibre type composition on the relationship. More specifically, by analysing the effect of fibre type compostion on the slope values Ingemann-Hansen and Halkjaer-Kristensen (1979) were able to ascertain whether or not quality of muscle, in terms of its percentage composition of FT fibres, had any velocity-specific effects on PT production.

It could be concluded, therefore, that the results of the present study, and of the study by Ingemann-Hansen and Halkjaer-Kristensen (1979), indicate that the ability to summarise the PT-V relationship by the mathematical equation of a straight line, is a convenient method for further investigation of the PT-V relationship.

5.1.2 interpretation of the relationship

Although the form of the relationship in the present study is clearly defined, how this relationship is interpreted is a matter of debate. It is important that this discussion clarifies how this relationship will be interpreted, since its interpretation is an important factor which will influence the discussion of the rest of the results in the present study.

The debate concerning the interpretation of the T-V relationship was analysed, at length, in the review of literature. This discussion showed that the major difference in interpretation of the torque-velocity relationship is a question of emphasis; that is, whether it is a T-V relationship of the limb movement, or whether it is representative of the F-V relationship of only those muscles invloved.

The proponents of the latter interpretation typically compare the torque-velocity relationship to the classical form of the in vitro force-velocity relationship of a muscle (Perrine and Edgerton, 1978;

Thorstensson, 1976). Although as discussed in the review this comparison is not justified; using such a comparison with the results of the present study would allow the following conclusions to be drawn:

> The relationship obtained for each subject showed similarities to the classical shape of the in vitro force-velocity curve, and the intercept and slope values obtained for each subject could be used to extrapolate each subject's maximum force at zero velocity and maximum velocity of contraction at zero force.

Clearly, it would be interesting to use this extrapolation to look at the effect of gender and age on the T-V relationship, described in terms of changes in maximum force and maximum velocity of contraction.

Extrapolation of this kind, from torque-velocity relationship obtained on a Cybex II, can be found in other studies, as was shown in the review of literature. For example, Thorstensson (1976) obtained a PT-Velocity relationship for two subject populations divided on the basis of their FT fibre type composition (Group A, FT fibre < 60%, and Group B, FT > 60%). PT scores were obtained between the velocity ranges of 0 deg/sec and 180 deg/sec inclusive. On the basis that the PT-V curves looked similar to the in vitro curve Thorstensson (1976) extrapolated the maximum velocity of contraction. This study has been referred to in more detail in the review of literature; the extrapolated curves are shown in Figure 2 p 45. On the basis of the relationships obtained for the two populations of different FT fibre-type compositions Thorstensson (1976) suggested that the following conclusion could be drawn about fibre types:

1. FT fibres have faster contraction velocities
2. FT fibres are able to produce a higher peak tension at any contraction velocity.

These comparisons between the relationships obtained from isolated muscle and those obtained from muscles involved in voluntary movement are based on the assumption that the measurements made on the isokinetic devices reflect muscle tension at specific muscle lengths, at different constant velocities of contraction. However, as was suggested in the review of literature, it could be argued that this assumption is erroneous or at best an oversimplification of what is a complex and co-ordinated action, involving the joint itself, the muscles, and the central nervous system.

Clearly this calls into question the validity of comparing the classical in vitro relationship with the torque-velocity relationship obtained on isokinetic devices, with the view to making rationalisations on the physiology of human muscle in vivo. Moreover, it also calls into question the validity of extrapolating the relationship beyond the points actually measured.

Indeed, Ingemann-Hansen and Halkjaer-Kristensen (1979), using the intercept and slope values calculated to summarise the negative exponential relationship, found a discrepancy between the predicted PT value at 0 deg/sec and the actual measured value. The actual value was significantly ($p < 0.05$) lower than the predicted value. Ingemann-Hansen and Halkjaer-Kristensen (1979) stated that this signified that the relationship plateaued at the lower velocities, a trend that would have been wrongly predicted from the equation representing the relationship obtained from the PT scores measured between the range of 30 deg/sec to 360 deg/sec. As a result, they concluded that the exponential equation was an accurate representation of the PT-V relationship only within the range of velocities actually tested.

With these points the results of the present study will be based on the PT-V relationship interpreted in the following context:

1. The PT scores obtained are measurements which reflect the maximum torque the subjects could produce in a voluntary, maximum effort, isokinetic knee extension task. It is recognised, therefore, that the PT produced is the result of a complex and co-ordinated action involving the joint itself, the muscles, and the central nervous system.

2. The intercept and slope values calculated for each subject, when placed in the equation Log PT =

Intercept + Slope x Velocity, are highly accurate representative values of each subject's PT-Velocity relationship, between the velocity range of 30 deg/sec to 300 deg/sec inclusive. It is recognised, therefore, that PT scores predicted outside this velocity range from the intercept and slope values cannot be assumed to be correct.

In the interpretation of the PT-V relationship obtained this discussion has made it clear that no attempt should be made using the intercept and slope values to extrapolate to PT values beyond the velocities tested. However, this does not discount the facility to interpolate from the intercept and slope values; to predict PT scores other than those actually tested within the velocity range of 30 deg/sec to 300 deg/sec. There are two major of advantages of being able to interpolate:

(i) as already mentioned above it has allowed the development of PT generating capacities in the present study to be investigated not simply in terms of PT scores at four single velocities but also in terms of the whole PT-V relationship from 30 deg/sec to 300 deg/sec.

(ii) it allows for greater scope when comparing PT values with other studies; any PT value from 30 deg/sec to 300 deg/sec can be compared.

Section 2

Effect of Age on the PT-Velocity Relationship

The effect of age on the PT velocity relationship was analysed by investigating the differences between the mean intercept and slopes for each age and gender group. The results obtained for intercept and slope will be discussed separately because, as shown earlier, they represent different aspects of torque generating capacities.

5.2.1 Effect of Age on Intercepts

The results of the analysis for intercepts revealed that there were significant differences between the four age groups for both boys and girls ($p < 0.01$). This suggests that, irrespective of velocity, there were significant differences in the amount of torque produced between the age groups. It was shown that the 14 year-olds produced the greatest amount of torque, followed by the 11 year-olds, 8 year-olds, and finally the 5 year-olds.

This result was to be expected, since, as was indicated in the review of literature, studies investigating the development of strength suggest that during the years investigated in the present study children improve in strength as they get older. Moreover, this improvement was irrespective not only of differences in method of measuring strength, but also of the wide variation in sites measured, and of the variation in age ranges measured (Methany, 1941b; Jones, 1949; Molnar and Alexander, 1974; Montoye and Lamphier, 1977). The present study, therefore, confirms the well-established finding that strength improves with age.

In addition, in terms of the variation in methods of measuring strength, few studies have used the isokinetic method (Molnar and Alexander, 1974; Gilliam et al., 1979b; Myashita and Kanehisa, 1979), and only one of these studies has investigated at more than one velocity; Gilliam et al. (1979b) obtained PT scores at 30 deg/sec and 120 deg/sec. The present study differed from other studies, in that limb strength was measured isokinetically using speeds within the range of 30 to 300 deg/sec. It could be concluded, therefore, that the results of the present study, not only confirm the theory that strength improves with age, but also shows, for the first time, that this improvement occurs for limb strength measured at velocities from 30 deg/sec to 300 deg/sec.

The factors which could account for this increase in strength were discussed at length in the review of literature. It was shown that children's strength increases with age, firstly because they are getting bigger and, secondly, because of the maturation of the C.N.S.. Although the majority of this evidence comes from studies which do not measure strength isokineticlly, it is reasonable to suggest that since the results of the present study confirm the general trend that strength increases with age, that the general factors used to account for the increase in strength would also be the same. However, although these factors could be used to explain the general increase in strength, it is not necessarily true that the relative influence of these factors would be the same at all velocities. Given this possibility a pertinent question to raise was whether a child's development of maximal torque production at different velocities of movement is constant or develops at different rates. This question was investigated in an examination of the effect of age on slopes, the results of which will be discussed below.

5.2.2 Effect of Age on Slopes

The question the analysis was designed to answer was whether there was a consistent rate of decay in PT, with increasing velocity, for both girls and boys in the four age groups. This analysis found that there were significant differences between the four male age groups ($p < 0.01$), but no significant differences between the four female age groups. It was concluded, therefore, that at different velocities, males' maximal torque generating capacities develops at different rates, while this development for the girls is constant. Although this velocity-specific development was only shown for the males it is evident when the mean slopes for males and females are compared (Figure D-1, Appendix D), both sexes show a similar pattern of differences; that is, there was a steeper slope at age 8 than at age 5, almost no difference between the steepness of the slopes at age 11 compared to age 8 (boys had a slightly steeper slope and girls a slightly less steep slope), and finally a much less steep slope at age 14 compared to the slope at age 11. This suggests that, although the differences between the slopes were greater and significant for the males, both sexes were similar in the pattern of these differences.

A possible explanation of the significant differences between the male slopes, and of the fact that the females showed a similar trend, is that growth was affecting the development of strength in a velocity-specific manner.

However, there is little evidence from previous research which would either support or refute this effect of growth on the PT-Velocity relationship. Moreover, from what is known about the F-V relationship of isolated muscle it would be expected that there would be no change in the form of an individual's relationship. This could be surmised from A.V. Hill's mathematical equation for representing the F-V relationship:

$$(P + a)V = b(P_o - P)$$

where V is the speed of shortening

P_o is the isometric tension

P is the load

a and b are constants.

The general shape of a muscle's F-V relationship is indicated by the ratio a/P_o. According to this equation a change in an individual's isometric tension (P_o), as a result of growth, would not affect the general shape of the relationship (a/P_o), since a is a constant. It is recognised, however, that Hill's equation is only empirical, and that the constants can vary according to the type of muscle (Close, 1972; McMahon, 1984). For example, in human muscle Thorstensson (1976) suggested that the quality of an individual's muscle, in terms of its fibre type composition, will identify differences in the form of the F-V relationship.

However, little is known about the effect of growth on the quality of muscle, in terms of fibre type composition. The available evidence suggests that children's fibre type compositions are the same as those of adults (Komi et al., 1977; Bell et al., 1980). The main difference between the muscles of an adult and child is thought to be one of size. Indeed, Ikai and Fukunaga (1968) were able to show that the force output of a muscle, per centimetre squared, was the same for all individuals, irrespective of age and sex. This suggests that if the results of the present study were attributed to the F-V relationship of muscle, variability of the slopes would have been expected to have remained relatively constant at the different age groups.

However, as was argued in the review of literature, torque generation in a limb movement is a complex process; many factors, other than the physiological limits of muscle itself, determine torque production at different speeds of movement (Whitley and Smith, 1963; Knapik et al., 1980); even in a simple movement many muscles are involved. In order to produce force, the C.N.S. must organise and pattern the firing and frequency of firing to obtain motor patterns suitable to the movement. Furthermore, it has been suggested that the neural pathways required to produce maximal force at one speed are not the same at another speed, even although the same muscle groups are involved. The further away the tasks are, in terms of the speed of movement, the greater the neurospecificity (Whitley and Smith, 1963; Knapik et al., 1980). In addition, research suggests that factors such as training and exercise lifestyle can affect the amount of specificity

(Thorstensson et al., 1977; Caiozzo et al., 1981).

Given this velocity-specific nature of strength it is therefore possible that growth will cause strength to develop in a velocity-specific manner, as was found in the present study; the development of the neural pathways, suitable at one velocity, might vary at another velocity. Further evidence to substantiate this explanation comes from the fact that, as research has shown, one of the reasons that strength increases with age is the fact that the C.N.S matures. This maturation increases force generation by improving the C.N.S.'s ability, not only to increase motor unit firing and frequency of firing, but also to improve its ability to organise and pattern the firing and frequency of firing to obtain motor patterns more suitable to the movement (Asmussen and Heeboll-Nielson, 1955; Corlett, 1984).

It is, therefore, not unreasonable to suggest that growth, which affects this development of the neural system, might cause the development of strength at different velocities to proceed at different rates, given that it has been suggested that the neural pathways required to produce maximal force at one speed are not the same at another speed. This explanation of the velocity-specific differences in strength development obtained in the present study would confirm the conclusions of Asmussen (1977), who suggested that growth might influence various parts of the neuromuscular system differently or asychronously, and that this would cause specificity in the development of strength.

Although growth could be used to account for the differences in slopes in the present study, this difference might also be due to sampling bias. To explain this it must be considered that, given the velocity-specific nature of strength, it would be expected that, within each age group represented in the present study, there would be a wide variation in the possible slope values. In other words, differences in slope values could be due to individual differences in neural patterns, at different velocities, which would also be affected by the exercise lifestyle and training of the individual. The differences in slope values could also be due to individual differences in fibre type composition (Thorstensson, 1976; Coyle et al., 1979; Gregor et al., 1979).

Given these individual differences, it is possible that the mean slope values for the males at one or more of the ages were not truly representative of the population mean slope value, especially since the number of subjects sampled at each age, in the present study, was fairly small: n=14 to 16. More specifically, the steepest value for slope was obtained at age 11, which was significantly different from the slopes at age 5 and 14. It could, therefore, be that the males sampled at age 11 were biased towards those who tended to have steep slopes. This type of error in sampling would explain the significant differences between the mean males' slope values of the 4 age groups. Furthermore, if this sampling bias did cause the differences between the slopes which were significant for the males there is no basis to conclude that development of strength is velocity-specific.

Against this argument, however, is the fact that both females and males show the same pattern of slopes across age, as illustrated in Figure C-1; this similarity argues against the suggestion of poor sampling, since it is unlikely that the same sample bias would be repeated. Indeed, this finding suggests that the differences obtained for the females and males was a result of a common factor. As discussed above, this common factor is most likely to be growth, affecting the development of strength in a velocity-specific manner.

The fact that the results of the present study indicated that growth might affect the development of strength specific to velocity is an important finding. It indicates for the first time that the development of children's torque generating capacities and associated neuromuscluar mechanisms in maximum voluntary movements perfomed at different velocities can develop at different rates. Clearly this indicates a need for research to investigate these velocity-specifc differences in more detail, particularly their significance in the development of children's strength. This type of detail was beyond the scope of the present study; its purpose was to explore the possibility of velocity-specific differences. However, the pattern of slopes obtained suggested that strength developed in two stages: in the first stage strength improvements with increasing age were relatively greater at the slow velocities, shown by a increase in gradient of slopes; and, in the second stage, the strength improvements with increasing age were relatively greater at the fast velocities, shown by a decrease in the gradient of the slopes. On the basis of these two stages it is tempting to suggest that in the development of strength there is first of all an improvement of the absolute maximum torque that can be generated (shown as greater ability to generate torque at slow velocities), which is then followed by an improvement in the percentage of the maximum that can be produced (shown as a greater ability to produce torque at fast velocities).

In addition to the two stages of development described above, the pattern of slopes also suggested that the onset of puberty might have been the factor influencing the start of the second stage; that is, the change from the strength improvement being greater at the slow velocities to the improvement being greater at the fast velocities. This was suggested by the fact that this improvement was not shown before the mean onset of the males' and females' respective puberties; the mean onset of puberty is thought to occur at age 13 in males, and, age 11 in females. More specifically, the first decline in slope values for the males was not shown until age 14, and the decline for females was not shown until age 11. However, although the change in trend of the slopes does appear to coincide with the onset of puberty in males and females it should be noted that this conclusion is based on the developmental pattern shown by the slope values for only four selected age groups (5, 8, 11 and 14 years). A better indication of whether or not puberty was affecting the results would have been obtained if all ages between 5 and 14 had been examined. This would have allowed a clearer identification of the developmental pattern in the slopes; any change in trend at puberty would be more evident.

There are two conclusions to be drawn from this discussion:

1. The results indicated that as children got older the amount of torque that they could produce, at any of the velocities, increased. The fact that children's strength improves with age was to be expected from past research. The results of the present study, however, add to this area of research, by showing this improvement in strength at specific velocities, between

30 deg/sec to 300 deg/sec.

2. The results of the analysis of the effects of age on the slope values indicated that the rate of strength development varied across velocities. The fact that there were significant differences between the males' slopes, and that girls and boys showed the same pattern of differences, suggests that growth was affecting the development of strength in a velocity-specific manner. Although further research is needed to investigate the significance of these differences for the development of strength, the results of the present study suggested the following:

a) the development of strength was affected in two stages; at the first stage, strength increases with age were relatively greater at the slow velocities, and, at the second stage, strength increases with age were relatively greater at the fast velocities;

b) the timing of the second phase suggests that the onset of puberty may be a contributory cause.

Section 3

Variation in PT Scores

The third question concerned the variation in PT scores for this subject population, using several parameters: age, height, weight, hip-to-ankle length, hip-to-knee length, knee-to-ankle length, thigh circumference, and Cybex lever length.

The relationship between strength measurements and body size measurements has been the focus of extensive research, as was shown in the review of literature. For the present study, two aspects of this relationship have been analysed:

1. the magnitude of the correlations
2. the best explanation of the variance in intercepts.

5.3.1 Magnitude of the Correlations

The results of this study indicated a very high positive relationship ($p < 0.001$) between the PT scores and the body size variables, all lying between 0.83 and 0.94. This indicates that the body size measures account for between 71% to 89% of the variation in PT scores. Furthermore, it could be concluded from these results that all the body size measures account for a large proportion of the variance in PT scores for this subject population.

Many studies have investigated the relationship between body size and strength (Jones, 1949; Maglischo, 1968; Carron and Bailey, 1974; Molnar and Alexander, 1974; Lamphiear and Montoye, 1976). The review of literature highlighted the wide range of correlations reported in these studies. Indeed, in comparison to the correlations reported in the present study, some of the previous studies studies reported much lower correlations (Jones, 1949; Carron and Bailey, 1974; Gilliam et al., 1979a;), while others reported similar correlations (Molnar and Alexander 1974; Gilliam et al., 1979b).

However, the review of literature also pointed out that the interpretation of the relationship between body size variables and strength demands the recognition that measurements of body size are also commonly used measurements of growth and maturation (Jones, 1949; Carron and Bailey, 1974). Since it has been shown that children's strength increases because they are getting bigger and more mature (Jones, 1949; Asmussen, 1980; Corlett, 1984), the magnitude of the correlations will therefore be affected by the age range of the subject population and by the variability in their developmental stage. Indeed, it was shown that the wide range in the magnitude of correlations reported could be attributed to variations within the subject population, variations in age range and developmental stage (Jones, 1949; Carron and Bailey, 1974).

Taking into account these facts, it could be concluded that the correlations between strength and body size obtained in the present study were a reflection of the fact that strength increased, because the subjects got bigger and more mature. The fact that the correlations were extremely high can be explained by the fact that, not only were the subjects sampled from a wide age range, but they were also sampled from specific ages, three years apart, within this age range. The effect of this sampling was not only to select children from a wide developmental range, but also to select children from different stages within this range. Given this fact, together with the fact that children's strength increases because they are getting bigger and more mature, it is not surprising that the correlations were high.

5.3.2 Best Explanation of the Variance of Intercepts

In the present study step-wise regression was used to pick out the variable, or best combination of variables, which would explain the highest variation in intercepts (intercepts were used to summarise the amount of PT scores at all four velocities, see section 4.3.1). This was done because, although all the variables were highly related to the PT scores, the results also indicated that the variables themselves were closely related to each other; correlation co-efficients were between 0.77 and 0.97 ($P < 0.001$); see Table E-4. This meant that the variables could be responsible for the same variation in PT scores. To take account of this possibility, step-wise regression was used to examine whether or not all explanatory variables were needed and which variable, or combination of variables, would best explain this variation. The results of this step-wise regression analysis are discussed below.

In the present study, when the step-wise regression for all subjects (n = 114, Table E-7) was examined, six variables were chosen to explain the highest variation in the intercept values six variables: hip-to-ankle length, age, Cybex lever length, thigh circumference, and hip-to-knee length. Together these variables explained 94% of the variation.

It was shown in the literature review that this type of result is common, with several studies reporting that a combination of variables would explain the highest variation in a strength measurement (Clark, 1957; Maglischo, 1968; Lamphiear and Montoye, 1976). In addition, it was argued in the review of literature that this was a reflection of the fact that children are not exactly geometrically similar in their growth, and that the variation in body proportions does not allow the relationship between body size and strength to be shown universally by one measurement. If children were truly geometrically similar then changes in dimensions could be represented by one measurement, such as height. As was shown in the review of literature this assumption has been used in several studies, where changes in simple body dimensions, such as height, have been used to represent changes in other dimensions, such as the cross-sectional area of muscle (Carron and Bailey, 1974; Asmussen, 1980; Corlett, 1984).

Studies that have tested this model, however, have shown that growth of dimensions takes place at different rates (Malina and Johnston, 1976; Marshall et al., 1978). These different growth rates would mean that some measures would explain more of the individual differences in the devlopment of strength variation than others.

It would appear that the results of the present study support this notion, since six variables were required to explain the highest variation in the intercept values. However, if the results obtained are examined more closely, they suggest that the best single variable, hip-to-ankle length, accounted for the majority of the variation, 89%. This means that the five other factors only added in total 5% to the explanation of the variation.

A similar occurrence was found in the other step-wise regression analyses; girls only (Table E-5), and the boys only (Table E-6):

1. For the girls only, two variables were selected to

explain the highest variation in the intercepts: age and Cybex lever length. As above, one variable explained the majority of the variation, in this case it was age, accounting for 90% of the variation, with the inclusion of the additional variable adding only 3%.

2. For the boys only, four variables were selected to explain the highest variation in intercept values: hip-to-ankle length, age, hip-to-knee length, and Cybex lever length. In a similar fashion to the step-wise regression for all subjects, hip-to-ankle length explained the majority of the variation, 91%, with the addition of the other three variables only increasing this by 3%.

The fact that these results indicated that the additional variables only contributed a small proportion to the explanation, indicates that differences in growth rates of the body's dimensions did not explain the variance of strength.

This is contrary to the findings of some studies, where variables selected were shown to be important for the explanation of variance in strength scores (Maglischo, 1968; Lamphiear and Montoye, 1976). However, this contrary finding could be explained by the wide developmental range of subjects sampled in this study; not only were the subjects sampled from a wide age range, but they were also sampled from specific ages, three years apart, within this age range. Given this range, only the general trend in the relationship between strength and any of the body size variables would be shown. More specifically, they would indicate that as body size increased strength increased. Since all body dimensions measured increased, these variables accounted for the same variation in strength. This would account not only for the fact that one variable could explain the majority of the variation in strength scores but also for the minimal effect of the other variables.

Although the present study could not demonstrate the value of using several variables to explain the variation in strength, as was found in other studies, it does, however, confirm the findings of Espenshade (1963). Espenshade investigated the relationships of age, height, and weight to performance, for boys and girls on the Californian Physical Performance tests, in order to evaluate these factors as potential norms for testing performance. She was concerned that the common practice of using age, height, and weight to establish test norms might not be as valuable as previously thought. In her conclusions Espenshade (1963) stated that although the combination of age, height, and weight did give a higher predictive value than age alone, in some tests of motor performance, the level of improvement in accuracy of prediction was not sufficient to justify the labour involved. She therefore recommended that age alone be used as a basis for the development of test norms.

The present study confirms this conclusion, in that the use of variables other than the best single variable would be of little consequence in explaining the variation in PT scores. In addition, it would be feasible to use all the variables, since, as was discussed earlier, the magnitude of the correlations indicated that each variable by itself explained a high proportion of the variation in the PT scores.

It could be concluded, therefore that although several variables were selected to obtain the best explanation of the variation in PT scores, the best single variable explained the majority of the variation. This result was a reflection of the fact that all the body size measures were reponsible for the same variation in PT scores; that is, as subjects get bigger and more mature strength increases. The fact that the body size measures were able to explain a large proportion of the variance was shown to be related to the wide range of developmental stages represented in the subject population of this study.

Section 4

Sex Differences

In the present study sex differences of the PT scores and of body size measurements were investigated. Although the main interest was the sex differences for the PT scores, sex differences in body size measurements were also investigated because of the particularly close relationship between changes in strength and changes in body size for children. Indeed, the strength of this relationship was shown in the last section, where the body size measures accounted for between 69% to 88% of the variation in the PT scores. This is relfecting the fact that children's strength increases because they are getting bigger and more mature. Given this close relationship between strength and body size, sex differences in body size would be an important factor when explaining sex differences in strength. The sex differences obtained for PT scores and body size will be discussed seperately for each age.

5.4.1 Sex differences at age 5

From the results (section 4.5.3) it can be seen that the proportional sex differences were slight; indeed it was confirmed that there were no significant differences in the PT scores at any of the velocities at this age. From a physiological point of view this result would be expected, since there is no known physiological reason for sex differences in strength at this age. It was indicated in the review of literature that the major physiological reason for sex differences in strength are differences in muscle size. However, it is only after the onset of puberty in males that significant sex differences in muscle size occur. Indeed, at age five boys and girls are thought to be of similar body and muscle size. As confirmation of this similarity of body size at age five the results indicated that there were no significant sex differences for any of the body size measures.

In spite, of the similarity of size at this age there are studies which have indicated sex differences in strength even for children below the age of 5. For example, Metheny (1941b), in a review of studies of sex differences in elementary and pre-school children, reported that in all studies the boys had higher scores than the girls. Indeed in her own study she found that there were significant differences in strength even when differences in body size had been accounted for. The results of the present study are contrary to these findings. However, it must be remembered that only grip strength was used in all of the studies, reviewed by Metheny (1941b), whereas, in the present study the results are for knee extension at 4 velocities. The fact that no sex differences were found could be due to the fact that the present study's results refer to knee extension and not grip strength.

Indeed, as was also indicated in the review of literature there are a few studies, using other strength measures, which have found no sex differences at this age (Martin, 1918; Torpey, 1960). For example, Torpey (1960) investigating knee extensor strength found no sex differences. The results of the present study therefore add to the number of studies that have found that there are no sex differences in strength at age 5. Furthermore, this confirmation refers to knee extensor strength measured at four different velocities.

Sex differences before puberty are explained as differences in use of the muscles; that is, by different levels of physical activity, and involvement in different types of physical activity (Rarick and Thompson, 1956; Hoffmann et al., 1979; Andres et al., 1981). It is thought that these differences are due to social sterotyping, which has also been shown to be evident at a young age (Rees and Andres, 1981).

The fact that the present study indicated that there are no significant sex differences indicates that the results are not affected in any significant way by differences in levels of physical activity. Indeed, from previous research it is known that strength in the lower body is less affected by this factor, in comparison to strength in the trunk and upper body (Wilmore, 1974; Hoffman et al, 1979; Asmussen, 1980).

For example, Asmussen et al. (1980) reported that sex differences in children at any height were almost non-existent on lower body strength, but more apparent in upper and trunk strength. It is suggested that this is because males and females use the lower body muscles in a similar way (running, walking). In other words, lower body strength is less affected by differences in levels of physical activity; this explains why no sex differences have been found in the present study, which uses a lower body strength measure, but have been found in other studies, where grip strength, an upper body strength measure, was taken.

5.3.2 age 8

From the results section it can be seen that the proportional sex differences (Figure 19) indicate that at each velocity girls exceed the boys' score. Statistically, however, these differences were not significant. This indicates that the variability between the scores of the boys and girls made the appearance of better scores in the girls only a chance occurrence. This result would have been expected from a physiological point of view since, as discussed above, there is no reason for any sex differences before puberty. However, although not significant the slight bias in the results towards higher scores for the girls could be related to the sampling of the subjects. It can be seen from the differences in body size (Figures 11 and 12) that the girls sampled are slightly bigger in all measures than the males; indeed this difference was significant for thigh circumference ($p < 0.01$). This trend would suggest that in the sampling of subjects, the female subjects chosen tended to be slightly bigger than the male subjects; this difference would explain the slight trend for the girls to have slightly higher mean strength scores than the boys.

From the results reported in other studies a sex difference biased in favour of the males being stronger would have been expected. Indeed, in terms of sex differences before puberty, Jones (1949) and Espenschade and Ekert (1980) reported that, although there is great variability between the scores, with some girls being stronger than some boys, on average boys will have a higher score than the mean strength score of the girls. Moreover, as was discussed above, boys have been shown to be significantly stronger than the girls even as young as age five (Metheny 1949a, 1949b).

No such conclusions could be drawn from the present study. Indeed, the present study indicated that in the case of knee extensor strength, measured at four velocities, for children aged eight, there were no significant sex differences.

5.4.3 Age 11

At age 11 the proportional differences shown in Figure 19 indicated that on average the boys were stronger at each velocity than the girls. This result was expected, since the majority of studies report that the sex differences at these ages are in favour of boys being stronger than girls (Martin, 1918; Jones, 1949; Montoye and Lamphier, 1977). However, only the sex difference at 30 deg/sec was significant, the other three velocities showing no significant differences. This indicates that apart from 30 deg/sec there was no real difference between the PT scores of the boys and girls. The results of the present study also indicated that at age 11 there were no significant differences in the males' and females' body size measurements (see results section 4.1.5).

From a physiological point of veiw these results would have been expected, since there is no reason for significant differences in either strength or body size before the onset of puberty in the males (which on average occurs at age 13).

However, while the differences in the body size measures were not significant, it can be seen, nevertheless, that the boys did tend to have greater mean body size measurements than the girls (Figures 11 and 12). While this slightly larger size in the boys might account for the general trend towards boys having greater mean scores than the girls it does not explain why the sex differences appeared to increase and become significant at 30 deg/sec as velocity decreased; this trend can be seen in Figure 19, where the magnitude of difference decreases from 6.5% at 300 deg/sec, a significant sex difference, to 16.1% at 30 deg/sec. Although the Hotelling's _t_test indicated that this trend was not significant the slight differences in males' and females' slope values might explain this tendency in the results. More specifically, as was shown in section 5.2.1 from almost identical mean slope values at age 8, males' slopes increased in gradient at age 11, indicating that strength was increasing more at the slow velocities; whereas, the females' slopes decreased in gradient, indicating that the increase in strength was greater at the high velocities. As a consequence of this slight difference in the slopes, the greater sex difference at the slow velocities, particularly the significant difference at 30 deg/sec, was a result of the fact that boys were able to produce greater relative torque at the slow velocities.

It could be concluded, therefore, that although boys had greater mean scores than the girls at every velocity the difference at 30 deg/sec was the only one that was significant. Slight differences in body size and slope values might explain the sex differences at this age.

5.4.4 Age 14

At age 14 the proportional differences shown in Figure 19 indicated that on average boys were stronger than girls at each velocity. In fact three out of the four velocities indicated that the difference between the mean PT for males and females was significant. This would suggest, that in comparison to age 11, there was a greater sex difference. More specifically, the fact that there was a greater number of significant sex differences, in comparison to age 11, indicated that the scores of males and females overlapped less, where fewer girls were as strong as the average boy. This decrease in the overlap of strength scores between 11 to 14 would confirm the age trends for sex differences in strength reported in other studies (Jones, 1949; Espenschade and Ekert, 1980).

The fact that there were significant sex differences would confirm what is expected from a physiological point of view, where a superiority of muscle size, as a result of the growth spurt in males, would cause a superiority in strength; the growth spurt resulting from the onset of puberty at 13 would cause a significantly greater body and muscle size in males. Indeed, it would appear from examining the body size measurement in the present study that significant differences in the body size measurements were evident at no other age and suggest that, as expected, male subjects at 14 had reached puberty, where one of the consequences was that they were bigger than the female subjects. This suggests that the strength differences at this age could be attributed to the fact that boys, as a result of the growth spurt, were significantly bigger and possessed a greater muscle size than the females at this age.

However, if the results are examined more closely it could be argued that there is evidence against the interpretation that increased muscle size, resulting from puberty, accounts for the strength differences. First of all, it would be expected that if increased muscle size was affecting the strength scores there would be a general improvement in strength at all velocities. However, at 30 deg/sec the magnitude of sex difference was actually shown to decrease slightly from age 11 to 14. More specifically, the sex difference at 30 deg/sec was significant at age 11, and, by contrast, at age 14 the difference at 30 deg/sec was not significant. Indeed it was the smallest difference of the four velocities. This absence of the expected increase in sex difference at 30 deg/sec questions whether the significant sex differences obtained at velocities 120, 210, and 300 deg/sec were in fact the result of an increased muscle size.

This question is also raised by the fact that while there were significant differences for the majority of body size measurements, no signifcant sex differences were found for body weight and thigh circumferance. If muscle size had been affected by the growth spurt, sex differences would have been expected in weight and thigh circumference. This might suggest that puberty, while affecting the growth of other dimensions, had not affected muscle size to any significant extent. Indeed, it has been shown that different physical dimensions have different rates of growth in the growth spurt (Malina and Johnston, 1967; Espenschade and Eckert, 1980). For example, it has been found that increases in strength, muscle size and weight occur after the greatest increase in the linear measurements such as height (Carron and Baily, 1974). Since in the present study the significant differences were all related to the linear dimensions of the body, and not to its mass in terms of weight and thigh circumferance, it could surmised that significant changes in muscle size were also unlikely to have occurred.

It could be concluded, therefore, that this lack of change in muscle size might explain why there was no real change in the sex differences in strength from age 11 to 14 at 30 deg/sec. Furthermore, it also suggests that there was another factor, other than muscle size, contributing to the significant sex differences at the other velocities.

This other factor, as for age 11, might be related to the differences between the sexes in their slope values, their ability to produce torque at the slow and high velocities. Indeed, if the magnitude of the proportional differences is examined, it can be seen that as velocity increases the magnitude of the sex differences also increases. This trend was the reverse of the trend at age 11, but it reflects the fact that from age 11 to age 14 there was also a significant decrease ($p < 0.05$) in the boys' mean slope value; this indicates that there was a relatively greater increase in strength at the faster velocities from age 11 to 14 years. Although females also showed a decrease in their mean slope value from 11 to 14 it was much smaller and was not significant. In fact, as was indicated by the Hotelling's t-test, the trend towards the sex difference increasing as the velocity increased could be attributed to the fact that the slopes of males and females were significantly different ($p < 0.01$); that is, boys were significantly better than girls at producing a greater proportion of their maximum strength at the fast velocities.

It could be concluded, therefore, that while the general trend towards boys being on average stronger at every velocity than girls could be attributed to differences in body and muscle size, the significant trend ($p < 0.01$) of sex differences increasing as velocity increases is attributable to a significantly better ability of boys to generate a greater proportion of their maximum strength at the faster velocities.

In addition, as was suggested earlier, this ability might be affected by the onset of puberty in boys, where from age 11 there was a dramatic and significant reduction in the steepness of the gradient of the slope value. This was discussed in section 5.2.2, where for males the pattern of slopes clearly showed that up until age 11 the slopes increased, indicating that the improvement in strength was greater at the slow velocities; whereas, from age 11 to age 14 (which includes the mean age for the onset of puberty) there was a large and significant ($p < 0.05$) reversal of this trend, with the mean slope value decreasing, indicating that the improvement in strength was greater at the high velocities.

The fact that the present study found that boys were significantly better ($p < 0.01$) at producing a greater relative amount of torque at fast velocities than girls adds to the number of studies that have reported the existence of such a sex difference (Komi and karlsson, 1978; Anderson et al., 1979; Gilliam et al., 1979b).

However, the study by Gilliam et al. (1979b) is the only other study that provides information on whether this sex difference is apparent in children. According to Gilliam et al. (1979b) a velocity-specifc sex difference was shown in children aged between 7 and 13 years; that is, significant sex differences ($p < 0.05$) were obtained at 120 deg/sec, independent of body weight, but not at 30 deg/sec. Clearly the implication in Gilliam et al.'s (1979a) study was that this ability for boys to produce relatively greater torque at faster velocities was apparent in children as young as age 7.

This is contrary to the results of the present study where there was no evidence of this sex difference occurring at least until age 11. However, the fact that Gilliam et al. (1979b) investigated the velocity-specific differences for the whole subject population, and not for specific ages, might have masked age differences in this sex difference. Indeed, this was implied by the authors themselves when they indicated that although the sex difference was found using the whole subject population it was really only caused by their taller and heavier subjects. Since the heavier and taller subjects were most likely to be the older and more mature subjects this implies that, as in the present study, the appearance of this sex difference was only caused by the older and more mature subjects.

It would appear, then, that the results of the present study confirm the findings of Gilliam et al. (1979b) to the extent that level of maturity is important for the appearance of this sex difference. In addition, however, the results of the present study would more specifically define the appearance of this sex difference by suggesting that it may be related to the onset of puberty in the males.

Although this study gives credence to the possibility of a velocity-specific sex difference, it offers no information that would help to explain this difference. Indeed, there is little information from past research that would explain this sex difference. However, Anderson et al. (1979) did speculate that since this sex difference was not related to differences in muscle size it was probably a qualitative difference between the sexes, possibly in their fibre-type composition or fibre recruitment.

This explanation could be considered plausible, since, as was discussed in the review of literature, several studies have shown a relationship between the percentage of FT fibres in a muscle and the ability to produce force at fast velocities (Thorstensson, 1976; Coyle et al., 1979; Gregor et al., 1979). It is suggested by these researchers that a higher percentage of FT fibres will give a greater ability to produce torque at fast velocities. Given these findings, it would be logical to suggest that the sex difference in the present study was the result of boys developing a greater number of FT fibres at puberty. However, as was also indicated in the review, the available evidence would argue against this; that is, the fibre type distribution of males and females not only varies little from birth, but also remains unaffected by the gender of the subject. Clearly there are no sex differences in fibre composition that could explain the velocity-specific sex difference in strength.

However, recent studies have shown that there may be sex differences in the relationships between these fibre types and force and speed production. As was shown in the review, these studies found that while males showed a significant relationship between FT fibre-type composition and ability to produce high tension at fast velocities, this relationship was not evident for females (Komi and Karlsson, 1978; Jacobs and Tesch, 1981; Karlsson and Jacobs, 1981). For example, Komi and Karlsson (1978) found that the females, who had a slightly higher composition of FT fibres than the male subject group, not only took twice as long to develop 70% of their maximal leg force, but they also demonstrated a lower activity for enzymes responsible for muscle contractility and glycogenic activity. Clearly, females had a lower capacity for force production in a short time (an effect similar to producing force at a fast speed), in spite of the fact that they had a higher percentage of FT fibres than the males. This type of result, by Komi and Karlsson (1978), was typical of the other studies, and it was generally concluded that there was a sex difference in the relationships between fibre types and performance. In addition, it has further been suggested that the cause of this sex difference is most likely to be located in the C.N.S system, in its control of movement (Inbar et al., 1981; Karlsson and Jacobs, 1981). This veiwpoint is summarised by Karlsson and Jacobs (1981):

> Observations suggest that sexually mediated differences in neuromotoric control may exist, affecting muscle force production, speed, and the accepted relationships between muscle fibre types and exercise performance (p. 110).

This sex difference in the relationships between fibre types and force and speed production offers an explanation of the velocity-specific sex difference in strength in the present study; it would suggest that although the fibre type composition of the muscles of males and females is the same, sex differences in the neural control of these fibres cause velocity-specific sex differences in strength. Furthermore, since the appearance of this velocity-specific sex difference in strength was thought to be affected by the onset of puberty in males, it would indicate that this sex difference in the relationship between fibre type and performance may also be affected by the onset of puberty.

However, this explanation of the sex differences found in the present study is only speculation; the results of the present study cannot confirm or contradict the hypothesis that the velocity-specific sex difference is related to sex differences in the relationships betweeen fibre types and performance. However, the fact that a velocity-specific sex difference in strength was found would suggest that further research is required to investigate this sex difference.

Section 5

Reliability of Peak Torque Scores

One of the subproblems of this study was to determine if it was possible to obtain reliable measures of PT. There were two aspects investigated to determine this reliablilty; to determine whether the machine itself gave reliable and valid measures of PT and secondly whether the subjects gave reliable measures.

5.5.1. Reliability and Validity of Cybex II

The results of this study indicated that the Cybex II was giving reliable and valid measurements of torque throughout the testing period. The procedures used to determine this reliability were not only the standard procedures used in the majority of studies to date (Moffroid et al., 1969; Thorstensson, 1976; Knapik and Ramos, 1980; Scudder, 1980), but also included the additional guidelines suggested by the manufacturers to prevent possible inaccuracies resulting from overshoot and the damping system. These inaccuracies were referred to in the review of literature reported in the studies by Murray et al. (1982a), Murray et al. (1982b), Murray et al. (1986) and Sapega et al.(1982).

Although the guidelines suggested by the manufacturers were given to prevent these inaccuracies it would be ideal if the present study were able to give independent evidence to show that the inaccuracies suggested by Spega and Murray did not affect the results of the present study. This would be particularly important to discount the possibility that any velocity-specific error occurred.

This evidence can be obtained for the PT scores of the present study and is made possible by the fact that each subject's relationships between PT and velocity could be represented very accurately by intercept and slope values, calculated from the regression of Log PT on velocity. Based on the assumption that the PT scores were valid and not subject to velocity-specific errors this predictable pattern means that intercept and slope values calculated from just three of the velocities can be used to predict a value of the fourth velocity. Indeed any discrepancies between the actual values and the predicted value would indicate that the actual values were being affected by errors such as overshoot or velocity-specific error in the damping system.

Using this procedure, predicted PT scores were obtained for each velocity using the mean PT values at 300 deg/sec, 210 deg/sec, 120 deg/sec, and 30 deg/sec, for boys and girls of each age group (Tables A-1 to A-4, Appendix A). For example, to predict PT at 300 deg/sec intercept and slope values were calculated from the mean PT scores at 210 deg/sec 120 deg/sec and 30 deg/sec. The predicted value was then compared with the actual values obtained; any discrepancy between these two values would indicate possible error in the accuracy of measurement. This type of procedure was then followed for each of the other velocities. Table 4 shows the comparison between the predicted PT scores and the actual mean PT score for each velocity, for each age and gender group. The differences between the actual and predicted PT scores gives an indication of the possible errors in the PT scores caused by overshoot or the damping system; the mean and standard deviation of differences at each of the velocities were as follows:

0.7, and 0.5 at 300 deg/sec,

0.5, and 0.3 at 210 deg/sec,

1.6, and 1.0 at 120 deg/sec,

3.2, and 3.3 at 30 deg/sec.

Put in context with the PT scores obtained for each age group at each velocity it could be said that the error obtained was negligible and would not affect the results of the present study. Indeed, it could be concluded that the ability to successfully predict the PT score at one velocity from the PT scores at the other three velocities would argue against overshoot and the damping system causing velocity-specific inaccuracies in the measurement of PT and would suggest that the PT scores in the present study were indeed both reliable and valid.

TABLE 4

Actual and Predicted Peak Torque Scores for Subjects at Four Velocities

Age	Sex	Actual $\bar{X}$ PT at 300	(a) Predicted $\bar{X}$ PT at 300	Actual $\bar{X}$ PT at 210	(b) Predicted $\bar{X}$ PT at 210	Actual $\bar{X}$ PT at 120	(c) Predicted $\bar{X}$ PT at 120	Actual $\bar{X}$ PT at 30	(d) Predicted $\bar{X}$ PT at 30
5	F	2.5	3.0	4.9	4.3	7.4	7.6	12.4	13.2
	M	3.2	3.1	5.0	4.9	7.3	7.9	12.6	11.2
8	F	5.8	5.3	9.5	9.8	16.1	16.9	29.6	26.7
	M	4.7	4.5	8.1	8.0	13.2	14.1	24.6	22.3
11	F	9.6	8.5	15.3	15.9	25.3	27.5	47.8	47.3
	M	10.3	8.8	16.8	17.9	28.0	31.4	57.0	46.0
14	F	17.4	16.4	27.8	28.7	46.4	47.6	79.6	75.4
	M	22.4	22.4	35.3	34.8	53.5	54.8	85.7	83.1

(a) n PT score at 300 deg./sec. predicted from linear regression of Log PT on velocity using mean PT scores at 210, 120 and 30 deg./sec.
(b) n PT score at 210 deg./sec. predicted from linear regression of Log PT on velocity using mean PT scores at 300, 120 and 30 deg./sec.
(c) n PT score at 120 deg./sec. predicted from linear regression of Log PT on velocity using mean PT scores at 300, 210 and 30 deg./sec.
(d) n PT score at 30 deg./sec. predicted from linear regression of Log PT on velocity using mean PT scores at 300, 210 and 120 deg./sec.

5.5.2 Subject Reliability for PT Scores

Section 4.1.2 described, for subjects aged 5, 8, 11, and 14, reliability in producing PT representative of their maximum effort in a voluntary knee extension task at 4 velocities, using a Cybex II. This reliability is described in terms of the occurrence of best PT scores between the initial and repeated tests, and the magnitude of variation between these two tests. By describing the reliability in this way it was hoped to evaluate the effects of technical and psychological factors on the reliability of PT scores for the subject population used in the present study.

It was indicated in the review that previous research has not provided this information for the subject population and movement task performed in the present study. Indeed, investigating the reliability of PT score had two purposes: firstly, to provide information about the reliability of the present study's PT scores, and, secondly, to provide information that would be useful for future testing in this area.

In terms of the PT scores in the present study it was possible to draw the following conclusions concerning the ability of the subjects to produce reliable measures of PT.

1. That week of tesing had no significant effect on the results. This was shown by the fact that the majority

of 95% confidence intervals for proportional difference, at each age, at each velocity, were not significant (Figure 10).

2. That the intertest error was slight and could be attributed to the normal variations that occur in any human performance.

More specifically, in terms of the magnitude of error between the two weeks the results indicated that the majority of differences were below 7%, with only two being above this value. This result shows similarities to the magnitude of error (7.9% to 9.8%) found by Molnar and Alexander (1979) when they tested children at 30 deg/sec. On the basis of their results Molnar and Alexander(1979) suggested that this error could be attributed to variations that occur in any human performance, and not to technical and pyschological factors influencing the results. Similar conclusions could, therefore, be drawn in the present study, but not only for 30 deg/sec but also for 210 deg/sec, 120 deg/sec, and 300 deg/sec.

Although these results verify the reliability of scores in the present study the results also show trends that have implications for future testing. The most important finding in this respect was that although week of testing did not significantly affect the occurrence of best PT scores obtained for subjects at each age at each velocity there was a general trend which indicated that the occurrence of best PT scores was affected by velocity. This trend was shown in the 95% confidence intervals for the average proportional differences, using all subjects, at each velocity (shaded intervals Figure 10). Significant differences ($p < 0.05$) were obtained at 30 deg/sec and 120 deg/sec in favour of better PT scores occurring in week 1, and at 300 deg/sec a significant difference ($p < 0.05$) in favour of better PT scores occurring in week 2. In other words, it would appear that as velocity decreases the bias towards better PT scores being produced in week 1 increases.

A possible explanation of why better PT scores were produced in week 2 at 300 deg/sec could be that the task of producing torque, at high constant speeds, required a greater degree of familiarisation and learning. Murray et al. (1980) also found that better PT scores were produced in the second week in isokinetic tests; whereas, in the isometric tests, the opposite trend was found. They concluded that isokinetic tests required a greater degree of motor learning, in comparison to isometric tests, possibly because the experience of constant speed testing was unfamiliar to the subjects. The result of the present study is therefore consistent with the findings of Murray et al. (1980). This explanation is also given further credence by the fact that at 300 deg/sec age appeared to affect the magnitude of the intertest error (Figure 10). At this velocity the magnitude of error increased as age decreased. This implies that at 300 deg/sec there is a factor causing the majority of subjects to produce better PT scores in week 2, and that this factor is more apparent in the younger children. The fact that the younger children experienced the greatest difficulty in producing their best scores in the first week would be expected if a degree of motor learning was required for subjects to produce their best PT scores.

For future testing this result would imply that for best PT scores to be achieved in the first testing week more familiarisation trials may be required.

Although motor learning is a possible explanation for better PT scores being produced in week 2 at the fastest velocity (300 deg/sec), it does not explain why the opposite trend was found at the lower velocities; higher PT scores were produced in week 1 at velocities 120 deg/sec and 30 deg/sec. However, this different trend could be explained by the fact that at the lower velocities, particulary at 30 deg/sec, the task is more uncomfortable than at 300 deg/sec. Given this, it could be inferred that better PT scores were produced in the first week because of an inhibitory influence caused by the experience of the fist week preventing subjects from giving a similar effort in the second week. In other words, the ability to produce best PT scores at the slower velocities, particularly at 30 deg/sec, was more related to motivation than to learning and familiarisation. For future testing this result would imply that best PT scores are more likely to be obtained in the first test, and efforts should be made to motivate the subject as much as possible in this test.

In conclusion the results of the present study indicated, firstly, that the PT scores of the present study were reliable and, secondly, that in future studies one week of testing would be sufficient to obtain best PT scores, with the recommendation that the familiarisation trials at the fast velocities should be increased and that the subjects should be highly motivated at the slow velocities.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

This study was undertaken to investigate the development of children's torque generating capacities in maximal limb movements performed at a range of angular velocities. To be able to obtain meaningful informatin from this investigation the answers to five specific questions were sought:

1. what was the relationship between the peak torque and velocity for the subjects?
2. what effect did age have on the peak torque scores?
3. to what extent did commonly used parameters of growth, i.e. age and measures of body size, explain the variation in peak torque scores?
4. were there any sex differences in (a) peak torque scores? (b) body size measurements?
5. was it possible to obtain PT scores that were representative of the subject's maximum voluntary effort?

This study was designed to answer these questions. The results were reported in chapter four and discussed in chapter five. The following conclusions and recommendations arise from the results and the discussion:

6.1.1 Conclusions

There are five conclusions that could be drawn from the present study:

1. For each subject, irrespective of age and gender, there was a negative exponential decrease in PT as the velocity of angular motion increased. Furthermore, the intercept and slope values calculated from the regressions of log PT on velocity, when used in the equation Log PT = intercept + slope velocity, were highly accurate representations of each subject's PT-V relationship. Using this mathematical equation to describe each subject's PT-V relationship was extremely convenient for defining and analysing the PT generating capacities of children at a range of angular velocities.

2(a) The PT generating capacities of children significantly increased ($p < 0.05$) with age; this was true for all velocities tested. This confirms the previously well-established theory that children's strength increases with age. More importantly, however, this result goes further; for the first time it shows this increase at a range of constant velocities.

2(b) In addition, the rate of this increase was shown to be velocity-specific; that is, the rate of improvement of strength at one velocity was not the same for another velocity. The fact that there were significant differences ($p < 0.01$) between the males' slopes, and that girls and boys showed a similar pattern of differences, suggested that growth was affecting the development of strength in a velocity-specific manner.

3. The correlations between the PT scores and body size measures were significant ($p < 0.001$), lying between 0.83 to 0.94; each body size measure accounted for between 69% and 88% of the variation in the PT scores. These relationships are a reflection of the fact that the PT scores increased because the subjects were getting bigger and more mature. The fact that body size measures were able to explain a large proportion of the variance was shown to be related to the wide range of developmental stages represented in the subject population used in the present study.

4. For subjects aged 5, 8, and 11 years there were no significant differences between males and females in their ability to produce PT at a range of velocities in maximal voluntary knee extension. At age 14, however, boys were found to be significantly stronger at 3 out of the 4 velocities; that is, at 300 deg/sec ($p < 0.01$), 210 deg/sec ($p < 0.01$) and 120 deg/sec ($p < 0.05$). Although this result indicated that significant sex differences only became apparent at age 14, the result

was more notable for the fact that there was a signifcant trend ($P < .01$) indicating that as velocity increased the magnitude of the sex difference increased. This velocity-specific sex difference confirms the results of recent studies and, in addition, indicates for the first time that the appearance of this sex difference is related to the stage of development or maturation of the individual.

5(a) Using the recommended calibration procedures of the manufatureres the Cybex II was shown to be both valid and reliable. Recent studies, however, have suggested that limitations of the Cybex could lead to inaccuracies in the measurement of PT. However, the ability to successfully predict the PT scores at one velocity from the PT scores at the other three velocities gave evidence against there being any velocity-specific inaccuracies in the measurement of PT.

5(b) In terms of subject reliability the results indicted that the best PT scores obtained were reliable estimates of the subjects best effort. There was a tendency, however, using this protocol, for better PT at the fast velocities to be produced in the second week and for better PT scores at the slow velocities to be produced in the first week. A possible explanation of this trend was that producing PT at the fast velocities demanded a greater degree of motor learning and familiarisation, causing better PT scores to be produced in the second week, and that the hard physical effort involved in producing best PT scores at the slow velocities had an inhibitory effect for subjects, causing lower scores in the second week.

6.1.2. Recommendations

One of the original aspects of the present study is the fact the PT scores were measured at a range of velocities. Using these measurements it was hoped to obtain information, not only on the developmental changes in the amount of torque produced, but also on the velocity-specific nature of this development. Analysing the data for this information was made easier by the fact that these two pieces of information could be summarised, from subects' PT-V relationship, by two values: intercept and slope.

Future studies should develop what has been done in the present study in order to provide more detailed information on the development of children's torque generating capacities at range of constant velocities. However, since this was a preliminary type of investigation, changes in design are recommended to allow for this more detailed investigation: subject population, range of tasks, protocol.

6.1.2(a) subject population

In the present study the data used was based only on the data obtained from four selected age groups within the age range of 5 to 14 years. While this sampling did identify general developmental trends, more detailed conclusions were not possible. This is particularly true for the velocity-specific aspects of strength development. Indeed, from the results obtained in the present study no clear conclusions, only speculations, could be drawn about the velocity-specific nature of strength development; future studies could investigate these speculations. Two aspects of the velocity-specific nature of strength development require further research:

1. to investigate whether there is a specific pattern to the velocity-specific nature of strength development. In the present study it was speculated that, with increasing age, strength develops in two sequential stages; in the first stage strength improvements are relatively greater at the slow velocities, and in the second stage strength improvements are relatively greater at the fast velocities.
2. to investigate more fully the velocity-specific sex difference found in the present study, particularly, the point at which it appears and whether or not it is apparent in subjects older than those in the present study.

In order to investigate these aspects more fully, and to generally give more detailed developmental information than was possible in the present study, future studies should extend the age range to include older aged children (up to 17 years). More importantly, a much greater selection of ages within this age range should be sampled. This broader sampling of children throughout the developmental range would give a much clearer indication of the mean developmental pattern of torque generation, both in terms of the amount of torque as well as the velocity-specific nature of this development. However, although extending the age range would be more informative, the ideal investigation of these developmental changes would be through a longitudinal design. This would allow a more accurate assessment of the developmental changes that take place in strength.

6.1.2(b) range of tasks

In the present study the task selected was knee extension. Future studies should widen the scope of the present study by investigating torque generating capacities in other movements. Indeed, if the negative exponential model used to describe the PT-V relationships in the present study were found to be applicable to other subjects, in other movements, it would be an ideal means of comparing the development of torque generation in different movements; the comparison would be expressed in terms of both the amount of torque produced and the velocity-specific nature of that development.

6.1.2(c) protocol

Future studies testing children at a range of velocities only require one testing session to achieve subjects' best PT scores. However, in this first test future studies should also take into account the velocity related reliability trends found in the present study. These trends suggested that for achieving subjects' best PT scores familiarisation is important at the fast velocities, whereas motivation is more important at the slow velocities.

REFERENCES

Alexander, J. and Molnar, G. (1973) Muscular strength in children: preliminary report on objective stanadards. Archives of Physical Medicine and Rehabilitation 54, 424-427.

Anderson, M.B., Cote III, R.W., Coyle, E.F. and Roby, F.B. (1979) Leg power, muscle strength and peak EMG activity in physically active college men and women. Medicine, and Science in Sport 11(1), 81(abstract)

Andres, F.F., Rees, C.R., Weiner, S.A. and Weiss, D.J. (1981) Actual and perceived strength differences. Journal of Physical Education Recreation and Dance 52(5), 20-21.

Asmussen, E. (1973) Growth in muscular strength and power. In Physical Activity Human Growth and Development (editied by G.L. Rarick), pp. 60-79. New York: academic Press.

Asmussen, E. (1980) Dimensions and physical performance capacity. Japanese Journal of Physical Fitness and Sports Medicine 29(3), 133-142.

Asumssen, E. and Heeboll-Nielsen, K. (1955) A dimensional analysis of physical performance and growth in boys. Journal of Applied Physiology 7, 593-603.

Asmussen E. and Heeboll-Nielsen, K. (1956) Physical performance and growth in children. Influence of sex, age and intelligence. Journal of Applied Physiology8, 371-380.

Asmussen, E., Heeboll-Neilsen, K, and Molbech, S.V. (1959) Description of muscle tests and standard values of muscle strength in children. Communications from the Testing and Observation Institute of the Danish National Association for Infantile Paralysis 5(suppl.), 60.pp.

Asmussen, E. and Molbech, SV. (1958) Muscular asymmetries in normal children. Communications from the Testing and Observation Institute of the Danish National Association for Infantile Paralysis 2, 8.pp.

Astrand, P.O. and Rodahl, K. (1977) Textbook of Work Physiology. New York: McGraw-Hill.

Bar-Or. O., Dotan, R., Inbar, O., rothstein, A., Karlsson, J. and Tesch, P. (1980) Anaerobic capacity and muscle fibre type distribution in man. International Journal of Sports Medicine 1, 89-92.

Barry, A.J. and Cureton, T.K. (1961) Factorial analysis of physique and performance in prepubescent boys. Research Quarterly 32(3), 283-300.

Belanger, A.Y. and McComas, A.J. (1981) Extent of motor unit activation during effort. Journal of Applied Physiology: Respirat. Environ. Exercise Physiol. 51(5), 1131-1135.

Bell, R.D., MacDougall, J.D., Billeter, R. and Howald, H. (1980) Muscle fibre types and morphometric analysis of skeletal muscle in six-year-old children. Medicine and Science in Sports and Exercise 12(1), 28-31.

Bosco, C. (1985) Stretch-shortening cycle in skeletal muscle function and physiological considerations on explosive power in man. Atleticastudi Monograph, 1, 7-113.

Bosco, C. and Komi, P.V. (1980) Influence of aging on the mechanical behaviour of leg extensor muscles. European Journal of Applied Physiology 45, 209-219.

Burke, R.E. (1980) Motor unit types: functional specializtions in motor control. Trends in NeuroSciences Reference Edition 3, 255-258. Biomedical Press, Elsevier, North Holland.

Burke, R.E. and Edgerton, R.V. (1975) Motor unit properties and selective involvement in movement. Exercise and Sports Sciences Reviews Academic Press, New York. N.Y. 3, 31-83.

Burke, W.E., Tuttle, W.W.and Thomson, C.W., (1953) The relationship of grip strength endurance to age. Journal of Applied Physiology 5, 628-630.

Buchthal, F. and Schmalbruch, H. (1970) Contraction times and fibre types in intact human muscle. Acta. physiologica scandinavica 79, 435-452.

Caiozzo, V.J., Perrine, J.J. and Edgerton, V.R. (1981) Training-induced alterations of the in vivo force-velocity relationship of human muscle. Journal of Applied Physiology: Respirat. Environ. Exercise Physiol. 51(3), 750-754.

Campbell, D.E. (1979) Generation of horsepower at low and high velocity by sprinters and distance runners. Research Quarterly 50(1), 1-8.

Campbell, C.J., Bonen, A., Kirby, R.L. and Belcastro, A.N. (1979) Muscle fibre composition and performance capacities of women. Medicine and Science in Sports 11(3), 260-265.

Carpenter, A. (1942) The measurement of general motor capacity and motor ability in the first three grades. Research Quarterly 13(4), 444-465.

Carron, A.V. and Bailey, D.A. (1974) Strength development in boys from 10 throught to 16 years. Monographs of the Society for Research in Child Development (4, Serial No. 157), 1-37.

Cearley, J.E. (1957) Linearity of contributions of ages, height, and weights to prediction of track and field performances. Research Quarterly 28(39), 218-222.

Charteris, J. and Goslin, B.R. (1982) The effects of position and movement velocity on isokinetic force output at the knee. Journal of Sports Medicine 22, 154-160.

Chu, D.A. and Smith, G. (1971) Isokinetic exercise: controlled speed and accommodating resistance. Journal of the National Athletic Trainers Association 6(1), 50-51.

Clarke, H.H. (1950) Improvements of objective strength tests of muscle groups by cable-tension methods. Research Quarterly 21, 399-419.

Clarke, H.H. (1956) Recent Advances in Measurement and Understanding of Volitional Muscular Strength. Research Quarterly 27(3), 263-275.

Clarke, H.H. (1957) Relationships of Strength and Anthropometric Measures to Physical Performance Involving the Trunk and Legs. Research Quarterly 28(3), 223-232.

Clarke, H.H.(Ed.) (1979), Physical and motor sex differences. In Physical Fitness Research Digest series 9(4), 1-28.

Clarke, H.H. and Carter, G.H. (1959) Oregon simplifications of the strength and physical fitness indices. Research Quarterly 30(1), 3-10.

Clarke, H.H. and Degutis, E.W. (1962) Comparison of skeketal age and Various Physical and Motor Factors with the pubescent development of 10, 13, and 16 year old boys. Research Quarterly 33(3), 356-368.

Clarke, H.H. and Harrison, J.C.E. (1962) Differences in physical and motor traits between boys of advanced, normal, and retarded maturity. Research Quarterly 33(1), 13-25.

Clarke H.H. and Henry F.M. (1961) Neuromotor specificity and increased speed from strength development. Research Quarterly 32(3), 315-325.

Clarke, H.H., Irving, R.N. and Honeyman Heath, B. (1960) Relation of maturity, structural, and strength measures to the somatotypes of boys aged 9 through 15 years of age. Research Quarterly 32(4), 449-460.

Clarke, H.H. and Petersen, K.H. (1961) Contrast of maturational, structural, and strength characteristics of athletes and nonathletes 10 to 15 years of age. Research Quarterly 32(2), 163-176.

Clarkson, P.M., Johnson, J., Dextradeur, D., Leszczynski, W., Wai, J. and Melchionda, A. (1982) The relationship among isokinetic endurance initial strength level, and fibre type. Research Quarterly for Exercise and Sport 53(1), 15-19.

Close, R.I. (1972) Dynamic properties of mammilian skeletal muscles. Physiological Reviews 52, 129-197.

Conger, P.R., Quinney, H.A., Gauthier, R. and Massicotte, D. (1982) A Comparison of the CAHPER fitness-performance test, 1966-1980. CAPHER Journal 49(1), 6-11

Corlett, J.T. (1984) Power function analysis of physical performance by Tswana children. Journal of Sports Sciences 2(2), 131-137.

Costill, D., Daniels, J., Evans, W., Fink, W., Krahenbuhl, G. and Saltin, B. (1976) Skeletal muscle enzymes and fibre compoistion in male and female track athletes. Journal of Applied Physiology 40(2), 149-154.

Costill, D., Sharp, R. and Troup, J. (1980) Muscle strength: contributions to sprint swimming. Swimming World 21(2), 29-34.

Counsilman, J.E. (1972) Isokinetic exercise. Athletic Journal 52(6), 55.

Counsilman, J.E. (1976) The importance of speed in exercise. The Athletic Journal 56(9), 70-71.

Coyle, E.F., Costill, D.L., and Lesmes, G.R. (1979) Leg extension power and muscle fibre composition. Medicine and Science in Sport 11(1), 12-15.

Coyle, E.F., Feiring, D.C., Rotkis, T.C., Cote III, R.W., Lee, W. and Wilmore, J.H. (1981) Specificity of power improvements through slow and fast isokinetic training. Journal of Applied Physiology: Respirat. Environ. Exercise Physiol. 51(6), 1437-1442.

Cullumbine, H., Bibile, S.W., Wikramanayake, T.W. and Watson, R.S. (1950) Influence of age, sex, physique and muscular development on physical fitness. Journal of Applied Physiology 2, 468-511.

Desmedt, J.E. (1980) Patterns of motor commands during various types of voluntary movement in man. In Trends in NeuroSciences Reference Edition 3, 265-268. Biomedical Press, Elsevier,North Holland.

Eckert, H.M. (1964) Linear relationships of isometric strength to propulsive force, angular velocity, and angular acceleration in the standing broad jump. Research Quarterly 35(3) 298-306.

Eckert, H. (1965) A concept of force-energy in human movement. Journal of the American Physical Therapy Association 45(3), 213-218.

Edstrom, L. and Ekblom, B. (1972) Differences in sizes of red and white muscle fibres in vastus lateralis of musculus quadriceps femoris of normal individuals and athletes. Relation to Physical Performance. Scandinavian Journal of Clinical and Laboratory Investigation 30, 175-181.

Ellis, J.D., Carron, A.V. and Bailey, D.A. (1974) Physical performance in boys from 10 through 16 Years. Human Biology 47(3), 263-281.

Eloranta, V. and Komi, P.V. (1980) Function of the quadriceps femoris muscle under maximal concentric and eccentric contractions. Electromyogr. Clin. Neurophysiol. 20, 159-174.

Eloranta, V. and Komi, P.V. (1981) Postural effects on the function of the quadriceps femoris muscle under concentric contraction. Electromyogr. clin. Neurophysiol.21, 555-567.

Eriksson, O. and Saltin, B. (1974) Muscle metabolism during exercise in boys aged 11 to 16 years compared to adults. Acta paediatrica belgica 28, 257-265.

Espenschade, A. (1940) Motor Performance in Adolescence including the study of the relationships with physical growth and maturity. Monographs of the Society for Research in Child Development 5 (1 Serial no. 24), 1-126.

Espenschade, A. (1963) Restudy of relationships between physical performance of school children and age, height and weight. Research Quarterly 34(2), 144-153.

Esphenshade, A.S. and Eckert, H.M. (1980) Motor Development (2nd ed.) Columbus, Ohio: Merrill.

Fenn, W.O., Brody, H. and Petrilli, A. (1931) The tension developed by human muscles at different velocities of shortening. The American Journal of Physiology 97(1), 1-14.

Fenn, W.O. and Marsh, B.S. (1935) Muscular force at different speeds of shortening. Journal of Physiology 85, 277-297.

Fleishman, E.A. ,Kremer, E.J. and Shoup, G.W. (1961) The dimensions of physical fitness: a factor analysis of strength tests. (technical report 2, prepared under contract nonr 609(32) for the office of naval research). New Haven, Conn: Yale University.

Fleishman, E.A., Thomas, P. and Munroe, P. (1961) The dimensions of physical fitness: a factor analysis of speed, flexibility, balance and coordination tests. (technical report 3, prepared under contract nonr 609(32) for the office of naval research). New Haven, Conn: Yale University.

Fugl-Meyer, A.R., Gustafsson, L. and Burstedt, Y. (1980) Isokinetic and static plantar flexion characteristics. European Journal of Applied Physiology 45, 221-234.

Fujiwara, M. and Basmajian, J.V. (1975) Electromyographic study of two-joint muscles. American Journal of Physical Medicine 54(5), 234-242.

Garhammer, J. (1978) Muscle fibre types and weight training. Track Technique 72, 2297-2297.

Genuario, S.E. and Dolgener, F.A. (1980) The relationship of isokinetic torque at two speeds to the vertical jump. Research Quarterly for Exercise and Sport 51(4), 593-598.

Gettman, L.R., Culter, L.A. and Strathman, T.A. (1980) Physiologic changes after 20 weeks of isotonic Vs isokinetic circuit training. Journal of Sports Medicine 20, 265-264.

Gilliam, T.B., Sady, S.P., Freedson, P.S. and Villanacci, J.F. (1979a) Isokinetic torque Levels for high school football players. Archives of Physical Medicine and Rehabilitation 60, 110-114.

Gilliam, T.B., Villanacci J.F. Freedson, P.S. and Sady, S.P. (1979b) Isokinetic torque in boys and girls ages 7 to 13: The effect of age, height and weight. Research Quarterly 50(4) 599-609.

Glassow, R.B. and Kruse, P. (1960) Motor performance of girls age 6 to 14 years. Research Quarterly 31(3), 426-433.

Gleim, G.W., Nicholas, J.A. and Webb, J.N. (1978) Isokinetic evaluation following leg injuries. Physician and Sports Medicine 6(8) 75-82.

Gollnick, D. (1982) Relationship of strength and endurance with skeletal muscle structure and metabolic potential. International Journal of Sports Medicine 3, 26-32.

Gregor, R.J., Edgerton, V.R., Perrine, J.J., Campion, D.S. and DeBus, C. (1979) Torque-velocity relationships and muscle fibre compostion in elite female athletes. Journal of Applied Physiology: Respirat. Environ. Exercise Physiol. 47(2), 388-392.

Grimby, G. (1982) Isokinetic training. International Journal of Sports Medicine 3, 61-64.

Grimby, L. and Hannerz, J. (1975) Disturbances in voluntary recruitment order of low and high frequency motor units on blockades of proprioceptive afferent activity. Acta physiologica scandinavica 96, 207-216.

Grimby, L. and Hannerz, J. (1977) Firing rate and recruitment order of toe extensor motor units in different mode of voluntary contraction. Journal of Physiology 264, 865-879.

Haffajee, D., Moritz, U. and Svantesson, G. (1972) Isometric knee extension strength as a function of joint angle, muscle length and motor unit activity. Acta orthopaedica scandinavica 43, 138-147.

Hallen, L.G. and Lindahl, O. (1967) Muscle function in knee extension. Acta orthopaedica scandinavica 38, 434-444.

Harrison, A.J., Watkins, J. and Farrally, M. (1983) The development of fundamental motor abilities in young children with special reference to jumping ability. Scottish Journal of Physical Education 11(1), 11-16.

Hart, D.L., Barber, D.C. and Davis, H. (1981) Cybex II-data aquisition system. The Journal of Orthopaedic and Sports Physical Therapy 2(4) 117-119.

Heeboll-Nielsen, K. (1982) Muscle strength of boys and girls, 1981 Compared to 1956. Scandinavian Journal of Sports Science 4(2) 37-43.

Henriksson, J. and Reitman, J.S. (1976) Quantitative measures of enzyme activities in type I and type II muscle fibre of man after training. Acta physiologica scandinavica 97, 392-397.

Henry, F.M., Lotter, W.S. and Smith, L.E. (1962) Factorial structure of individual differences in limb speed, reaction and strength. Research Quarterly 33(1), 70-84.

Henry, F.M. and Whitley, J.D. (1960) Individual differences in strength, speed and mass. Research Quarterly 31(1), 24-33.

Hensley, L.D. and East, W.B. (1982) Body fatness and motor performance. Research Quarterly for Exercise and Sport 53(2), 133-140.

Hislop, H. and Perrine, J.J. (1967) The isokinetic concept of exercise. Physical Therapy 47, 114-117.

Hinson, M. and Rosentsweig, J. (1972) Comparing the three best ways of developing strength. Scholastic Coach March, p.66.

Hinson, M., Smith, W.C. and Funk, S. (1979) Isokinetics: a clarification. Research Quarterly 50(1), 30-35.

Hodgkins, J. (1963) Reaction time and speed of movement in males and females of various ages. Research Quarterly 34(3), 335-343.

Hopper, B. (1980) Getting a grip on strength. Swimming Technique August, 10-13.

Hulten, B., Thorstensson, A. Sojodin, B. and Karlsson, J. (1975) Relationship between isometric endurance and fibre types. Acta physiologica scandinavica 93, 135-138.

Hugh-Jones, P. (1947) The effect of limb position in seated subjects on their ability to utilise the maximum contractile force of the limb muscles. Journal of Physiology 105, 332-344.

Hunsicker, P.A. and Donnelly, R.J. (1955) Instruments to measure strength. Research Quarterly 26(4), 408-420.

Hunsicker, P. and Greey, G. (1957) Studies in human strength. Research Quarterly 28(2), 109-122.

Ikai, M. and Fukunaga, T. (1968) Calculation of muscle strength per unit cross-sectional area of human muscle by means of ultrasonic measurement. Internationale Zeitschrift fur Angewandte Physiologie Einschliesslich Arbeitsphysiologie. 26, 26-32.

Ikai, M. and Steinhaus, A.H. (1961) Some factors modifying the expression of human strength. Journal of Applied Physiology 16(1), 157-163.

Inbar. O., Kaiser, P. and Tesch, P. (1981) Relationships between leg muscle fibre type distribution and leg Exercise Performance. International Journal of Sports Medicine 2(3), 154-159.

Ingemann-Hansen, T. and Halkjaer-Kristensen, J. (1979) Force-velocity relationships in the human quadriceps muscles. Scandinavian Journal of Rehabilitative Medicine 11, 85-89.

Ismail, A.H., Christian, J.E.and Kesler, W.V. (1963) Body compoistion relative to motor apitude for preadolescent boys. Research Quarterly 34(4), 462-470.

Jacobs, I. and Tesch, P. (1981) Short time, maximal muscular performance: relation to muscle lactate and fibre type in females. In Women and Sport (edited by J. Borms, M. Hebbelinck and A. Venerando), Medicine and Sport, 14, 125-132. Karger, Basel.

Johnson, J. and Siegel, D. (1978) Reliability of an isokinetic movement of the knee extensors. Research Quarterly 49(1), 88-90.

Johnson, T. (1982) Age related differences in isometric and dynamic strength and endurance. Physical Therapy 62(7), 985-989.

Jones, A. (1980) Time as a factor in exercise. Bodybuiding Monthly 4(2), 25-28.

Jones, H.E. (1949) Motor Performance and Growth. 1-181 Berkeley: University of California Press, Publications in Child Development.

Jorgensen, k. (1976) Force-velocity relationships in human elbow flexors and extensors. In P.V. Komi (ed.) Biomechanics, V.A. University Park Press: Baltimore MD pp. 145-151.

Kane, R.J. and Meredith (1952) Ability in the standing broad jump of elementary school children 7,9, and 11 years of age. Research Quarterly 23, 198-208.

Kanehisa, H. and Miyashita, M. (1980) An attempt at the classification of adolescents into sprint or endurance types. The Journal of Sports Medicine and Physical Fitness (Italy) 20(4), 441-446.

Karlsson, J. and Jacobs, I. (1981) Is the significance of muscle fibre types to muscle metabolism different in females than in males. In Women and Sport (edited by J. Borms, M. Hebbelinck and A. Venerando), Medicine and Sport, 14, 97-101. Karger, Basel.

Katch, F.I. (1977) Isokinetic ergometry: Measurement of maximum force and work rate capacity. National Association for Girls and Womens Sports Research Report 3, 167-179.

Katz, B. (1939) The relation between force and speed in muscular contraction. Journal of Physiology 96, 45-64.

Knutsson, F. (1982) Assessment of motor function in spasticity. Triangle 21(1).

Komi, P.V. (1973a) Measurement of the force-velocity relationship in human muscle under concentric and eccentric contractions. In Medicine and sport: Biomechanics III, (edited by S. Cerguiglini), 8, 224-229. Karger, Basel.

Komi, P.V. (1973b) Relationships between muscle tension, EMG and velocity of contraction under concentric and eccentric work. In: New Developments in Electromyography and Clinical Neurophysiology (edited by J.E. Desmedt) 1, 596-606. Karger, Basel.

Komi, P.V. (1979) Neuromuscular performance: Factors influencing force and speed production. Scandinavian Journal of Sports Science. 1, 2-15.

Komi, P.V. (1981) Fundamental performance characteristics in females and males. In Women and Sport (edited by J. Borms, M. Hebbelinck and A. Venerando), Medicine and Sport, 14, 102-108. Karger, Basel.

Komi. P.V. and Karlsson, J. (1978) Skeletal muscle fibre types, enzyme activities and physical performance in young males and females. Acta physiologica scandinavica. 103, 210-218.

Komi, P.V. and Karlsson, J. (1979) Physical performance, skeletal muscle enzyme activities, and fibre types in monozygous and dizygous twins of both sexes. Acta physiologica scandinavica Suppl 462.

Komi, P.V. and Tesch, P. (1979) EMG frequency spectrum, muscle structure, and fatigue during dynamic contractions in man. European Journal of Applied Physiology 42, 41-50.

Komi, P.V., Viitasalo, H.T., Thorstensson, A. Sjodin, B. and Karlsson, J. (1977) Skeletal muscle fibres and muscle enzyme activities in monozygus and dizygous twins of both sexes. Acta physiologica scandinavica 100, 385-392.

Knapik, J.J., and Ramos, M.U. (1980 Isokinetic and Isometric torque relationships in the human body. Archives of Physical Medicine and Rehabilitation 61, 64-67.

Krogman, W.M. (1948) A handbook of the measurement and interpretation of height and weight in the growing child. Monographs of the Society for Research in child Development XIII, (3, serial no. 48), 1-68.

Lamb, D.R. (1984) Physiology of Exercise, Resposes and Adaptions. (2nd ed.) New York: Macmillan.

Laubach, L.L. and McConville, J.T. (1969) The relationship of strength to body size and typology. Medicine and Science in Sports 1(4), 189-194.

Lambert, O. (1965) The relationship between maximum isometric strength and maximum concentric strength at different speeds. International Federation of Physical Education Bulletin 35, 13-20.

Lamphiear, D. and Montoye, H.J. (1976) Muscular strength and body size. Human Biology 48(1), 147-160.

Larsson, L., Grimby, G. and Karlsson, J. (1979) Muscle strength and speed of movement in relation to age and muscle morphology. Journal of Applied Physiology: Respirat. Environ. Exercise Physiol. 46(3), 451-456.

Lesmes, G.R., Costill, D.L., Coyle, E.F. and Fink, W. (1978) Muscle strength and power changes during maximal isokinetic training. Medicine and Science in Sports 10(4), 266-269.

Lieb, F.J., Nevada, R. and Perry, J. (1971) Quadriceps Function: An electromyographic study inder isometric conditions. The Journal of Bone and Joint Surgery 53a(4), 749-758.

Lindahl, O. and Movin, A. (1965) The mechanics of knee extension. Acta orthopaedica scandinavica 38, 226-234.

Lotter, W.S. (1960) Interrelationships among reaction times and speeds of movement in different limbs. Research Quarterly 31(2), 147-155.

Lotter, W.S. (1961) Specificity or generality of speed of systematically related movements. Research Quarterly 32(1), 55-62.

Maglischo, C.W. (1968) Bases of norms for cable-tension strength tests for upper elementary junior high and senior high school girls. Research Quarterly 39(3), 595-603.

Malina, R.M. and Johnston, F.E. (1967) Significance of age, sex and maturity differences in upper arm composition. Research Quarterly 38(2), 119-229.

Marshall, G.R., Bailey, D.A., Leahy, R.H. and Ross, W.D. (1978) Allometric growth in boys studied longitudinally age seven to sixteen Paper presented in the "2nd International Symposium on Kinanthropometry", Leuven, Belgium, July 10-13.

Martin E.G. (1918) Muscular strength and muscular symmetry in human beings: 1.Children. American Journal of Physiology 46, 67-84.

McDavid, R. (1977) Predicting potential football players. Research Quarterly 48(1), 99-104.

McMahon, T.A. (1984) Muscles, Reflexes, and Locomotion. Princeton New Jersey: Princeton University Press.

Mero, A., Luhtanen, P., Viitasalo, J.T. and Komi, P.V. (1981) Relationships between the maximal running velocity, muscle fibre characteristics, force production and force relaxation of sprinters. Scandinavian Journal of Sports Science. 3(1), 16-22.

Merton, P.A. (1954) Voluntary strength and fatigue. Journal of Physiology London 230, 359-370.

Metheny, E. (1941a) Breathing capacity and grip strength of preschool children. University of Iowa Studies. Child Welfare 18(2), 1-207.

Metheny, E. (1941b) The present status of strength testing for children of elementary school and pre school age. Research Quarterly 12, 155-130.

McCloy, C.H. (1935) The influence of chronological age on motor performance. Research Quarterly 6(2), 61-64.

Meredith, H.V. (1935) The rhythm of physical growth: a study of eighteen anthropometric measures on Iowa city males ranging in age between birth and eighteen years years. University of Iowa child Welfare Studies 11(3).

Meredith, H.V. and Boynton, B. (1937) The transverse growth of the extremities: An analysis of the girth measurements for arm, forearm, thigh and leg taken on Iowa city white children. Human Biology 9, 366-403.

Milner-Brown, H.S., Stein, R.B. and Yemm, R. (1973a) The orderly recruitment of human motor units during voluntary isometric contractions. Journal of Physiology 230, 359-370.

Milner-Brown, H.S., Stein, R.B. and Yemm, R. (1973b) Changes in firing rate of human motor units during linearly changing voluntary contractions. Journal of Physiology 230, 371-390.

Miyashita, M. and Kanehisa, H. (1979) Dynamic peak torque related to age, sex, and performance. Research Quarterly 50(2) 249-255.

Moffroid, M.T. and Kusiak, E.T. (1975) The power struggle: Definition and evaluation of power of muscular performance. Physical Therapy 55(10), 1098-1104.

Moffroid, M.T. and Whipple, R.H. (1970) Specificity of speed of exercise. Physical Therapy 50(12).

Moffroid, M., Whipple,R., Hofkosh, J., Lowman, E. and Thistle, H. (1969) A study of isokinetic exercise. Journal of Physical Therapy 49(7), 735-746.

Molnar. G. E. and Alexander, J. (1973) Objective quantitative muscle testing in children. Archives of Physical Medicine and Rehabilitation 54, 224-228.

Molnar, G.E. and Alexander, J.A. (1974) Development of quantitative standards for muscle strength in children. Archives of Physical Medicine and Rehabilitation 55, 490-493.

Molnar, G. E., Alexander, J. and Gutfeld, N. (1979) Reliability of quantitative strength measurements in children. Archives of Physical Medicine and Rehabilitation 60, 218-221.

Montpetit, R.R., Montoye, H.J. and Laeding, L. (1967) Grip strength of school children, Saginaw, Michigan: 1899 and 1964. Research Quarterly 38(2), 231-240.

Montoye, H.J. and Lamphiear, D.E. (1977) Grip strength in males and females, aged 10 to 69. Research Quarterly 48(1), 109-120.

Morris, C.B. (1948) the measurement of strength of muscle relative to the cross section. Research Quarterly 19, 295-303.

Morrow, J.R. and Hosler, H.H. (1981) Strength comparisons in untrained men and trained women. Medicine and Science in Sports and Exercise 13(3), 194-198.

Muller, E.A. (1970) Influence of training and of inactivity on muscle strength. Archives of Physical Medicine and Rehabilitation 51, 449-462.

Murray, P.M., Baldwin, J.M., Gardner, G.M., Sepic, S.B. and Downs, W.J. (1977) Maximum isometric knee flexor and extensor muscle contractions-normal patterns of torque versus time. Physical Therapy 57(6), 637-643.

Murray, P.M., Gardner, G., Mollinger, L. and Sepic, S. B. (1980) Strength of isometric and isokinetic contractions, knee muscles of men aged 20 to 86. Physical Therapy 60(4), 412-419.

Murray, D.A. and Harrison, E. (1986) constant velocity dynamometer: and appraisal using mechanical loading. Medicine and Science in Sports and Exercise 18(6), 612-624.

Murray, D.A. Harrison, E. and Wood, G.A. (1982a) Cybex II reliability and valididty: an appraisal Free communication presented at ACSM 29th annual Meeting, May 26-29, Minneapolis, Available from Dept of Human Movement and Recreation Studies, University of Werstern Australia Nedlands, W.A 6009.

Murray, D.A., Wood, G.A., Mills, J. Cresp, P. and Harrison, E. (1982b) Electromechanical dynamometer for human muscle function testing. Paper presented at 22nd Annual conference on Physical Sciences and Engineering in Medicine and Biology, August 9-13, Perth, Western Austrailia. Available from Dept of Human Movement and Recreation Studies, University of Werstern Australia Nedlands, W.A 6009.

O'Brian, Davies, B. and Dagget, A. (1982) Women in Sport. In Science and Sporting Performance(edited by B. Davies and G.Thomas) pp. 52-67. Oxford: Clarendon Press.

Otis, J.C. and Godbold, J.H. (1983) Relationship of isokinetic torque to isometric torque. Journal of Orthopaedic Research 1(2), 165-171.

Patton, R.W., Hinson, M.M. Arnold, B.R. and Lessard, B. (1978) Fatigue Curves of Isokinetic contractions. Archives of Physical Medicine and Rehabilitation 59, 507-509.

Perrine, J.J. (1968) Isokinetic exercise and the mechanical energy potentials of muscle. Journal of American Association for Health, Physical Education and Recreation 39, 40-44.

Perrine, J.J. and Edgerton, V.R. (1978) Muscle force-velocity and power-velocity relationships under isokinetic loading. Medicine and Science in Sports 10(3), 159-166.

Pierson, W.R. and O'Connell, E.R. (1962) Age, height, weight, and grip strength. Research Quarterly 33(3), 439-443.

Pipes, T.V. (1978) Isokinetic strength training and its effectiveness for the competative swimmer. Swimming Technique 15(2), 52-55.

Pipes, T.V. and Wilmore, J.H. (1975) Isokinetic Vs isotonic strength training in adult men. Medicine and Science in Sports 7(4), 262-274.

Radford, P.F, (1981) Isokinetics: a history and review. Scottish Journal of Physical Education 9(1), 21-27.

Ralston, H.J., Polissar, M.J., Inman, V.T. and Close, J.R. (1949) Dynamic features of human isolated muscle in isometric and free contractions. Journal of Applied Physiology 1, 526-533.

Rarick, G.L. and McKee, R. (1949) A study of twenty third grade children exibiting extreme levels of achievement on tests of motor proficiency. Research Quarterly 20, 142-150.

Rarick G.L. and Oyster, N. (1964) Physical maturity, muscular strength and motor performance of young school age boys. Research Quarterly 35(4), 523-531.

Rarick, G. L. and Thompson, J.J. (1956) Roentenographic measures of leg muscle size and ankle extensor strength of seven-year-old children. Research Quarterly 27(3), 321-332.

Rasch, P.J. and Pierson, W.R. (1963) Some relationships of isometric strength, isotonic strength, and anthropometric measures. Ergonomics 6, 211-215.

Rees, C.R. and Andres, F.F. (1981) Strength differences in young children "real" or "imagined"? Motor Skills: Theory into Practice 5(2), 117-121.

Reynolds, E.L. (1944) Differential tissue growth in the leg during childhood. Child Development 14(4), 181-205.

Rodgers, K.L. and Berger, R.A. (1974) Motor-unit involvement and tension during maximum, voluntary concentric, eccentric, and isometric contractions of the elbow flexors. Medicine and Science in Sports 6(4), 253-259.

Rosentstwieg, J. and Hinson, M.M. (1972) comparison of isometric, isotonic and isokinetic exercises by electromyography. Archives of Physical Medicine and Rehabilitation 53, 16-17.

Sale, D. and MacDougall, D. (1981) Specificity in strength training: a review for the coach and athlete. Canadian Journal of Applied Sports Science 6(2), 87-92.

Sale, D.G., MacDougall, J.D., Upton, A.R.M. and McComas, A.J. (1983) The effects of strength training upon motoneuron excitability in man. Medicine and Science in Sports and Exercise 15(1), 57-62.

Sapega, A.A., Nicholas, J.A., Sokolow, D. and Saraniti, A. (1982) The nature of the torque "overshoot" in Cybex isokineic dynamometry. Medicine and Science in Sports and Exercise 14(5), 368-375.

Scudder, G.N. (1980) Torque curves produced at the knee during isometric and isokinetic exercise. Archives of Physical Medicine and Rehabilitation 61, 68-73.

Seaborne, D. and Taylor, A.W. (1981) The effects of isokinetic exercise on vastus lateralis fibre morphology and biochemistry. Journal of Sports Medicine 21, 365-370.

Seils, L. (1951) The relationship between measures of physical growth and gross motor performance of primary-grade school children. Research Quarterly 22, 244-260.

Sharman, I.M. (1981) Grading the Young Sportsman. Medisport 3(2), 57-60.

Slaughter, M.H., Lohman, T.G. and Boileau, R.A. (1982) Relationship of anthropometric dimensions to physical performance in children. Journal of Sports Medicine 22, 377-384.

Smith, L.E. (1961) Individual differences in strength, reaction latency, mass and length of limbs, and their relation to maximal speed of movement. Research Quarterly 32(2), 208-220.

Smith, L.E. and Whitley, J.D. (1963) Relation between muscular force of a limb, under different starting conditions and speed of movement. Research Quarterly 34(4), 489-496.

Sockolov, R., Irwin, B., Dressendorfer, R.H. and Bernauer, E.M. (1977) Exercise performance in 6-11 year-old boys with duchenne muscular dystrophy. Archives of Physical Medicine and Rehabilitation 58, 195-201.

Spackman, B. (1971) A new approach to strength building. Athletic Journal 51(5), 72-73.

Teeple, J., Lohman, T.G., Misner, J.E., Boileau, R.A. and Massey, B.H. (1975) Contribution of physical development and muscular strength to the motor performance capacity of 7 to 12 year old boys. British Journal of sports Medicine 9(3), 122-129.

Teeple, J. and Massey, B. (1976) Force-time parameters and physical growth of boys ages 6 to 12 years. Research Quarterly 47(3), 464-471.

Thistle, H.G., Hislop, H.J., Moffroid, M.M. and Lowman, E.W. (1967) Isokinetic contraction: a new concept of resistive exercise. Archives of Physical Medicine and Rehabilitation 48, 279-282.

Thorstensson, A. (1976) Muscle strength, fibre types and enzyme activities in man. Acta physiologica scandinavica (suppl 443) 1-46.

Thorstensson, A., Grimby, G. and Karlsson, J. (1976) Force-velocity relations and fibre composition in human knee extensor muscles. Journal of Applied Physiology 40(1), 12-15.

Thorstensson, A, Larsson, L., Tesch, P. and Karlsson, J. (1977) Muscle strength and fibre composition in athletes and sedentary men. Medicine and Science in Sports 9(1), 26-30.

Torpey, J.E. (1960) Strength tests for young children-a pilot study. Research Quarterly 31(2), 238-239.

Troup, J., Plyley, M., Sharp, R. and Costill,D. (1981) The age group swimmer: considerations for training and performance. Swimming World 22(4), 22-24.

Vincent, M.F. (1968) Motor performance of girls from twelve through eighteen years of age. Research Quarterly 39(4), 1094-1100.

Wear, C.L. and Miller, K. (1962) Relationships of physique and developmental level to physical performance. Research Quarterly 33(4), 615-631.

Whitley, J.D. and Smith, L.E. (1963) Velocity curves and static strength-action strength correlations in relation to mass moved by the arm. Research Quarterly 34(3), 379-395.

Wilkie, D.R. (1950) The realtion between force and velocity in human muscle. Journal of Physiology 110, 249-280.

Williams, M. and Stutzman, L. (1959) Strength variations throughout the range of joint motion. The Physical Therapy Review 39(3), 145-152.

Wilmore, J.H. (1974) Alterations in strength, body composition, and anthropometric measurements consequent to a 10 week weight training programme. Medicine and Science in Sports 6, 133-138.

Yamashita, N. (1976) The mechanism of generation and transmission of forces in leg extension. Journal of Human Ergology 4(1), 43-52.

TABLE A-1

Mean, Standard Deviation and Range of Peak Torque Scores Obtained for Children Aged 5, in Isokinetic Knee Extension [n(F) = 12, n(M) = 14]

Velocity	Sex	$\bar{X}$ P.T.	S.D.	Minimum	Maximum
300°/sec.	F	2.5	0.8	1.2	4.0
	M	3.2	1.1	1.2	5.0
210°/sec.	F	4.9	1.1	2.8	6.7
	M	5.0	1.0	3.3	6.8
120°/sec.	F	7.4	1.7	4.4	10.4
	M	7.3	1.6	4.1	9.7
30°/sec.	F	12.4	3.5	7.8	18.8
	M	12.6	2.9	9.2	17.0

TABLE A-2

Mean, Standard Deviation and Range of Peak Torque Scores Obtained for Children Aged 8, in Isokinetic Knee Extension [n(F) = 13, n(M) = 15]

Velocity	Sex	$\bar{X}$ P.T.	S.D.	Minimum	Maximum
300°/sec.	F	5.8	1.5	4.0	8.6
	M	4.7	1.6	2.2	7.8
210°/sec.	F	9.5	2.5	7.1	16.1
	M	8.1	2.7	3.5	12.8
120°/sec.	F	16.1	3.2	13.0	23.1
	M	13.2	4.3	5.3	20.2
30°/sec.	F	29.6	6.8	20.6	42.0
	M	24.6	8.7	12.0	40.2

TABLE A-3

Mean, Standard Deviation and Range of Peak Torque Scores Obtained for Children Aged 11, in Isokinetic Knee Extension [n(F) = 15, n(M) = 16]

Velocity	Sex	$\bar{X}$ P.T.	S.D.	Minimum	Maximum
300°/sec.	F	9.6	2.5	5.1	14.6
	M	10.3	1.8	7.3	13.2
210°/sec.	F	15.3	3.6	8.4	23.4
	M	16.8	2.5	11.7	21.6
120°/sec.	F	25.3	5.5	14.3	36.6
	M	28.0	4.8	19.7	37.2
30°/sec.	F	47.8	7.8	30.2	57.6
	M	57.0	13.3	36.0	85.2

TABLE A-4

Mean, Standard Deviation and Range of Peak Torque Scores Obtained for Children Aged 14, in Isokinetic Knee Extension [n(F) = 15, n(M) = 14]

Velocity	Sex	$\bar{X}$ P.T.	S.D.	Minimum	Maximum
300°/sec.	F	17.4	3.9	10.2	24.0
	M	22.4	5.3	12.0	32.2
210°/sec.	F	27.8	5.4	19.2	36.6
	M	35.3	6.1	22.8	46.2
120°/sec.	F	46.4	8.0	35.4	61.2
	M	53.5	9.7	31.2	65.4
30°/sec.	F	79.6	11.2	54.0	98.4
	M	85.7	15.0	56.4	106.8

TABLE B-1

Differences Between Test and Retest Measures of Body Size (n = 114)

Variable	Mean Difference	S.D.	95% Confidence Intervals for Population Mean Difference
Height (cm)	-0.01	0.14	(-0.034, 0.015)
Weight (Kg)	-0.56	0.32	(-0.110, 0.002)
Hip to Ankle Length (cm)	-0.02	0.71	(-0.11, 0.15)
Knee to Ankle Length (cm)	-0.03	0.91	(-0.14, 0.14)
Hip to Knee Length (cm)	-0.05	0.75	(-0.09, 0.19)
Thigh Circumference (cm)	0.02	0.63	(-0.1, 0.13)

TABLE B-2

Means and Standard Deviations of Height (cm.)

Obtained for Girls and Boys

Age	Sex	n	$\bar{X}$	S.D.
5	F	12	112.2	5.3
	M	14	113.1	5.8
8	F	13	127.4	7.6
	M	15	127.3	9.3
11	F	15	145.3	6.4
	M	16	147.1	4.5
14	F	15	160.8	4.0
	M	14	168.4	9.1

TABLE B-3

Means and Standard Deviations of Weight (kg.) Obtained for Girls and Boys

Age	Sex	n	$\bar{X}$	S.D.
5	F	12	18.6	2.8
	M	14	19.4	2.7
8	F	13	27.8	3.4
	M	15	25.0	4.6
11	F	15	35.2	6.2
	M	16	39.0	6.1
14	F	15	52.3	7.5
	M	14	56.4	7.8

TABLE B-4

Means and Standard Deviations of Hip-to-Ankle Measures (cm.) Obtained for Girls and Boys

Age	Sex	n	$\bar{X}$	S.D.
5	F	12	48.8	3.7
	M	14	48.7	3.7
8	F	13	60.0	2.9
	M	15	57.8	6.5
11	F	15	69.9	4.6
	M	16	70.5	4.0
14	F	15	77.1	2.7
	M	14	82.0	4.4

TABLE B-5

Means and Standard Deviations of Hip-to-Knee Measures (cm.) Obtained for Girls and Boys

Age	Sex	n	$\bar{X}$	S.D.
5	F	12	19.7	2.4
	M	14	20.0	2.3
8	F	13	24.8	2.6
	M	15	24.4	3.7
11	F	15	30.0	4.3
	M	16	30.2	3.9
14	F	15	33.2	2.6
	M	14	35.9	2.4

TABLE B-6

Means and Standard Deviations of Knee-to-Ankle Measures (cm.)

Obtained for Girls and Boys

Age	Sex	n	$\bar{X}$	S.D.
5	F	12	29.2	1.8
	M	14	28.7	2.2
8	F	13	35.1	2.0
	M	15	34.4	3.4
11	F	15	40.0	2.5
	M	16	40.4	3.2
14	F	15	43.9	2.3
	M	14	46.0	3.4

TABLE B-7

Means and Standard Deviations of Thigh Circumference (cm.) Obtained for Girls and Boys

Age	Sex	n	$\bar{X}$	S.D.
5	F	12	35.1	3.5
	M	14	33.3	2.8
8	F	13	42.4	4.2
	M	15	37.4	4.1
11	F	15	47.2	4.1
	M	16	46.3	5.8
14	F	15	55.7	5.3
	M	14	52.8	4.2

TABLE B-8

Means and Standard Deviations of Cybex Lever Length (cm.) Obtained for Girls and Boys

Age	Sex	n	$\bar{X}$	S.D.
5	F	12	16.3	2.3
	M	14	16.9	1.7
8	F	13	23.4	2.8
	M	15	21.2	2.9
11	F	15	26.4	2.3
	M	16	28.5	2.3
14	F	15	29.8	2.5
	M	14	33.5	2.2

TABLE C-1

Mean and Standard Deviations of Intercept Values

For Boys and Girls of 4 Age Groups

Age	Sex	n	Mean Intercepts Log Peak Torque	S.D.
5	F	12	2.67	0.29
	M	14	2.64	0.21
8	F	13	3.52	0.20
	M	15	3.29	0.39
11	F	15	3.98	0.19
	M	16	4.14	0.22
14	F	15	4.52	0.14
	M	14	4.58	0.19

Note: Mean intercepts calculated from each subject's linear regression of log peak torque on velocity.

TABLE C-2

Mean and Standard Deviations of Slope Values
For Boys and Girls of 4 Age Groups

Age	Sex	n	Mean Slopes (10^{-3})	S.D. (10^{-3})
5	F	12	-5.808	1.099
	M	14	-5.195	1.110
8	F	13	-6.055	0.873
	M	15	-6.010	0.873
11	F	15	-5.976	0.681
	M	16	-6.234	0.535
14	F	15	-5.703	0.713
	M	14	-4.979	0.491

Note: Mean slopes calculated from each subject's linear regression of log peak torque on velocity.

TABLE D-1

ANOVA Summary Table for Intercept Values (Log Peak Torque)
Obtained from Boys at Four Ages (n = 59)

Groups	D.F.	Sum of Squares	Mean Square	F Ratio	Significance Level
Between	3	32.18	10.73	155.8	$p < 0.01$
Within	55	3.78	0.07		

TABLE D-2

ANOVA Summary Table for Mean Slope Values
Obtained from Boys at Four Ages (n = 59)

Groups	D.F.	Sum of Squares (10^{-6})	Mean Square (10^{-6})	F Ratio	Significance Level
Between	3	16.60	5.533	8.92	$p < 0.01$
Within	55	34.12	0.620		

TABLE D-3

ANOVA Summary Table for Mean Intercept Values (Log Peak Torque)
Obtained from Girls at Four Ages (n = 55)

Groups	D.F.	Sum of Squares	Mean Square	F Ratio	Significance Level
Between	3	24.03	8.01	190.56	$p < 0.01$
Within	51	2.14	0.04		

TABLE D-4

ANOVA Summary Table for Mean Slope Values
Obtained from Girls at Four Ages (n = 55)

Groups	D.F.	Sum of Squares (10^{-6})	Mean Square (10^{-6})	F Ratio	Significance Level
Between	3	1.07	0.356	0.50	N.S.
Within	51	36.03	0.707		

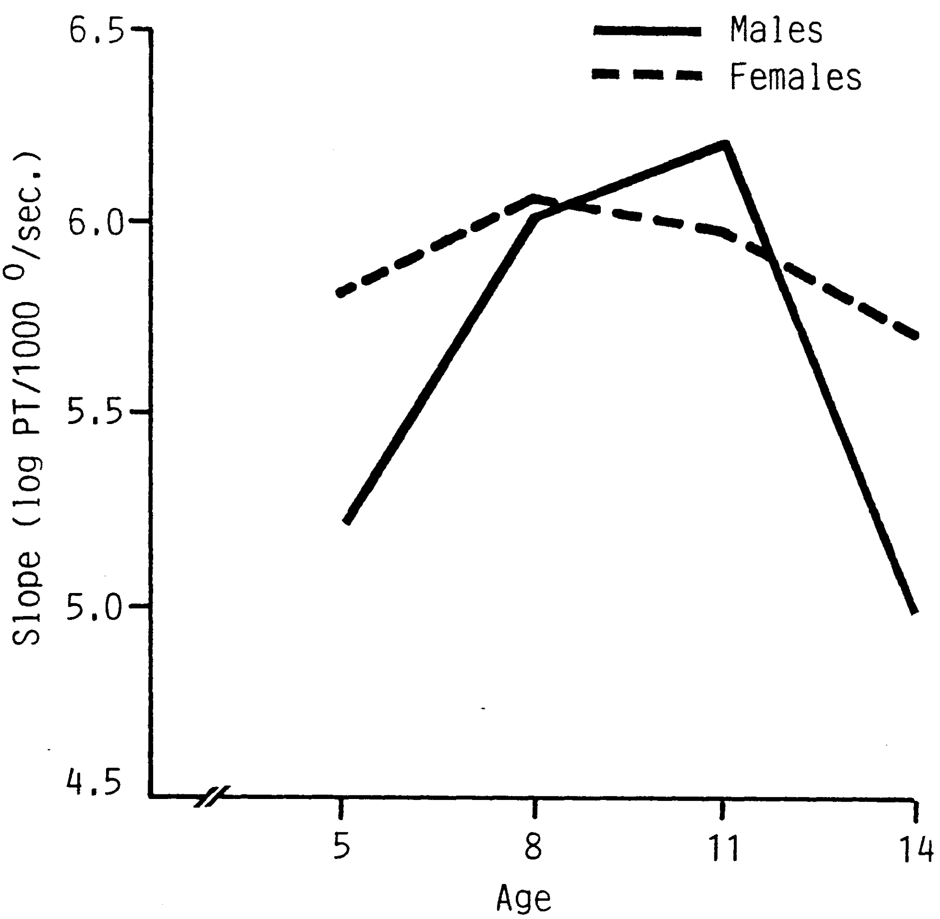


Figure D-1 Mean slope values for males and females at 4 different age groups

Note Mean slopes calculated from each subject is linear regression of Log PT on velocity.

TABLE E-1

Pearson Product-Moment Correlation Coefficients of the Relationship Between Peak Torque and 8 Variables at 4 Velocities (n= 114)

	300°/sec.	210°/sec.	120°/sec.	30°/sec.
Age	0.869	0.889	0.904	0.926
Height	0.908	0.924	0.939	0.934
Weight	0.911	0.931	0.944	0.928
Hip to Ankle Length	0.880	0.898	0.916	0.919
Knee to Ankle Length	0.852	0.867	0.884	0.896
Hip to Knee Length	0.819	0.837	0.856	0.851
Thigh Circumference	0.799	0.822	0.847	0.849
Cybex Lever Length	0.836	0.861	0.879	0.902

Note: All significant at $p < 0.001$

TABLE E-2

Pearson Product-Moment Correlation Coefficients of the Relationship Between Peak Torque and 8 Variables at 4 Velocities

Females Only (n= 55)

	300°/sec.	210°/sec.	120°/sec.	30°/sec.
Age	0.891	0.897	0.915	0.942
Height	0.896	0.906	0.913	0.918
Weight	0.888	0.900	0.922	0.932
Hip to Ankle Length	0.881	0.885	0.891	0.897
Knee to Ankle Length	0.860	0.861	0.863	0.879
Hip to Knee Length	0.803	0.807	0.817	0.813
Thigh Circumference	0.841	0.847	0.867	0.878
Cybex Lever Length	0.817	0.823	0.837	0.861

Note: All significant at $p < 0.001$

TABLE E-3

Pearson Product-Moment Correlation Coefficients of the Relationship Between Peak Torque and 8 Variables at 4 Velocities Males Only (n= 59)

	300°/sec.	210°/sec.	120°/sec.	30°/sec.
Age	0.873	0.903	0.914	0.920
Height	0.919	0.939	0.957	0.946
Weight	0.930	0.956	0.961	0.925
Hip to Ankle Length	0.883	0.909	0.933	0.934
Knee to Ankle Length	0.851	0.874	0.899	0.907
Hip to Knee Length	0.833	0.860	0.884	0.877
Thigh Circumference	0.825	0.857	0.867	0.860
Cybex Lever Length	0.846	0.883	0.906	0.931

Note: All significant at $p < 0.001$

TABLE E-4

Pearson Product-Moment Correlation Coefficient Matrix
Between 8 Variables (n = 114)

	Age	Height	Weight	HAL	KAL	HKL	ThC
Age							
Height	0.942						
Weight	0.904	0.941					
Hip to Ankle Length (HAL)	0.934	0.978	0.909				
Knee to Ankle Length (KAL)	0.910	0.953	0.879	0.952			
Hip to Knee length (HKL)	0.867	0.975	0.867	0.952	0.812		
Thigh Circum- ference (ThC)	0.855	0.889	0.940	0.855	0.841	0.785	
Cybex Lever Length (CBL)	0.901	0.922	0.888	0.942	0.911	0.885	0.811

Note: All significant at $p < 0.001$

TABLE E-5

Stepwise Regression Analysis on Intercepts With 8 Predictor Variables

Females Only (n = 55)

Predicted Variable	t-ratio	r^2
Age	21.64	90.0
Cybex Lever Length	4.94	93.2

TABLE E-6

Stepwise Regression Analysis on Intercepts With 8 Predictor Variables

Males Only (n = 59)

Predicted Variable	t-ratio	r^2
Hip to Ankle Length	24.14	91.2
Age	3.68	93.0
Hip to Knee Length	-2.39	93.6
Cybex Lever Length	2.22	94.2

TABLE E-7

Stepwise Regression Analysis on Intercepts
With 8 Predictor Variables (n=114)

Predicted Variable	t-ratio	r^2
Hip to Ankle Length	29.84	89.0
Age	6.29	91.9
Cybex Lever Length	3.98	93.0
Thigh Circumference	3.05	93.5
Hip to Knee Length	-2.23	93.8

$H_0: \mu_1 = \mu_2$ (uncorrelated data)

Is $n_1 = n_2 = n$? — Yes — $t = \dfrac{\bar{X}_1 - \bar{X}_2}{\sqrt{\dfrac{S_1^2 + S_2^2}{n}}}$ [*df* = 2(*n* - 1)]

No

Is $\sigma_1 = \sigma_2$ tenable? — Yes — $t = \dfrac{\bar{X}_1 - \bar{X}_2}{\sqrt{\dfrac{[(n_1-1)S_1^2 + (n_2 - 1)S_2^2]}{n_1 + n_2 - 2}\left(\dfrac{1}{n_1} + \dfrac{1}{n_2}\right)}}$ [df = n_1+n_2-2]

No

$$t' = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\dfrac{S_1^2}{n_1} + \dfrac{S_2^2}{n_2}}}$$

<u>Welch's Method</u>

$$df = \frac{(S\bar{X}_1^2 + S\bar{X}^2)^2}{\dfrac{(S\bar{X}_1^2)^2}{(n_1 + 1)} + \dfrac{(S\bar{X}_2^2)^2}{(n_2 + 1)}} - 2$$

[Take the nearest whole number and use standard *t* table]

<u>Figure F-1</u> Flowchart for the use of the *t*-test

PILOT STUDY

Statement of Problem and Purpose of Study

G.1.1 Statement of Problem

As indicated in chapter one the purpose of the main study is to investigate the development of children's torque generating capacities in maximum voluntary limb movements at a range of velocities. In order to achieve this broad purpose meaningfully the main study was designed so that answers could be obtained to the following five questions:

1. what was the relationship between the peak torque scores and velocity for the subjects of each age group?
2. what was the effect of age on the peak torque scores at each velocity?
3. to what extent did commonly used parameters of growth, i.e. age and measures of body size, explain the variation in PT scores?
4. were there were any sex differences in (a) peak torque scores? (b) body size measurements?
5. Was it possible to obtain PT scores that were representative of the subjects' maximum voluntary effort?

Central to the main study was the test on the Cybex II to obtain PT scores at a range of angular velocities. However, the research using this device is only in its infancy; this is particularly true of research on children. This lack of information posed problems for the design and method of the present study. For example, it was the intention to obtain PT-velocity relationships for a wide age range of children; however, in previous research, the youngest age tested was seven years (Alexander and Molnar, 1973; Gillian et al., 1989b), and only one of these studies has tested at this age at more than one velocity (Gillian et al., 1989b). Clearly, previous research gave no indication of a feasible age and velocity range which could be used in the main study; a pilot study was required to develop guidelines in this area.

It was also important to construct detailed procedures to ensure maximal efforts. A general framework for the testing of knee extension, for example, is provided by the Cybex manufacturers; general guidelines are given for the adjustment of equipment for knee extension, the positioning of the subject, and the procedures for recording torque. However, it is not known whether these guidelines can be applied for both adults and children; in other words, can young subjects be fitted on to the machine to achieve the standardised testing postion outlined in the guidelines of the manufacturers?

In addition, although there are general guidelines, there is less guidance from manufacturers, and less research on specific aspects of procedure, such as the number of trials and retests required. Indeed, the number of trials and retests varies from study to study. For example, Alexander and Molnar (1973) used the average of three trials to obtain maximum PT scores in children, whereas Thorstensson (1976), measuring the PT at a range of velocities in adults used the best PT score out of six trials. Whether three trials or six trials is better has remained unclear. It is, therefore, a matter of importance to use a number of trials and retests appropriate to obtaining subjects' best efforts.

It could be concluded that before using the Cybex to test children at a range of velocites and in a wide age range of children, more detailed information has to be obtained on testing children on the Cybex. The pilot study was designed to provide this more detailed information.

G.1.2 purpose

The purpose of the pilot study was to obtain information to provide the basis for the design and method of the main study, which was attempting to measure the PT scores of children at a range of velocities. More specifically, information was required for the following:

1. the testing procedures,
2. the number of trials and retests required,
2. a suitable age and velocity range to obtain the PT-velocity relationship in children.

Methods

G.2.1 Subjects

Ten subjects were involved in the pilot study. The age range was between 5 and 12 years and included both boys and girls. The number of children, in their respective age and sex groups are listed in Table G-1.

The children selected were users of the Department of Physical Education and Recreation at Glasgow University. The test was explained to parents, and their consent was obtained before the child was tested. The tests were carried out in the Department of Physical Education and Recreation at Glasgow University.

G.2.2 Equipment

To contol limb velocity and to measure the torque produced in maximal efforts in knee extension the equipment used was Cybex II Isokinetic Dynamometer. This equipment was also used in the main study and is described in chapter three (3.1.3) of the main study.

TABLE G-1

Age and Sex of Subjects (n = 10)

Group	Subject Number									
	1	2	3	4	5	6	7	8	9	10
Sex	F	F	F	F	F	M	M	M	M	M
Age	7	10	12	5	6	8	9	11	12	12

G.2.2 Treatment of Subjects

The pilot study measured the PT produced by children, boys and girls aged 5 to 12 years in maximal voluntary left leg knee extension performed at a range of velocities using a Cybex II; some children were tested at velocities 300, 240, 180, 120 and 60 deg/sec and some at velocities 300, 210, 120, and 30 deg/sec. The children were tested three times on three separate weeks. More specifically this test involved the followng steps:

1. Subjects were seated, positioned on the Cybex for knee extension of the left leg.

2. Measurements were made of this position.

3. At each velocity subjects performed 3 submaximal familiarisation trials, followed by three maximum efforts which were recorded.

   a) 3 subjects (subject numbers 1 to 3) were tested at velocities 300, 210, 120, and 30 deg/sec.

   b) 7 subjects (subject numbers 4 to 10) were tested at velocities 300, 240, 180, 120, and 60 deg/sec.

4. Every subject, apart from number 10, did the test a total of three times, at weekly intervals. For the purposes of this test, one week was interpreted as not less han 4 days and not greater than 10 days. Subject number 10 was only tested twice because of failure to arrive at appointments made within the time limits allowed.

G.2.4 Procedures for Testing

The procedures used are similar to those described in the main study, including the testing position of the subject, the measurement of the testing position, the protocol for warm-up, and the measurement of PT. Changes made to procedures as a result of the pilot study have been referred to in the procedures of the main study.

Results and Conclusions

The purpose of the pilot study was to develop a method of obtaining PT scores for children. This invloved finding appropriate procedures, numbers of trials and retests, and suitable age and velocity ranges.

The information obtained from the pilot study for each of these aspects will now be reported. It should be noted that the purpose of this pilot study was not to determine a statistically reliable method for measuring PT at a range of velocities, but to develop a workable method to be used in the main study. The reliability of this method will be investigated in the main study.

G.3.1 Procedures

The procedures of the pilot study were based on the guidelines from the Cybex manufacturers, on research studies, and on personal experience of testing adults on the Cybex. In general the procedures of the pilot study were found to work; thus, the procedures are almost exactly repeated in the main study. More specifically, the testing position of the subject, the measurement of the testing position, and the protocol for warm-up and measurement of PT are adopted in the main study. The major changes made as a result of the pilot study involved the testing position for younger subjects. These changes will be described in chapter three of the main study.

The pilot study also gave important information on how these procedures should be presented to children. First of all, it was felt that children, unlike adults, needed a less formal and more appealing form of test. This was best achieved by constantly involving the children in exaggerated role playing to hold their attention. Secondly, the shorter attention span of children also meant that they were less tolerant of inactive periods. It was therefore important, in the interests of keeping their attention, to minimise the amount of time spent in obtaining the standardised testing position and associated measurements; the efficiency of obtaining and measuring this position was improved as a result of the pilot study.

Finally, it was felt that the instructions to the subjects had to be simplified, particularly for the younger ones. For example, to assume the testing position for each trial, older children, after one demonstration, were able to achieve this position without help, whereas younger children required the help of the tester.

G.3.2 Trials and Retests

To measure PT in knee extension it was possible, from previous research and from the manufacturesrs' guidelines, to obtain specific guidelines for the correct procedures for testing. However, there was less information on the most appropriate number of trials and repeated tests for obtaining representative measures of maximum PT. The purpose of the pilot study was to provide guidelines on the appropriate number of trials and retests for providing a representative score of best efforts.

It should be noted that it was decided at the outset of the pilot study that the score used to represent the maximum value of PT would be based on the best score rather than the average of all the trials. Jones (1949) justified the use of the best rather than the average values, in strength testing for children, on the basis that in these tests subjects cannot achieve above maximum scores. Furthermore, Jones (1949) argues that, given the variability of human performance, particularly in children, it is not practical to expect repeated maximal efforts; submaximal efforts are to be expected. To calculate an average value, where one of the trials was performed submaximally, would give unrepresentative scores of maximum effort.

It was therefore decided that the appropriate number of trials and retests necessary to ensure that subjects produced maximal PT scores would be evaluated by investigating the occurrence of best PT scores in the trials and retests of the pilot study.

G.3.2(a) trials

In this study three trials were given, at each velocity, on each of the three testing weeks. The occurrence of best PT scores in the trials was examined. Figure G-1 shows the percentage of times that maximal PT score was produced in trials 1, 2, and 3, for each testing week separately, along with the total of all three weeks.

It can be seen that in percentage terms, whether the results were examined for each week separately or for the total of the three weeks, the best PT scores were obtained in trials 1, 2, and 3 in nearly equal proportions.

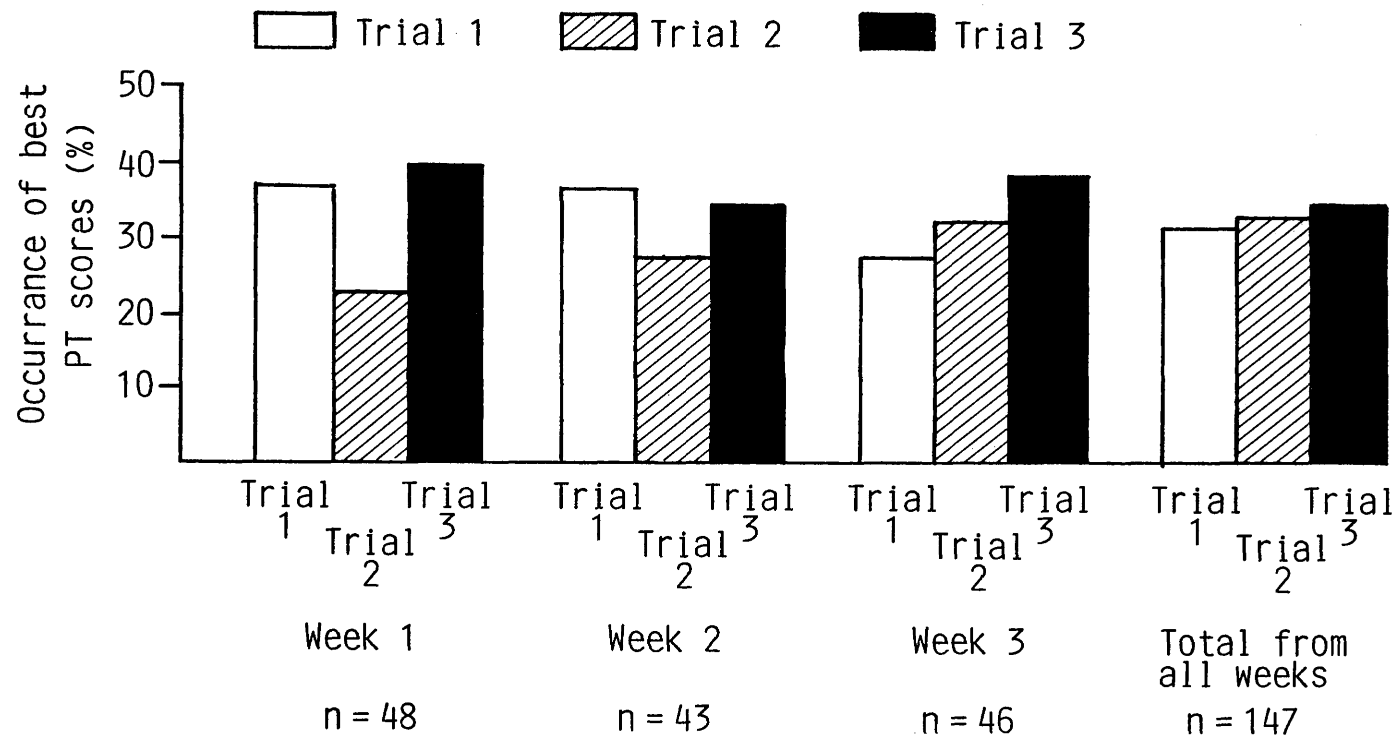


Figure G-1 Percentage occurrence of best PT scores for trials 1 to 3.

The occurrence of PT in trials was important for determining whether three trials were enough to obtain maximal PT scores. For example, if the lowest percentage of best PT scores had occurred in week 1 and the greatest in week 3, it would have indicated that the subjects' PT scores increased as the number of trials given increased. More than three trials would therefore be necessary to ensure that best PT scores would be achieved. Indeed, this result and conclusion were produced in a study by Johnston and Siegel (1978), who examined the variability of PT scores over ten trials. A linear trend was shown in the PT scores of the first three trials. Johnston and Seigl (1978) suggested that this was a learning effect and concluded that in isokinetic testing more than three trials should be given. It should be noted, however, that other studies have not found this trend in the first three trials of isokinetic testing (Thorstensson, 1976; Molnar and Alexander, 1979).

If the results of this study are examined more closely it can be seen that in the total percentages of the three weeks there is a very slight trend towards best PT scores increasing as the trial number increases; in trial 1 the percentage is 32%, in trial 2 the percentage is 33% and in trial 3 the percentage is 35%. Although this trend is slight it suggests that more than three trials should be used for testing in the main study. Given that this was only a slight trend, and given the need to keep the test as short as possible for the children, four trials would be recommmended for the main study.

G.3.2(c) retests

In the pilot study the subjects were tested three times, each test separated by one week. To determine the appropriate number of tests required to obtain scores representative of best effort, the best PT scores (highest score of the three trials), for each subject at each velocity, were compared across the three testing weeks to find the week in which the highest value was obtained. The best PT scores for each subject at each velocity are shown in Tables G-2 and G-3. Using this data the occurrence of these highest scores for each testing week was obtained (the data for subject 10 was not included, since this subject only completed two tests).

It was found that 62% of the highest PT scores were produced in week 1, 36% in week 2, and 2% in week 3.

The results indicate that a very small proportion of highest PT scores were produced in week 3. Indeed, the 2% value was the result of only one highest PT score being produced in week 3: subject 9 at velocity 60 deg/sec (see Table G-2). Furthermore, there was no more than a 1 ft.lb difference between this highest score, produced in week 3, and the second highest score, produced in week 2: 33 ft.lbs in week 3, compared with 32 ft.lbs in week 2.

The reason for the very small proportion of best PT scores being produced in week 3, could be that by the third test the subjects were not motivated enough to produce their best efforts. Indeed, it was noted during the third test that many of the subjects appeared to be less motivated, and less interested in the test. It could be concluded that the third test was of little value in obtaining best PT scores.

The results relating to the occurrence of best PT scores in week 1 and week 2, indicated that the majority of best PT scores was obtained in week 1, approximately double the percentage of best PT scores obtained in week 2. There did not appear to be any systematic trends in these results which would indicate that the better performance in week 1 or week 2 was related to age or velocity. Indeed, whether better PT scores were produced in week 1 or week 2 varied for any subject at any velocity.

It could be concluded, therefore, that although PT was higher in the first week a greater proportion of the time, some subjects at some velocities needed a second week to produce their best score. It would be recommended for the main study that two tests be used to find subjects' best PT score at a range of velocities.

TABLE G-2

Best Peak Torque Scores for Each Velocity at Each Testing Week (n = 3)

Velocity (deg/sec)	Testing Week	Subject Number 1	2	3
300	1	4.1	7.8	10.0
	2	4.2	8.0	9.8
	3	3.6	6.3	5.5
210	1	8.0	13.0	18.6
	2	7.3	14.8	16.5
	3	7.0	11.9	12.0
120	1	14.3	26.7	28.6
	2	13.8	26.6	24.5
	3	10.1	19.8	17.4
30	1	33.6	52.2	56.8
	2	29.4	53.4	47.4
	3	27.3	41.4	40.8

TABLE G-3

Best Peak Torque Scores for Each Velocity at Each Testing Week (n = 6)

Velocity (deg/sec)	Testing Week	Subject Number 4	5	6	7	8	9	10
	1	2.0	3.8	2.5	6.4	7.6	10.4	11.6
300	2	2.8	3.2	3.0	6.2	7.5	10.8	12.6
	3	2.5	2.0	2.7	5.4	7.0	10.0	
	1	3.5	4.8	3.8	9.3	12.1	14.8	13.0
240	2	3.3	4.2	3.9	8.2	12.0	14.4	15.0
	3	3.1	2.8	3.6	7.9	11.2	13.7	
	1	4.5	6.5	7.0	12.1	19.5	18.6	20.9
180	2	4.7	5.6	6.1	12.0	18.5	19.2	20.1
	3	3.8	5.4	5.3	10.8	13.7	18.4	
	1	5.8	10.3	10.2	17.3	27.8	23.6	30.4
120	2	6.5	7.3	9.1	19.0	28.0	26.4	28.2
	3	5.9	7.0	8.9	15.0	23.8	23.0	
	1	8.8	16.1	18.2	32.8	43.8	22.6	43.2
60	2	10.0	13.3	16.5	27.0	40.0	32.0	39.6
	3	9.9	10.1	15.0	23.3	32.4	33.0	

G.3.3 Age and Velocity Range to Obtain PT-V Relationship

In this study PT scores were obtained for children aged 5 to 12 years; some children were tested at velocities 300, 240, 180, 120, and 60 deg/sec and some at velocities 300, 210, 120, and 30 deg/sec. The purpose of this section is to evaluate whether it was feasible to obtain PT-V relationships for a wide age range of children, using a wide velocity range. This was evaluated from the results of the pilot study by constructing PT-V plots for each subject; the highest PT score out of all the trials of the three testing weeks was used to represent subjects' PT at each velocity. Three of these plots are shown in Figure G-2; this figure gives examples of the PT-V relationships constructed from the two different velocity ranges as well as from the oldest and youngest subject tested.

These results suggest that all subjects show a similar pattern in the relationship between PT and velocity, irrespective of age or velocity range. These patterns are also consistent with relationships in other studies with adult subjects (Thorstensson, 1976; Perrine and Edgerton, 1978; Gregor et al., 1979) and indicate that it is feasible to obtain PT-velocity relationships for the age and velocity ranges used in the pilot study.

Two conclusions could be drawn from these results concerning the age and velocity range used to obtain PT-velocity relationships:

1. Consistent PT-V relationships were obtained for all subjects in the pilot study, ranging in age from 5 to 12 years. It could be concluded that it would be feasible to obtain PT-V relationships in children as young as five in future testing.

2. It was found that using four velocities, sampled from a velocity range of 30 deg/sec to 300 deg/sec, gave the same result as five velocites, sampled using a narrower velocity range of 60 deg/sec to 300 deg/sec. It could therefore be concluded that using the four velocity range would be more appropriate for future testing for two reasons: firstly, the PT-V relationship would be obtained from a wider velocity range; and, secondly, testing at fewer velocities would reduce the length of the test.

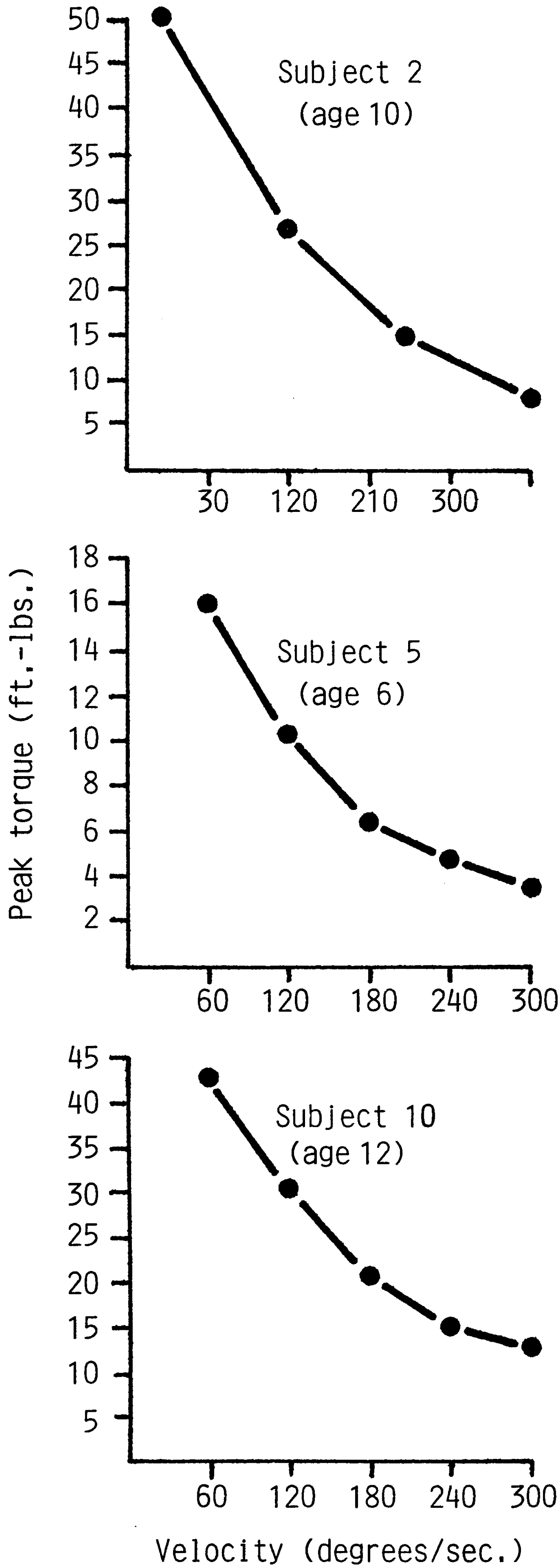


Figure G 2 Relationship between PT and velocity

G.3.4 Conclusions

The purpose of the pilot study was to obtain information which would help both in the design and the method for the main study, which was attempting to measure the PT scores of children at a range of velocities. Specific information was required for the following:

1. the testing procedures,
2. the number of trials and retests required,
2. the appropriate age and velocity range for obtaining PT-V relationships in children.

The following recommendations resulted from the pilot study:

1. The procedures of the pilot study could be used in the main study. The major changes required were to do with how the procedures were presented to the subjects.
2. In order to obtain scores representing subjects' best effort, each subject should be given four trials at each velocity and should be given two separate tests, one week apart.
3. In order to obtain PT-V relationships in a wide age range of subjects, using a wide velocity range, it is recommended that children as young as age five be tested, and that 300, 210, 120, and 30 deg/sec should be the velocities sampled from the Cybex's range.