Reciprocal Muscle Group and Functional Dynamic Stability Ratios of the Hamstrings and Quadriceps Muscle Groups During Maximal Isokinetic Concentric and Eccentric Contractions

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Declaration

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and has not previously, in its entirety or partially, been submitted at any university for the purpose of obtaining a degree.

10/02/2000
Date

Abstract

The concentric hamstring quadriceps reciprocal muscle group ratio has been the focus of a very large part of studies involving isokinetic dynamometry. The main aim of this study was to reevaluate the functional relevance of this ratio and explore a strength ratio between maximal eccentric strength of the hamstrings and the concentric strength of the quadriceps muscle groups, referred to as the functional dynamic stability ratio. At the same time the inter-relationship between the eccentric and concentric strength of the same muscle group (critical deficit ratio) was investigated.

As background a detailed discussion of research concerning the conventional hamstring quadriceps ratio and the biomechanics of the knee joint and musculature was presented. The importance of the eccentric strength of the hamstring muscle group regarding functional muscle action and anterior cruciate ligament stability was also discussed. The functional dynamic stability ratio was hypothesised to be a 1:1 ratio due to the simultaneous concentric quadriceps and eccentric hamstring muscle contraction during walking, jogging and running activities.

The bilateral concentric and eccentric peak torque of the hamstrings and quadriceps muscle groups of 45 (N=45) rugby players were evaluated using a Kin-Com© isokinetic dynamometer. The calculated average concentric reciprocal muscle group ratio was (0.64, SD=0.15) and eccentrically (0.61, SD=0.15). The average functional dynamic stability ratio resulted to 0.77 (SD= 0.14) for the left leg and 0.79 (SD= 0.16) for the right leg. Critical deficit ratios were 1.26 (SD=0.26) for the right hamstring, 1.33 (SD=0.210 right quadriceps, 1.28 (SD=0.21) lefts hamstring and 1.29 (SD=0.17) for the left quadriceps muscle groups.

Values obtained were in accordance to that of available research. The functional dynamic stability ratio was found to be striving towards a 1:1 ratio to achieve optimal knee joint and hamstring integrity.

Opsomming

Die groter deel van studies in die veld van isokinetiese dinamometrie, was meesal oor die konsentriese hamstrings quadriceps spierkrag verhouding. Menslike beweging tydens hardloop aktiwiteite en die gepaartgaande spierkontraksies toon egter dat die hamstring eksentries en die quadriceps konsentries tergelyke tyd saamtrek. Die doel van hierdie studie was dus om die funksionaliteit van die tradisionele hamstring quadriceps kragverhouding te re-evalueer en die moontlikheid van 'n funksionele dinamiese stabiliteits verhouding tussen die eksentries krag van die hamstrings en konsentriese krag van die quadriceps te ondersoek. Ook is daar ondersoek ingestel op die verhouding tussen die eksentriese en konsentriese krag van dieselfde spiergroep.

As agtergrond is die konvensionele hamstring quadriceps verhouding ondersoek in die lig van kniegewrig biomeganika tydens stap, draf en hardloop aktiwiteite. Die noodsaaklikheid van eksentriese hamstring spierkrag vir funksionele spierkontraksie en anterior kruisligament stabiliteit was ook ondersoek en bespreek. Die gevolglike hipotese was dat die maksimale eksentriese krag van die hamstrings en die konsentriese krag van die quadriceps strewe na 'n 1:1 verhouding vir optimal knie gewrig en spier funksie.

Die maksimale konsentriese en eksentriese krag (hamstring en quadriceps spiergroepe) van 45 (N=45) rugbyspelers is m.b.v. 'n Kin-Com© isokinetiese dinamometer getoets. Die konvensionele hamstring quadriceps gemiddelde konsentriese verhouding was (0.64, SA=0.15) en eksentries (0.61, SA=0.15). Die gemiddelde funsionele dinamiese stabiliteits verhouding wat bereken is, was 0.77 (SA= 0.14) vir die linker been en 0.79 (SD= 0.16) vir die regter.

Al die verhoudings wat ondersoek en bereken is, het ooreengestem met beskikbare literatuur. Die funksionele dinamiese stabiliteits verhouding het inderdaad 'n neiging getoon om te strewe na 'n 1:1 verhouding vir optimale knie funksie.

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Chapter One

Introduction

The concept of isokinetic evaluation has been studied with growing interest since its introduction by Hislop and Perrine in 1967. Quantifiable isokinetic evaluation of muscle strength, muscle endurance and joint range of motion have become an invaluable tool in performance assessment and rehabilitation.

Frequently used isokinetic muscle performance parameters include peak torque, average torque, work, power and reciprocal muscle group ratios (Aagard *et al*, 1995; Baltzopoulos & Brodie, 1989; Chan & Maffulli, 1996). The reciprocal muscle group ratio has, according to Dvir (1995), been the aspect of isokinetics most frequently researched, albeit a controversial parameter in isokinetics. This parameter compares ipsi-lateral agonist-antagonist muscle strengths while other popular parameters focus on bilateral muscle strength comparisons. The latter have been restricted to the study of concentric muscle contractions. In the early 1990's technological advancements in isokinetic dynamometry enabled pioneers to assess eccentric muscle strength.

To generate tension in a muscle, the muscle may shorten, lengthen or remain constant in length (Wilkie, 1950). If the fibres remain the same lengths, the contraction is referred to as an isometric contraction. When the fibres shorten or "draw together", it is called a concentric contraction. Concentric contractions of the muscles involved in a particular joint cause the joint angle to decrease with associated increase in limb speed. An eccentric muscle contraction can be defined as a contraction type characterized by the lengthening of the muscle fibres whilst generating force even higher than that of concentric contractions (Albert, 1995; Perrine, 1993). Albert (1995) defines eccentric muscle contraction as muscle force development that involves external force application with a tension increase during physical lengthening of the musculo-tendinous unit. Eccentric muscle contraction is involved in the deceleration of the limb toward the terminal joint angle. The eccentric contraction strength of the muscle is therefore crucial in maintaining joint stability (Albert, 1995).

Eccentric muscle contraction has been studied in sports that include running and throwing activities (Kellis & Baltzopoulos, 1995). The hamstring muscle group has been the focus of research for many years and two significant reasons for this are:

i. The hamstring is one of the most often injured muscle groups (Jönhagen *et al*, 1994; Heiser *et al*, 1984; Burkett, 1970; Worrell, 1994; Worrell & Perrine, 1992; Upton *et al*, 1996; Smith, 1997).
ii. Much evidence exists to highlight the importance of the hamstring muscle group in its contribution to knee stability in anterior cruciate ligament damaged or deficient knees (More *et al*, 1993; Baratta *et al*, 1988; O'Connor, 1993; Draganich *et al*, 1989; Osternig *et al*, 1996).

Despite already proven causative factors in muscle strains, sportsmen across the world are still pestered by hamstring strains (Worrell, 1994; Upton *et al*, 1996). Insufficient eccentric strength has been shown to be a causative factor but very little functional quantitative information is available to aid rehabilitation specialists in the treatment of injured athletes (Aagard *et al*, 1995).

The purpose of this study was to evaluate the maximal concentric and eccentric torques of the quadriceps and hamstring muscle groups of rugby players engaging in sprinting and agility activities. An isokinetic dynamometer was used to investigate the functional and dynamic stability ratio between the concentric strength of the quadriceps group and the eccentric strength of the hamstring group. Numerous studies investigating the concentric hamstring-quadriceps ratio have been published and used as basic guidelines for rehabilitation specialists. The majority of these studies have concluded that the hamstring muscle group's strength is approximately 60% that of the quadriceps, also referred to as a 2/3, 0.6 or 60/40 ratio (Kannus & Kaplan, 1991; Campbell & Glenn, 1982; Morris *et al*, 1983; Westing & Seger, 1989; Ghena *et al*, 1991; Highgenboten *et al*, 1989). Little research has been conducted investigating the ratio between the eccentric strength of the hamstring and concentric strength of the quadriceps muscle groups. The studies of Aagard *et al* (1996) and Osternig *et al* (1996) both came to the conclusion that this functional dynamic stability ratio is more valuable to a therapist and that in conditioning or rehabilitation, one should strive for a 1:1 strength ratio. This would mean that the eccentric hamstring peak torque must be equal to that of the concentric quadriceps peak torque, thus contributing to higher joint and muscle integrity.

Both in theory and practice, this ratio might supply the rehabilitation specialist with more functional information than the previous, commonly used reciprocal muscle groups ratio that compares the concentric strength of the hamstrings with the concentric strength of the quadriceps.

Statement of the problem

The traditional concentric hamstring quadriceps reciprocal muscle group ratio has been used in practice as an important parameter to assess knee muscle function and strength relationships. At present research has shown that there is no optimal value for this ratio and that the healthy/uninvolved limb should be used as the control (Kannus, 1994; Kannus, 1994; Read & Bellamy, 1990).

Peak eccentric co-contraction of the hamstrings occurs during the last 30-25° of knee extension and assists the anterior cruciate ligament in the dynamic stabilisation of the tibia (Baratta *et al*, 1988; O'Connor, 1993; Draganich *et al*, 1989). The hamstring muscle group is also a very important hip extensor (concentrically). If the eccentric strength of the hamstring is not sufficient in relation to the concentric strength of the quadriceps (responsible for knee extension), this may contribute to the cause of hamstring muscle and/or anterior cruciate ligament injury. Using the traditional hamstring quadriceps ratio to determine discharge from rehabilitation could result in premature termination of rehabilitation and the risk of re-injury is more probable.

Hypothesis

Two research questions guided this inquiry into the functional strength-measurement of the hamstring and quadriceps muscle groups as an approach to functional rehabilitation and early identification of possible hamstring and/or anterior cruciate ligament (ACL) injury:

1. The functionally significant muscle strength ratio between the concentric strength of the quadriceps and eccentric strength of the hamstrings.

2. The possible importance of the eccentric force that can be generated by the hamstring muscle group in the prevention of hamstring and ACL injury?

The research into the above mentioned questions will guide the researcher to evaluate the following hypothesis:

Hypothesis 1:

For optimal joint and muscle integrity, the concentric strength of the quadriceps and eccentric strength of the hamstring should be equal. This means a ratio of 1:1. Mechanically, this correlates with Newton's 3rd law of equal but opposite action and reaction (Norkin & Levangie, 1992). For a powerful knee extension (concentric quadriceps) action to be terminated, an equal but opposite action (knee flexion) is required from the hamstrings.

Hypothesis 2:

If the calculated ratio falls beyond a significant range, it may identify possible predisposition to injury of either the hamstring muscle group or anterior cruciate ligament, or both.

Hypothesis 3:

The findings of this study concerning this particular muscle strength ratio can be used in the evaluation of integrity of other articulations in the human body.

This research project will evaluate knee flexion and extension strength of active sportsmen that have been injury free in the lower limbs for the past 12 months. The results obtained from this study may add to information and parameters that can be used during isokinetic testing and exercise. Besides this particular ratio, the study will also evaluate the ratios between the concentric and eccentric strength of the same muscle groups to ensure optimal functioning.

Significance of the Study

Sport specific conditioning and injury rehabilitation has long been separated due to the perception that "injured" and "uninjured" athletes train differently (Tippett & Voight, 1995). Both conditioning and rehabilitation specialists make use of the scientific principles of training, including progressive overload (volume, intensity, and frequency), training specificity, individuality, genetic ceiling and detraining (Hawley & Burke, 1998). The study aims to contribute to the "functional" school of thought currently involved in rehabilitation and sport specific training. It proposes that when training muscular strength, the movement rather than the muscle is trained and therefore training, and rehabilitation, must always simulate what is required from the actual demands of the particular sport or activity (Tippett & Voight, 1995; Brotzman, 1995).

One of the most important objectives of any rehabilitation programme is to progress to full recovery and peak fitness to continue top performance (Brotzman, 1996; Bruker & Khan, 1995; Grimby, 1985). To achieve this, specific, valid, objective and reliable assessments must be performed regularly to determine the progression and supply the injured party with as much as possible feedback (Gross *et al*, 1996; Grimby, 1985). One of the most reliable and accurate devices available to fortunate institutions is an isokinetic dynamometer. This piece of machinery, besides the variety of other functions available with modern software, was designed to objectively measure muscle strength (Hislop & Perrine, 1967; Moffroid *et al*, 1969; Colliander & Tesch, 1989)

The most commonly used performance parameter produced by an isokinetic muscle strength test has been peak torque. It is widely used to determine bi-lateral strength differences and various muscle strength ratios or relationships (Kannus, 1994; Osternig, 1986; Baltzoploulos & Brodie, 1989). Calculating the concentric strength of the hamstring group as a percentage of the concentric strength of the quadriceps group produces a ratio that describes the strength relation between the hamstrings and quadriceps, called the hamstring quadriceps reciprocal muscle group ratio (HQR) (Perrine, 1993). The significance of this ratio is to evaluate the optimal synergistic strength of the muscle groups responsible for knee flexion and extension.

Electromyography of knee flexion and extension during walking, running and sprinting has shown that concentric contraction of the hamstring and quadriceps muscle group never happen simultaneously (Mann & Hagy, 1980; Montgomery *et al*, 1994; Mann *et al*, 1986; Mann, 1981). The angle at which peak flexion torque is generated is not the same angle at which peak extension occurs. Bearing this in mind, the validity of the traditional HQR which compares these two functionally unrelated variables becomes a questionable factor (Kannus & Kaplan, 1991; Aagard *et al*, 1995; Osternig *et al*, 1996).

Fortunately, due to technological advancements, isokinetic devices have become able to measure eccentric muscle contractions and this has opened a new door to researchers. Muscle strength ratios remained under the spotlight with Bennet & Stauber (1986) identifying the optimal strength ratio between concentric and eccentric strength of the same muscle group, called the critical deficit ratio.

Knee flexion is made possible by the contraction of mainly the hamstring muscle group whilst simultaneously the quadriceps muscle relax at first and close to terminal flexion contract eccentrically to decelerate the movement. The opposite is present during knee extension. The two muscle groups thus contract at the same time, but using different contraction types (Perrine, 1993).

This study mainly focused on the strength relationships between the maximal concentric strength of the quadriceps and maximal eccentric contraction strength of the hamstrings in healthy athletes. This ratio will be referred to as the *functional dynamic stability ratio* and may hold more specific and functional value to rehabilitation and conditioning specialists

Limitations

The following limitations must be acknowledged when considering the results of this study:

1. Isokinetic devices evaluate knee flexion and extension in an open kinetic chain position. Human movement during running consists of closed kinetic chain movements and the testing device can therefore be considered by many as a non-functional testing device.

2. The results of an isokinetic test are not the final test result that would determine the discharge of an injured athlete to continue full participation in his or her sport. Isokinetic test results may determine the start of functional field rehabilitation and the increased involvement of the strength and conditioning specialist with the rehabilitation specialist.

3. The subjects in the study were all men participating in rugby. The results and findings are therefore limited to this particular population group.

4. All subjects were in their pre-season training phase and optimal muscle strength gain was in progress. It may therefore be assumed that the values attained are not the optimal strength of the subjects.

5. Evaluation was performed at one velocity only. Actual human movement occurs at much higher velocities. The particular testing velocity was selected due to safety regulations.

Definitions

Specific terminology has been used in this study according to the following definitions:

Reciprocal muscle group strength ratio

The strength relationship of two muscle groups (agonist and antagonist) is known as the reciprocal muscle group ratio (Perrine, 1993; Dvir, 1995; Kannus, 1994; Osternig, 1986; Sapega, 1990). Quantified, this ratio is expressed as the weaker muscle group strength as a percentage of the stronger muscle group's strength, thus dividing the stronger by the weaker and multiplying it by 100 for a percentage value. For example, if the peak torque of the hamstrings at 60°/sec is measured to be 120 Nm and the quadriceps peak torque in the same test is 220Nm, the HQR will be 0.55 (55%), expressed as hamstring strength 55% that of the quadriceps strength. Traditionally this ratio could be expressed as a 65/35 (norm = 60/40) ratio. To arrive at this value 120Nm is added to 220Nm, which equals 340Nm. This could be interpreted as the "total" leg strength. The percentage each muscle group contributes to this value is then calculated. The 65/35 effectively then means that the hamstring are 5% weaker than the norm and the quadriceps 5% stronger than the norm.

Critical deficit ratio

Each muscle or muscle group in the human body has the ability and function to contract concentrically and eccentrically. This dual function is to ensure that each muscle or muscle group can both accelerate and decelerate the particular limbs it attaches to. The critical deficit ratio refers to the strength relationship between the maximal concentric and maximal eccentric torque of the same muscle group. It is generally accepted that eccentric strength is stronger than concentric strength. Particular to this study, research has shown that the eccentric strength of the hamstrings and quadriceps are approximately 30-40% stronger than the concentric strength (Albert, 1995; Bennett & Stauber, 1986).

Functional dynamic stability ratio

This term defines the peak torque ratio between the maximal eccentric hamstring strength and the maximal concentric quadriceps strength of the same leg. It is calculated by dividing the eccentric hamstring peak torque by the concentric quadriceps peak torque (Aagard *et al*, 1995).

Chapter Two

Review of Literature

Introduction

During the nineteenth century, physicians assessed muscular performance by means of crude manual muscle testing (MMT) and observing gait, posture and active range of motion (ROM). Although clinically useful in some conditions, MMT not only demanded experience but also lacked sensitivity to detect minor yet significant losses in strength. Also lacking was the reproducibility of tests. This resulted in a standard being restricted to the individual clinician's ability and expertise in these procedures (Sapega, 1990).

During the first half of the twentieth century the muscular dysfunction caused by the devastating effects of the poliomyelitis virus forced physicians, clinicians in physical medicine and rehabilitation, orthopaedic specialists and neurologists to develop better methods for assessment of muscular performance (Sapega, 1990). Pioneers in muscle strength testing research such as Lowman (1927), Sapega (1990), Schmier (1945) and Newman (1949) developed semi-quantitative methods of grading MMT's to quantitative testing devices. One of the methods was the static dynamometer. Its biggest shortcoming was the lack of information it provided concerning the dynamic qualities of muscle action (Chan & Maffulli, 1996).

The current demand for detailed medical documentation, increased patient expectation and development of sports medicine and rehabilitation created a bigger demand for more sophisticated means of quantification, particularly of dynamic muscular strength.

Indications for muscle strength testing

The presence and extent of muscular dysfunction in patients with neuromuscular disease or those that have sustained trauma to the spine or extremities are the main indications for muscle strength testing (Sapega, 1990). Until 30 years ago, bilateral strength assessments were most often performed with the use of MMT.

More recent indications include assessment of athletic or work related injury and disability, collection of baseline data for monitoring strength increases during rehabilitation and diagnostic information for many clinical problems in orthopaedic practice. Furthermore, the field of neuromuscular rehabilitation, athletic performance and injury prevention in the research laboratory and private practice, requires objective measurement and documentation of muscle testing (Gleeson & Mercer, 1996).

Many common musculo-skeletal injuries are the result of strength deficits and/or strength imbalances (Burkett, 1970; Bennet & Stauber, 1986; Yamamoto, 1993; Liemohn, 1978; Li *et al*, 1996). Orchard *et al* (1997) has shown that detecting muscle strength imbalances during pre-season evaluation reduced the amount of injuries to the lower limbs during the competitive season. With large amounts of money that are part of the professional sports world and the pressure surrounding rehabilitation off-time, the possibility that injury can be prevented holds promise.

Terminology

The force output of a muscle as well as the torque generated at the joint is a function of the tension that contracting muscle can develop (Hislop & Perrine, 1967). This is the parameter most often referred to as muscular strength. Each muscle or muscle group can however generate maximal force under different conditions and these conditions are determined by the method of measurement.

The type of muscular contraction has been shown to limit the amount of resistance that the muscle can overcome. The word contract literally means, "to draw together" or shorten. This causes some confusion with understanding the nature of muscular tension development. What science refers to as muscular contraction, occurs whenever the muscle fibres within the muscle generate tension, a situation that may exist when the muscle is shortened, remaining the same length or lengthened. The measurement can thus make use of isometric, concentric and eccentric contractions and the two dynamic actions can be performed through a wide spectrum of angular velocities (Komi, 1992; Gleeson & Mercer, 1996).

According to Sapega (1990) the classification of the different modes of muscular contraction are by means of the nature of the load applied or the direction and velocity of the change in length of the muscle, or both. Isometric, concentric and eccentric muscle contraction is therefor by definition the only muscle contraction possible *in vivo*. Isotonic muscle contraction does not, contrary to the belief, occur during any known form of clinical testing or exercise (Sapega, 1990; Albert, 1995). This is due to the fact that the internal muscular forces needed to move the external load of resistance, change dramatically as the mechanical advantage of the skeletal leverage system changes through the range of motion of the joint. The term *isotonic* can therefore rightfully be used to describe the resistance used for a particular muscle contraction (i.e. weight training), but not as a description of the muscular contraction.

An isometric contraction refers to a muscular contraction at a fixed velocity of 0°/sec applied to a fixed immovable resistance. This contraction can be performed at any angle of the possible joint range of motion (Sapega, 1990; Komi 1992; Luttgens *et al*, 1992).

During an eccentric contraction the force developed by the muscle is overcome by an opposing force such that the muscle merely provides active dynamic resistance as the opposing force stretches it to a more lengthened position (deceleration) (Kellis & Baltzopoulos, 1995). This inevitably means that without external force application eccentric contraction is impossible. On the other hand concentric muscle contraction involves, regardless of the specific loading characteristics, the shortening of the muscle (acceleration) (Sapega, 1990; Wilkie, 1950; Luttgens *et al* 1992; Komi, 1992).

An infinite number of values for muscle group strengths can be obtained either as isolated muscle preparations or for human movement as related to the type of action, the velocity of movement and the length of the muscle(s). Strength is thus not an assessment performed under a single set of conditions defined by Komi (1992) as the maximal force generated by the muscle at a specified or determined velocity. The particular mode of testing muscular strength supplies a secondary operational definition as to what type of strength is assessed (Sapega, 1990). Type of muscle strength is dependent on the type of muscular contraction used to assess it. Sapega (1990) prefers to define muscle strength as the actual capacity of a muscle or muscle group to actively generate tension, irrespective of the conditions under which the tension is developed. Explanation of the muscular strength will then involve detailed information of the testing conditions and environment.

Muscular work is best defined as the applied force multiplied by the distance through which it is applied, therefore measuring output of mechanical energy, measured in Newton (F x s = N). Muscular power refers only to the rate of muscular work output and is expressed in units of work per units of time (Fs/t = Watt) (Komi, 1992; Sapega, 1990; Luttgens *et al.*, 1992; Kannus, 1994)

Modes of testing

The primary objective in testing maximum muscle strength is to measure the maximum load that the particular muscle group can move through the determined range of motion at a predetermined velocity (Wilkie, 1950). There are several methods of assessing muscular strength, all making use of some kind of resistance, movable or immovable.

Manual muscle testing (MMT) making use of the isometric hold or eccentric breaking method is still in use in practice and maybe even more today than any other method (Sapega, 1990). This may most probably be due to the fact that despite the advantages of other complicated devices, there will always be a need for an economical and practical method of obtaining reasonable measurement of muscular strength.

Cable tensiometry consists of measuring the tension in a cable connecting the moving limb to an immovable object. This application of tensiometry is different from its original use for measuring the tension of steel cables linking various parts of an aeroplane. Isometric strength is assessed making use of tensiometry (McArdle *et al*, 1991). Dynamometry operates on the principle of compression, measuring isometric strength. If an external force is applied to the dynamometer, a steel spring is compressed and moves a pointer. By determining the amount of force needed to move the pointer a specific distance, one can determine the external force applied.

Dynamic variable-resistance weightlifting often referred to as isotonic testing includes the lifting of free weights, as well as weights that are coupled to elaborate weight-lifting machines, such as those found in gymnasiums. This method mostly makes use of 1-10 maximum repetition efforts (One repetition maximum or 1RM to ten repetitions maximum or 10RM). This refers to the maximum weight that can be moved against gravity through a predetermined range of motion for one to ten repetitions. Using free weights as the resistance holds one major limitation, the fact that the weakest point in the particular ROM limits the resistance that can be overcome by the maximal muscle contraction strength. This causes sub-maximal training of the muscles involved during the strongest part of the arc of movement. The difficulty in controlling the forces of inertia that develop with small differences in technique of lifting weights, makes this method inherently imprecise when applied to human muscular performance. It serves however good indications of gross upper or lower body strength, but not individual muscle strength (Maud & Foster, 1995).

Isokinetic dynamometers as testing and rehabilitative devices were developed in the later 1960's when James Perrine introduced the engineering concept of isokinetic exercise (Hislop & Perrine, 1967). This concept opened a new field of research and thirty years later scientific journals are still receiving numerous articles to be published involving isokinetic dynamometry in some way or another. While isometric and isokinetic-inertial exercise play an important role in rehabilitation, isokinetic evaluation and exercise have attracted much attention because of the special features it offers. Uniquely, isokinetic movement involves a dynamic preset velocity of movement, with resistance varying exactly (in direct proportion) in response to the force applied by the individual throughout a specified ROM, which means that all the muscles activated through the ROM will be trained maximally. The concept of accommodating resistance exposed science to a new concept in muscular contraction: the *isokinetic muscle contraction.* This is described by many as a muscular contraction at fixed velocity that enables the muscle to maximally contract through the whole ROM of the joint, thus adapting to the constantly changing mechanical skeletal leverage system (Thistle *et al*, 1967; Pipes & Wilmore, 1975; Dvir, 1995). A muscle or muscle group allowed to maximally contract through its functional ROM will demonstrate varying tension development as a result of the leverage at the joint of application and its own inherent length-tension and force-velocity relationships. There is therefore no accurate adjective describing the muscular contraction present in a muscle tested using isokinetic dynamometry. Eccentric, concentric and isometric strength measurement can be performed using the dynamometer and with the latest software development it is also possible that the resistance can be set constant and speed of movement variant, like free weight lifting.

Table 1

A Comparison of the Characteristics of Three Modes of Muscle Action (Chan & Maffulli, 1996)

Muscle Work	Speed	Resistance	Adjustment
Isometric	0°/sec	Variable	Fixed
Isokinetic-inertial	Variable	Constant	None
Isokinetic	Constant 0-500°/sec	Variable	Absolute

Several biomechanical and physiological factors influence the magnitude of the force developed by any muscle group. These include the following:

1. *The maximum torque that a muscle can generate is related to the muscle's action through the skeletal lever system.* The resistance applied can not exceed the force/torque that the contracting muscle can generate at its weakest or most disadvantaged position, which is ultimately determined by the lever action of the particular joint.
2. *Skeletal instability to external resistance loads.* Free weight and other resistance forms do not follow the anatomical/biomechanical rotational movement around a joint and is therefor linear and divergent to the natural movement. This results in a tendency to adapt the posture and movement to the movement of the resistance and thus pushing or pulling the body out of position.
3. *Stabilising muscles' strength.* Many forms of resistance can not be used because of poor stabilisation of the joint due to weakness of supporting/stabilising musculature.
4. *Neural contraction.* The type and number of motor units involved in a muscle contraction and the rate of motor unit firing.
5. *Muscle cross-sectional area.*
6. *Muscle fiber distribution and arrangement.*

7. *The length-tension characteristics of the muscle.*
8. *Subconscious limitation of voluntary effort.* The body regulates the exerted force within the limits of tolerance and safety.
9. *Efficiency of exercise performance.* Due to changing muscular capacity there is a need for accurate measurement of improvement and session to session or test to test fluctuations in performance.
10. *Spasticity and tremor.* To apply constant resistance when spasticity or tremor is present is difficult and sometimes even impossible.
11. *The velocity-tension characteristic of muscle.* There exists a direct relationship between velocity of contraction and tension generated.
12. *Joint stability.* As the muscle length and force relationship and the geometrical arrangement of the bony structure, ligaments, tendons, muscles, fascia, skin and atmospheric pressure influence torque production.
13. *Strength-to-mass ratio.* This reflects the ability to accelerate one's body.
14. *Body size.* Smaller athletes could have a higher strength-to-bodyweight ratio than larger athletes could.

(Komi, 1992, Luttgens *et al*, 1992; Chan & Maffulli, 1996; Kannus, 1994; Dvir, 1995; Thistle *et al*, 1967; Wilkie, 1950; Komi, 1992; Garrett *et al*, 1984; McArdle *et al*, 1991; Moffroid *et al*, 1967)

Hislop & Perrine (1967) suggested that because of the unique accommodative resistance feature of isokinetic dynamometry, it proves to be one of the safest and objective methods to use in evaluating muscle performance. Figures 1 and 2 explain the most important reasons for this statement.

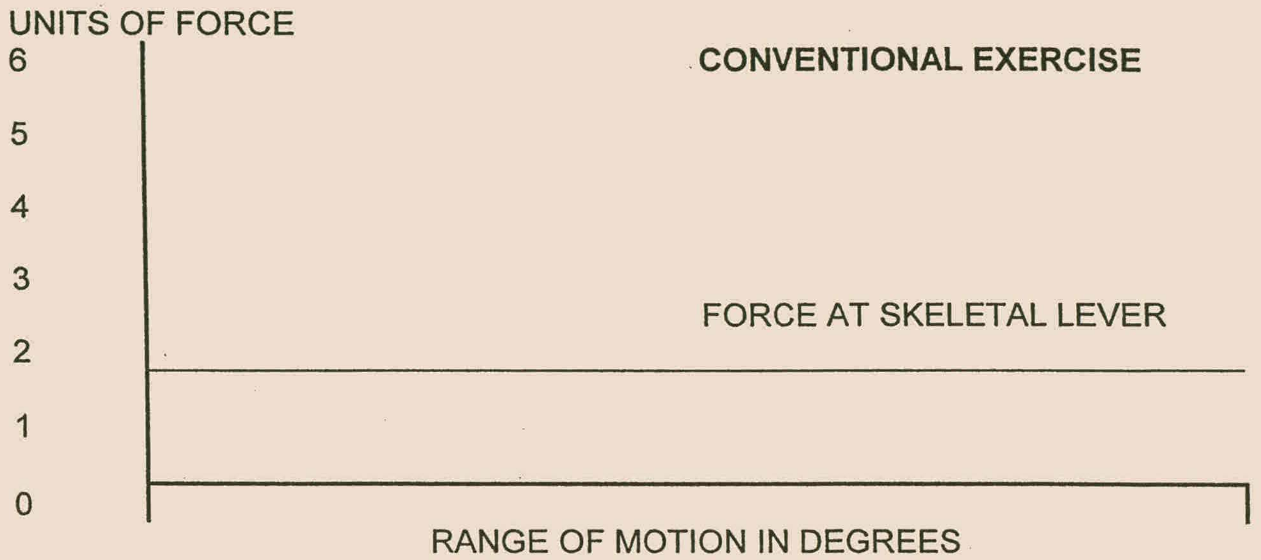

Figure 1a

During Conventional Isotonic Exercise Resistance Offered to the Skeletal Lever Remains Constant. (Hislop & Perrine, 1967)

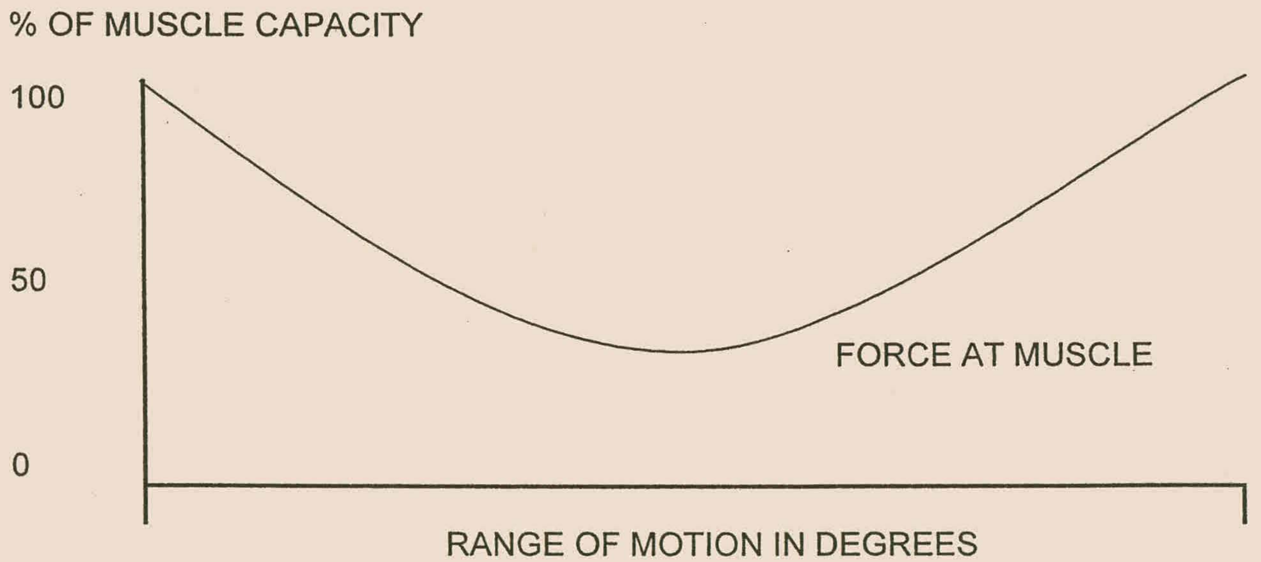

Figure 1b:

In isotonic exercise, resistance to the muscle varies because of the modifying effects of the lever system. Resistance has its greatest mechanical advantage on the muscle at the extremes of range and consequently the load is greatest at these points. Closer to mid-range the lever is most efficient and thgerfor the load of the muscle is proportionately less. Demands placed on the muscle are maximal only at the extremes of the range (Hislop & Perrine, 1967).

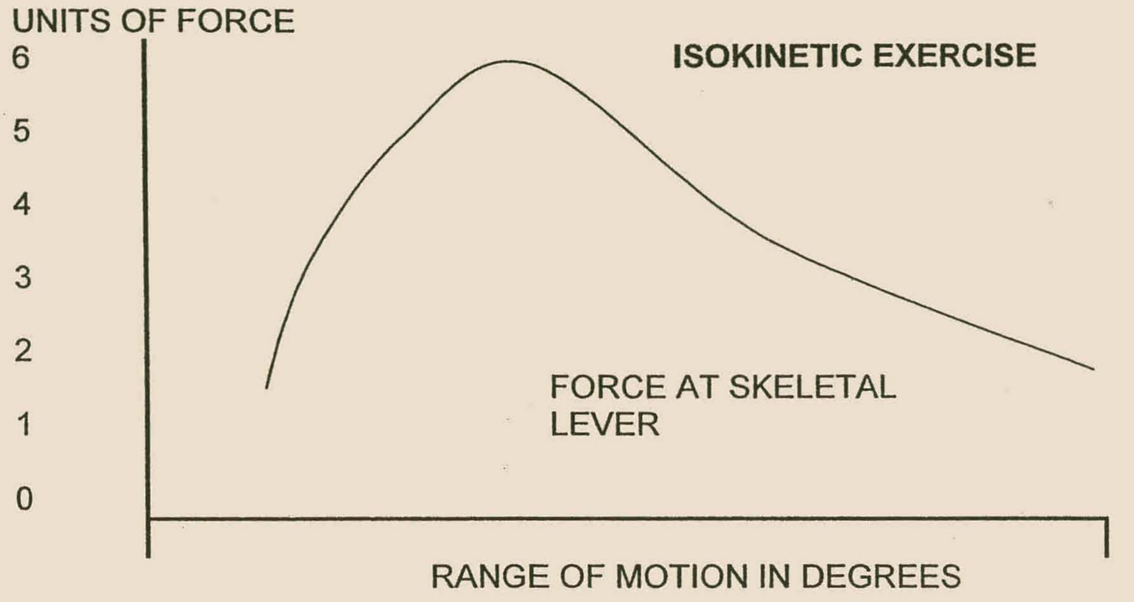

Figure 2a:

Force output at the skeletal lever during isokinetic exercise. At the extremes of range the muscle has its least mechanical advantage and resistance is least. Toward mid-range, where the mechanical advantage is greatest, the resistance increases proportionately (Hislop & Perrine, 1967).

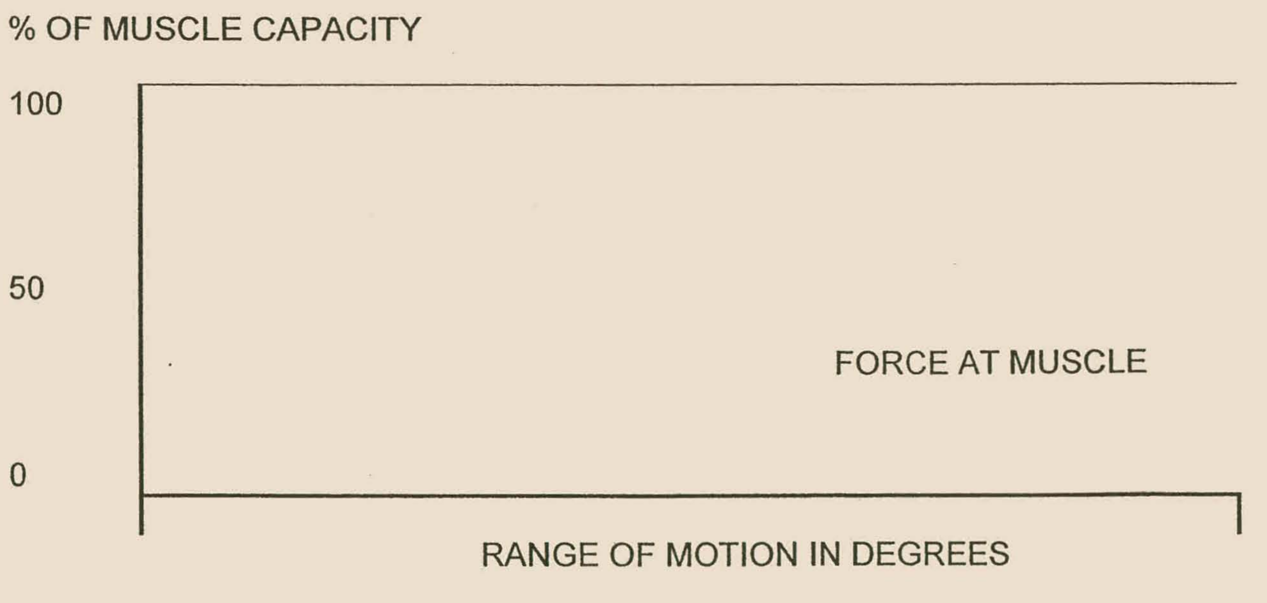

Figure 2b:

During isokinetic exercise the resistance accommodates the external force at the skeletal lever so the muscle maintains maximum output throughout the full range of motion (Hislop & Perrine, 1967).

As with any concept in science, isokinetic dynamometry did not escape criticism. There are many inherent disadvantages associated with isokinetics. Isokinetic movement does not appear in any human movement, thus the training effect is specific (Osternig, 1986). This training effect remains controversial and under investigation. Due to the isolation of one joint during isokinetic exercise or testing, it can cause excessive loading of the particular joint and may result in possible damage to healing tissue (Jurist & Otis 1985; Kaufman *et al*, 1991).

The most mentioned flaw is the fact that as an exercise device it holds certain orthopaedic dangers, since all movements performed on a isokinetic dynamometer is performed in an open kinetic chain (Kannus, 1994; Perrine, 1993; Chan & Maffulli, 1996; Read & Bellemy, 1990; Osternig, 1986; Kaufman *et al*, 1991). Most modern dynamometers can only measure movement up to a velocity of 500°/sec, while the actual functional movement on the sports field often exceeds 1000°/sec to 4000°/sec (Chan & Maffulli, 1996). To find a measuring tool that can measure muscular strength at functional velocities remains a quest for technological development. Although the velocities available on isokinetic devices may not accommodate the fast velocities required of many activities, isokinetics allow some similarity to the type of muscle contractions needed in functional and athletic activities and contraction velocities not capable to be tested with any other muscle testing device. If the objective of research or rehabilitation protocol is to isolate and evaluate strength of a particular muscle group, isokinetic evaluation remains one of the safest and most effective modalities available (Dvir, 1995; Perrine, 1993; Chan & Maffulli, 1996; Kannus, 1994; McArdle *et al*, 1991; Hislop & Perrine, 1967; Rothstein *et al*, 1998; Gleeson & Mercer, 1996; Pipes & Wilmore, 1975).

Isokinetic muscular performance evaluation supplies the clinician with valuable information about the isokinetic strength of the particular muscle group and thus is limited to that. It is recommended that when attempting to quantify individual sports performance and functional ability, isokinetics not be used. It forms but a part of the whole evaluation and protocol of peak muscular strength testing and specific rehabilitation (Murphy & Wilson, 1996).

Parameters of isokinetics and application in testing and rehabilitation

Isokinetic dynamometers are measurement devices providing clinicians with information about the dynamic nature of muscles. Strength measurement normally consists of relatively few maximal efforts, which may vary from one protocol to the next (Perrine, 1993, Baltzopoulus & Brodie, 1989; Osternig, 1986, Dvir 1995; Chan & Maffulli, 1996).

The basic measurement record consists of quantitative values that represent the amount of force exerted by the muscle/muscle group onto a force measuring force plate. Interfacing of microprocessors with isokinetic dynamometers has not only enabled the quantification of many parameters of muscle function, but also the graphical display of the force curve on computer. The objective is to produce a torque-angular position curve representing the force and angular displacement of the particular movement, which for this study is knee flexion and extension. Collectively the name given to a set of parameters derived from the force measurement (output/performance parameters) is *muscle performance.* The output parameters are directly influenced by a set of input or control parameters, i.e. information that is provided to the testing device such as test velocity and ROM. Table 2 lists the variables and parameters that determine the framework of a isokinetic test (Dvir, 1995).

Input parameters of strength testing

The input parameters that must be specified before the testing proceeds are divided into joint-dependent and joint-independent parameters.

Control/Input	*Performance/Output*
Joint-dependent ▪ Range of motion(ROM) ▪ Angular velocity ▪ Subject/patient positioning ▪ Stabilisation ▪ Alignment of the axes of the Dynamometer and joint ▪ Muscle contraction mode	**Moment/Torque** ▪ Peak ▪ Angle-based ▪ Angle of peak ▪ Average - Contractional work - Contractional power - Contractional impulse
Joint-independent ▪ Damp setting ▪ Isometric pre-activation ▪ Feedback	

Table 2:

Control (Input) and Performance (Output) Parameters in Isokinetic Testing (Dvir, 1995).

The joint-dependent parameters include range of motion and angular velocity. These vary according to the joint involved. Isokinetic ROM (IROM) differs from the normal ROM and is always smaller than the actual joint ROM. This is because of the time and angular displacement it takes for the limb to reach the predetermined velocity. Isokinetic ROM therefore refers to the ROM that is purely isokinetic as determined by the input parameters. An inverse relationship exists between the IROM and test velocity, i.e. the higher velocity the smaller the actual IROM (Dvir, 1995). The magnitude of the ROM also has been shown, especially during concentric knee extension, to have an effect on the isokinetic performance, speculating that a bigger ROM will have positive effects on performance (Narici *et al*, 1991).

Angular velocity is indeed the movement velocity of the lever arm of the dynamometer and not of the distal segment. It is expressed in degrees per second (°/sec) but often also as radian per second (1 rad=57.3°). The angular velocity directly influences the IROM, since a testing velocity of 500°/sec is sometimes not reached in the preset ROM (Reference, Dvir, 1995). Wilkie (1950) was one of the firsts to study the relationship between force and velocity in human muscle. It started with the assumption that the phenomenon of movement slowing down because of the resistance being increased partly is because of inertia (resistance) of the object, but mainly because of inherent properties of the muscle (Wilkie, 1950). Maximum force output of muscle groups have been shown to be influenced by the velocity of movement or testing by means of contraction type (Tihany *et al*, 1982; Figoni *et al*, 1988; Hageman *et al*, 1988). The ability of a muscle to generate concentric force is greater at slower velocities than at faster with most of the research on this done on the hamstrings and quadriceps muscle groups (Wilkie, 1950; Ryan *et al*, 1991; Tihanyi *et al*,1982; Westing *et al*, 1991; Westing *et al*, 1988; Figoni *et al*, 1988; Hageman *et al*, 1988).

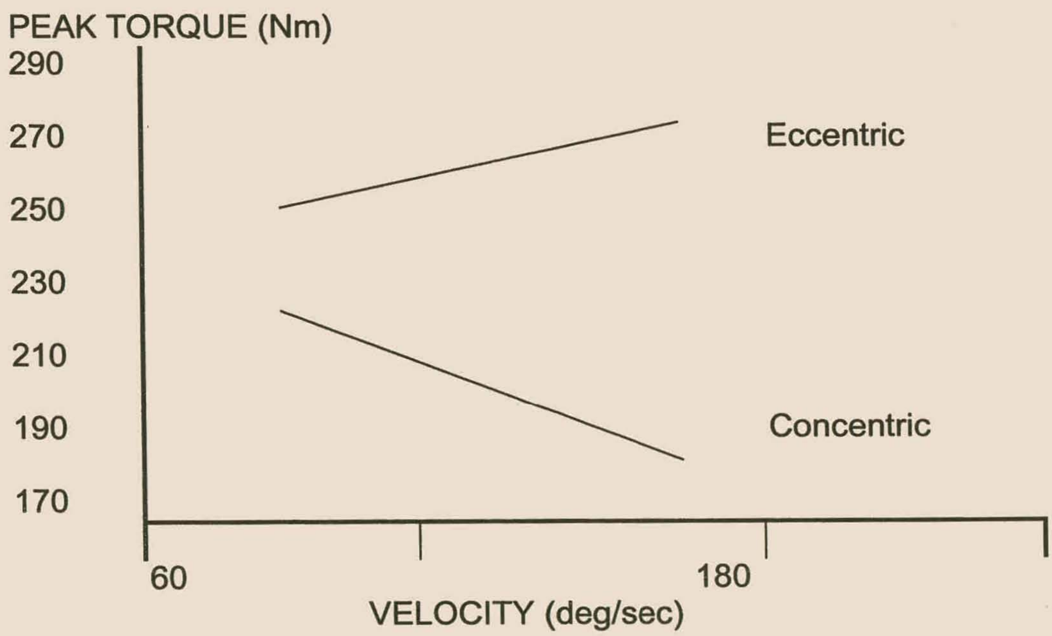

Figure 3:

Concentric and eccentric peak torque of the hamstring muscle group at two test velocities. Note that peak torque decreases with an increase in test velocity and for this muscle group, eccentric torque increases with the increase in test velocity (Worrell et al, 1991).

The force-velocity curve of eccentric contraction is quite different from that of the concentric contraction curve. While the concentric force decreases with increase in speed of movement, the maximum eccentric force remains the same and may even increase slightly with the increase in test velocity (Worrell *et al*, 1991; Perrine, 1993; Ryan *et al*, 1991; Baltzopoulus & Brodie, 1989). With the increase of concentric contraction speed, fewer cross-bridges are formed and less tension is developed/produced. In contrast to this, the cross-bridges do not have to undergo the complete series of chemical events during an eccentric contraction and the increase in velocity of contraction does not adversely effect the ability to generate tension (Perrine, 1993; Albert, 1995). The eccentric contraction and cross-bridge action is independent of the velocity until the velocity of lengthening exceeds the binding rate of the actin and myosin (Perrine, 1993). According to Baltzopoulus *et al* (1989), at higher velocities the limb may pass the optimal joint position for muscular performance. This is most probably why 60°/sec has been the set standard velocity of isokinetic strength for knee flexion and extension and most of the larger joints of the body (Perrine 1993; Dvir, 1995; Chan & Maffulli, 1996). This testing velocity is considered slow and isokinetic dynamometers capable of testing eccentric strength (active dynamometers) has only recently become available (Albert, 1995).

The hamstring and quadriceps muscle groups have been tested using a wide spectrum of velocities for example Borges (1989) measuring at 12°/sec and Ghena *et al* (1991) as high as 450°/sec. It is by far the most tested joint in the study of isokinetic dynamometry (Dvir, 1995). Albert (1995) reports of the general eccentric testing velocities ranging from 60, 120, 150 and 180°/sec, with only the athletic population benefiting from tests at the faster velocities (150-180°/sec). Test velocities greater than 180°/sec seems to provide less information than expected. Firstly, the higher the velocity, the smaller the IROM. Some studies have shown that even at velocities of as low as 90°/sec the first and last 15° of knee flexion and extension (ROM=90°) was non-isokinetic (Dvir, 1995). Secondly, Ghena *et al* (1991) demonstrated that the differences in force measurement and other relevant values between 180°/sec and 450°/sec did not vary as much to give considerable useful information about the muscle performance. The use of high velocities for muscle testing seems to be more useful in endurance performance testing. Test velocities between 60 and 180°/sec seem to be most useful for assessing the strength of the musculature involved in knee flexion and extension meeting the essential requirements of testing validity and reproducibility (Dvir, 1995; Albert, 1995; Perrine, 1993; Baltzopoulus & Brodie, 1989 and Gleeson & Mercer, 1996; Li *et al*, 1996). The large range of studies involving isokinetic strength testing generally use testing velocities within this range, which makes comparative research possible.

Joint-independent control or input parameters include the damp setting, isometric pre-activation and feedback methods. Engaging in isokinetic resistance necessitates acceleration of the limb to a predetermined test velocity that is much lower than natural performance movement. Subsequently the velocity of the limb is increased above the pre-set angular velocity. The dynamometer must in turn decelerate the accelerated limb to the pre-set velocity. This causes a phenomena called the 'impact artefact' (Winter *et al*, 1981) or 'torque overshoot' (Sapega *et al*, 1982) which graphically displays as a spike on the torque/moment-angular velocity (T/MAP) curve that usually is misinterpreted as the peak torque. Osternig (1986) explains it as an obstacle in high velocity testing since the range of motion where the 'overshoot' appears is hardly isokinetic and does not reflect muscle performance at the preset velocity.

Most modern active dynamometers have a computer controlled 'damping' or 'ramping' device that serves as a force absorber ensuring smooth movement and measurement from 0°/sec to the preset velocity. The overshoot phenomena must not be ignored since it supplies the clinician with important physiological information about the potential of and capacity to force generation of the subject or patient. Isometric pre-activation refers to the static tension which is generated in the tested muscle/s before movement of the lever-arm and segment (Dvir, 1995). Another form of demand on the muscles being tested is a lower isometric bias (Dvir, 1995) or minimum force limit. This refers to the minimum force that has to be maintained by the muscle/s to ensure smooth progression of isokinetic movement. The opposite of this measurement, which serves as a safety measure for contra-indicated high force development, is the upper moment limit (Dvir, 1995) or maximum force limit.

Table 3 describes the forms and characteristics of feedback. It has been well documented that especially visual (by means of graphical display of the T/MAP curve) and auditory feedback (by means of verbal encouragement) during isokinetic knee flexion and extension strength testing resulted in improved maximal voluntary contraction in isokinetic dynamometry under restricted velocity and ROM (Baltzopoulos *et al*, 1991; Hald & Bottjen, 1987; Winter *et al*, 1981; Perrine, 1993; Dvir, 1995; Chan & Maffulli, 1996).

Characteristic	**Explanation**
Form	- Auditory (verbal), visual or combination.
Amount	- How much information is given to the subject or patient.
Delay	- The period of time between the performance and the provision of the information, or between the presentation of the information and the next response.
Content	- The elements of performance to which the feedback refers, for instance peak or average moment.

Table 3:

The Characteristics of Feedback Used in Isokinetic Dynamometry (Dvir, 1995).

Output/Performance parameters of strength testing

Variability, reliability and reproducibility studies have shown that little more significant information could be obtained using any other parameters than peak and average moment/torque, work and power (Kannus, 1988b; Kannus, 1990; Kannus *et al*, 1991; Kannus, 1994; Kannus & Kaplan, 1991; Kannus & Yasuda, 1992; Kannus, 1992).

Moment/torque

The turning effect of a force, acting at a distance from a rotational axis, is referred to as moment/torque (Dvir, 1995; Perrine, 1993, Hay in Komi, 1992; Luttgens *et al,* 1992; Kannus, 1994). The torque about any point equals the product of the force magnitude and the perpendicular distance from the line of force to the axis of rotation (Torque [ft-lb or Nm] = force [N] x distance from axis of rotation [N]).

The distance between the axis of rotation, which in dynamometry is the axis of the dynamometer, and the point of force application (the force pad) is referred to as the moment arm. Dvir (1995) is of opinion that if a moment acts on the body it exerts bending stresses and may impart rotation. When torque acts on a body it exerts torsional stresses and may in addition impart axial rotation. He refers to moment when the major joint motion is along the anatomical planes and movements such as internal and external rotation is interpreted using the term torque. Torque is most often referred to in the research and therefor this study will make use of this term as expressing the muscular force exerted measured by the isokinetic dynamometer.

Peak and average torque

Peak and average torque are the isokinetic parameters most frequently used in assessment of isokinetic human muscle performance. The torque produced by the hamstring or quadriceps muscle group is assessed throughout the entire ROM. The peak value of the torque measured through the entire ROM is referred to as the peak torque (PT). An average value would be calculated from the tension produced by the muscle group throughout the ROM tested. This necessitates careful and correct standardisation of the tested ROM (Perrine, 1993). Average torque is clearly measured only over the IROM and explains the importance of correct procedures and standardisation. The dispute of using a single effort as representative of strength or the use of the totality of efforts to produce the muscle contraction through the full ROM, demonstrates the controversy surrounding the definition of strength (Dvir, 1995). PT has been shown to be and accurate and highly reproducible variable to measure (Kannus, 1994; Kannus, 1988b; Kannus, 1990; Kannus *et al*, 1991; Kannus & Kaplan, 1991; Kannus & Yasuda, 1992; Kannus, 1992; Gleeson & Mercer 1996) and its use in isokinetic tests has been accepted in critical reviews (Sapega, 1990; Baltzopoulus & Brodie, 1989; Osternig, 1986).

Concentric PT remains almost unchanged between the angular velocities of 0-60°/sec where-after a linear decline appears as velocity increases, while it remains the same or increase slightly during eccentric contractions (Wilkie, 1950; Ryan *et al,* 1991; Tihanyi *et al,* 1982; Westing *et al,* 1991; Westing *et al,* 1988, Worrell *et al,* 1991; Perrine, 1993; Ryan *et al,* 1991; Baltzopoulus & Brodie, 1989).

Angle of peak torque and angle specific torque

The standard sampling rate of isokinetic dynamometers is 100 Hz. The dynamometers available today has increased this sampling rate significantly and are able to measure the torque at much higher intervals than 100 times per second. The angle of peak torque refers to that angle of the tested ROM at which peak moment occurs. The angle of concentric peak torque for knee flexion and extension has been thoroughly researched. At low (60°/sec) and moderate (180°/sec) velocities the angle of hamstring and quadriceps peak torque usually occurs between 30° and 60° of knee flexion (Kannus *et al*, 1992). The angle of peak torque is very well known to vary as a function of test velocity in such a way that the peak torque occurs later in the ROM due the extended time it takes for peak tension development at higher velocities (Dvir, 1995; Perrine, 1993; Chan & Maffulli, 1996; Baltzopoulus & Brodie,1989). The angle of peak torque has also been shown to vary widely among subjects (Jurist & Otis, 1985; Highgenboten *et al*, 1988). In weak muscles such as the female hamstrings the angle of PT is effected by the strength of the muscle so the weaker the muscle the later the PT occurs, most probably due to slow neural recruitment (Kannus, 1994).

Reciprocal muscle group ratios are determined using the peak torque values of the two muscle groups and expressing the weaker group as a percentage of the stronger. The question however arises that since quadriceps peak torque occur more likely closer to 60° and hamstring peak torque closer to 30° of knee flexion (Kannus & Kaplan, 1991), what the significance is of comparing two strength values that occur at different angles in the ROM? The answer to this question might involve the use of the often-rejected average torque and/or angle specific peak torque.

Angle specific torque involves the measurement of torque at a specific angle other than the angle of PT. The reliability of the measurement of angle specific torque has been shown to be high if the specific angle/s fell close within the area of peak torque (Kannus, 1994). Angle specific torque loses reliability the more peripheral the angle, in other words the further from the angle of PT (Dvir, 1995). This could be because of isokinetic movement that is not present at the acceleration and deceleration phases of the movement. This is quite unfortunate since the torque at the more functional positions in the ROM can supply valuable information.

Contractional work

As previously defined, muscular work is the externally applied force multiplied by the distance through which it is applied (Sapega, 1990). In isokinetics the contractional work refers to the area beneath the torque-angular displacement curve (work [Joules, J] = torque x distance [degrees]) or can be calculated by multiplying the average torque by the angular displacement (Kannus, 1994; Dvir, 1995; Chan & Maffulli, 1996, Baltzopoulus *et al*, 1989). The clinical importance of contractional work is questionable since it can be predicted from PT and its significance, although specific, has lost its place in clinical practice (Kannus, 1994).

Contractional power

Contractional power, which is measured in watts, refers to the rate of muscular work output at specific speeds of contractions (McArdle *et al*, 1991; Dvir, 1995). The importance of this parameter lies in that it closely reflects aspects other than strength, since the increase in angular velocity seem to positively effect the contractional power (Dvir, 1995). However, this parameter's applicability stays within the athletic subject pool.

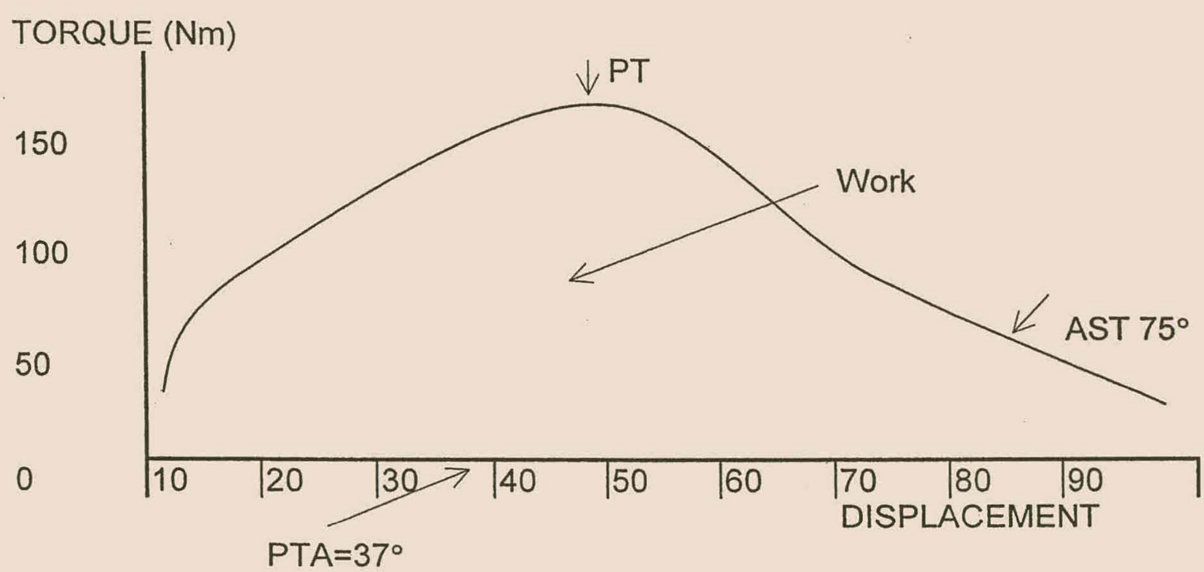

Figure 4:

A characteristic isokinetic moment-angular velocity curve of the male hamstrings. The speed of the dynamometer is 90°/sec. 0° refers to a fully extended knee joint. PT = peak torque; PTA = peak torque angle; AST = angle specific torque (Kannus, 1994).

Indications and contra-indications to knee flexion and extension isokinetic testing

Currently isokinetic techniques are used for five major purposes: strength testing, rehabilitation, research, diagnosis and to some extent as a training aid, depending on the availability (Chan & Maffulli, 1996). If the protocol is strictly adhered to, the isokinetic evaluation provides accurate objective data on a wide range of variables that can supply important information concerning the patient/subject's condition and rehabilitation protocol. The area of research has ranged from attempts to predict predisposition to injury (Burkett, 1970; Leimohn, 1978; Grace *et al*, 1984; Campbell & Glenn, 1982; Orchard *et al*, 1997), to the efficacy of various rehabilitation protocols to decrease time of recovery and return to top performance (Hislop & Perrine, 1967; Coole & Gieck, 1987; Gleeson & Mercer, 1996; Heiser *et al*, 1984; O'Connor, 1993). Isokinetic testing has successfully been employed in the strength measurement of patients with musculoskeletal injuries, with various neuromuscular conditions and screening athletes. For the purpose of this study, the use of isokinetics focuses directly on strength assessment, interpretation and use of some parameters and its employment in the rehabilitation process.

Isokinetic evaluation is primarily indicated to assess bilateral or ipsi-lateral strength differences in the musculature around a given joint to establish baseline values to evaluate status or from which the rehabilitation protocol will be constructed/designed. Besides strength differences, extended research during the past 30 years has investigated reciprocal muscle group ratios as a further aid to assessment and rehabilitation. In some conditions the patient's available information may not be satisfactorily interpreted. In these situations isokinetic evaluation provides valuable additional information (Dvir, 1995; Bennet & Stauber, 1986).

Most of the modern systems available today have the function of pre-setting minimum and maximum torque levels that can ensure the generation of muscle tension greater than a specific/minimal threshold, yet protect the involved structures from a potentially damaging stress. Maximum muscular contraction is also not necessary to ensure isokinetic motion. These features have modified the traditional relative and absolute contraindications to isokinetic testing (Dvir, 1995). Consultation procedures should include the thorough physical assessment of the joint involved to establish any contraindications. Table 4 lists the relative and absolute contraindications to isokinetic testing.

Absolute	**Relative**
• Severely limited ROM • Severe pain • Severe effusion • Acute sprain • Acute strain (musculo-tendinous unit) • Unstable bone fracture or joint • Soft tissue healing constraints	• Limited ROM • Pain • Effusion or synovitis • Chronic 3rd degree sprain • Subacute strain of the musculo-tendinous unit

Table 4:

Contraindications Spectrum to Isokinetic Testing and Activity. Adapted and Combined from Chan & Maffulli (1996), Dvir, (1995), Albert (1995).

Eccentric isokinetic testing is contraindicated for debilitated patients, patients with total joint replacements and neuromuscular disease causing poor motor control (Albert, 1995). The indications listed above are limited to the surrounding musculature of the specific joint tested. For male patients over the age of 40 and females over the age of 50 years, obesity and sedentary patients a pre-test health questionnaire can reveal contraindicated metabolic, cerebral, venous and/or cardiovascular (CV) conditions. Due to for instance the Valsalvic action often accompanying maximal testing, certain CV conditions might be contraindicated. Dvir (1995) absolutely contraindicates all patients suffering from any heart disease. The sound judgement of the clinician to substantiate isokinetic testing is of utmost importance.

Anatomy of the tibiofemoral joint

For the purpose of a detailed description of joint and muscle anatomy and biomechanics for this research project, Norkin & Levangie (1992) was used as reference.

As the largest joint in the body its location at the ends of two long levers makes the tibiofemoral joint particularly susceptible to injury. The articular surfaces of the tibia and femur are not congruent (only in full extension), resulting in the ligaments and muscles that surround the joint essential to provide the stability and strength and not its bony configuration. A total of 12 muscles cross the knee joint contributing to both stability and function.

Knee extension is accomplished primarily by contraction of the quadriceps femoris muscle group. The vasti medialis (VM), intermedius (VI) and lateralis (VL) are uni-articulate while the rectus femoris is bi-articulate, crossing both the knee and hip joint, also assisting in hip flexion. The rectus femoris originate from the inferior spine of the ilium attaching via the quadriceps tendon to the patella and extending into the patellar tendon that attaches to the anterior tibial tuberosity. The remaining three vasti originate on the femur and also merge into the quadriceps tendon that connects to the apex of the patella extending into the patellar tendon. The VM and VL also inserts via retinacular fibers of the joint capsule into the medial and lateral aspect of the patella. The VI is the purist knee extensor with its action parallel with the axis of the femur. The line of action of the VL is 12°-15° lateral. Proximal the VM action is 15°-18° medially and referred to as the vastus medialis longus (VML). The VM action distal can be 50°-55° medially, resulting to be referred as the vastus medialis oblique (VMO). The resultant pull of the quadriceps is 7°-10° medially and 3°-5°anteriorly (Lieb in Norkin & Levangie, 1992).

Seven muscles flex the knee. Contraction of primarily the hamstring muscle group produces knee flexion and hip extension. The semimembranosis (medial), semitendinosis (medial) and the long head of the biceps femoris (lateral) cross the knee and hip joint resulting in less torque production when the hip is an extended position. The short head of the biceps femoris and the popliteus muscle are the only flexors not crossing the hip. When the knee is flexed and non-weight bearing, the biceps femoris externally rotates the lower leg while the politeus, gracillis, semimembranosis and semitendinosis assist in medially rotating the lower leg (Luttgens *et al*, 1992). The posterior portion of the adductor magnus muscle is functionally considered part of the hamstring group due to the shared origin with the other three muscles and its vertical line of pull (Coole & Gieck, 1987). All of the hamstring muscles originate from the ischial tuberosity of the pelvis. The semimembranosus and semitendinosus attach to the postero-medial and antero-medial aspects of the tibia respectively. Some of the fibers of the semimembranosus attach to the medial meniscus that facilitates in the posterior motion of the meniscus during flexion (see arthrokinematics of knee flexion/extension). Both heads of the biceps femoris muscle insert at the lateral condyles of the tibia and head of the fibula. With the short head not crossing the hip joint it functions uniquely as a knee flexor. Also assisting in knee flexion is the gastrocnemius muscle, a bi-articulate muscle crossing the knee and ankle joint. Its two heads originate from the posterior aspect of the medial and lateral femoral condyles and inserts via the calcaneal tendon to the calcaneus. The gastrocnemius muscle is the only lower leg muscle (except the plantaris which is commonly absent) crossing the ankle and knee joints. Under specific conditions the gastrocnemius muscle contracts in what is referred to as a reverse direction (Luttgens *et al*, 1992) or paradoxical contraction (Sutton, 1984) contributing in knee extension. Besides plantar flexion the gastrocnemius functions in resisting large extension torques at heelstrike during the gait cycle, thus having a more important function as a dynamic stabiliser.

The sartorius muscle originates from the anterior superior iliac spine and inserts at the medial aspect of the tibia. This muscle assists in knee motion but is more common for hip motion than knee. The gracilis muscle, with its origin on the inferior half of the symphysis pubis arch, inserts to the medial tibia by way of the common pes anserinus. The gracilis is an important hip flexor and adductor with secondary functions in knee flexion and tibial medial rotation. The pes anserinus group consisting of the gracilis, semitendinosus and the sartorius muscles, form a very important stabiliser of the medial aspect of the knee joint. The popliteus muscle attaches to the medial aspect on the posterior surface of the tibia and originates from the posterior aspect of the lateral femoral condyle. In closed kinetic chain (CKC) movement the muscle assists in lateral rotation of the femur and in open kinetic chain (OCK) movement in medial rotation of the tibia. Even though the unlocking of the knee will occur during passive flexion of the joint, the popliteus plays an important role in this mechanism in weightbearing. It also attaches to the lateral meniscus and therefore assists in the posterior draw of the meniscus during flexion. The popliteus further assists the posterior cruciate ligament (PCL) in much the same manner the hamstring muscle group assists the anterior cruciate ligament (ACL).

The incongruency between the tibia and the femur enables the two bones to move different amounts guided by the muscles and ligaments. The space between the two bones is filled with two menisci that are attached to the tibia and add to congruency. The medial meniscus is C-shaped and thicker posteriorly than anteriorly and the lateral meniscus that is O-shaped of equal thickness. Both menisci are thicker along the peripheral ridge and thinner along the inner margin. Function of the menisci include lubrication of the joint, shock absorption, spreading of the stress over the articular cartilage surface and decreasing cartilage wear, improved congruency caused by increased radius of the curvature of the tibial condyles, prevention of hyperextension, increasing the area of contact between the two condyles improving weight distribution and prevention of the joint capsule entering the joint causing locking of the joint.

Of the several ligaments around the knee joint that act primarily as stabilisers and guide the movement of the bones in proper relation to one another, the four main ligaments of the knee joint are the anterior (ACL) and posterior cruciate (PCL) ligaments and the medial (tibial) and lateral (fibular) collateral ligaments.

The ACL primarily assists in preventing 86% of the anterior shear of the tibia from the femur during knee extension (Seto, *et al*, 1988) and the normal rolling and gliding movement of the joint. Furthermore it checks external rotation of the tibia in flexion and to a lessor extent checks hyperextension of the joint. The greatest amount of anterior shear forces occurs at knee flexion angles of less than 40° with the peak (0.3 body weight during isokinetic movement) at 25° of knee flexion (Kuafman *et al*, 1991).

During knee flexion the PCL prevents 95% of the posterior shear of the tibia from the femur. The greatest amount of posterior shear force occurs at knee flexion angles of greater than 40° with the peak (1.4-1.7 bodyweight during isokinetic movement) at 65° of knee flexion (Kuafman *et al*, 1991) and assists in prevention of hyperextension of the joint. In addition the ligament, together with the ACL, provides rotary stability. The medial collateral ligament consists of a superficial layer and a deep (medial capsular ligament) layer that blends in with the medial meniscus. The entire ligament is tight through the whole range of motion of the joint although some areas more than others due to the shape of the femoral condyles. All fibers are tight at full extension, anterior fibres in flexion and posterior fibres at ±45° of flexion, providing medial stability to the joint. The lateral collateral ligament lies under the tendon of the biceps femoris muscle not attached to the lateral meniscus. As cruciate ligaments relaxed. During medial rotation of the tibia the opposite occurs, relaxing the collateral and tightening the cruciate ligaments.

The Biomechanics of the Tibiofemoral Joint.

Flexion and extension are the primary motions at the knee joint and medial and lateral rotation the lessor. Flexion and extension occurs about a changing but definable axis of rotation. Small amounts of anterior/posterior displacement and various varus/valgus forces occur during the normal flexing knee joint due to the incongruency of the joint's articular surfaces and the variation in ligament elasticity. Excessive amounts of both these anatomical features result in abnormal knee function and ligamentous incompetence.

Normal knee motion – flexion and extension

The axis of rotation for flexion/extension of the tibiofemoral joint runs horizontally through the femoral condyles. The axis is slightly lower on the medial side of the joint causing some obliquity. From a slightly lateral position to the femur in full extension the tibia moves to a position medial to the femur in full flexion.

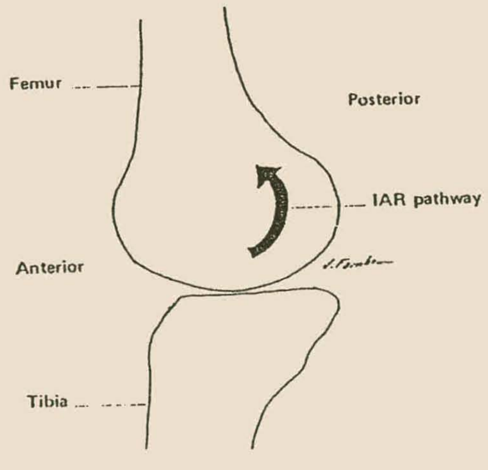

Figure 5:

Schematic drawing of the knee joint. The arrow represents the path of the instantaneous axis of rotation (IAR) for the joint as it moves from extension into flexion (Norkin & Levangie, 1992).

The axis of flexion/extension motion at the knee is however not relatively fixed, but moves through the ROM. The pathway of the instant axis of rotation forms a semicircle moving posteriorly and superiorly on the femoral condyles with increasing flexion. Knee ROM is influenced by hip position due to the 5½ two-joint muscles crossing the knee and the hip joint. Passive ROM of the knee flexion/extension is 130°-140°. With the hip hyper-extended ROM is 120° or less depending on the stretching of the rectus femoris muscle that can limit the flexion. Maximal knee flexion of approximately 160° is possible with the hip flexed and weight-bearing like the deep squat.

On level surface normal gait requires only 60° flexion, increasing to 80° for stair climbing and 90° for sitting and rising from the sitting position. Activities beyond simple mobility require 115° or more. Knee extension of 5°-10° is seen as normal with extension larger than that referred to as genu recurvatum. When the lower limb is weight-bearing with the knee part of a closed kinetic chain, range limitation of the ankle joint can restrict knee flexion and extension.

Motion at a joint occurs as a result of movement of one joint surface in relation to another. The term arthrokinamatics refers to the movements of joint surfaces. The term osteokinematics refers to the movement of the bones rather than the articular surfaces.

Arthrokinamatics

With the relatively large articular surfaces of the femoral condyles on the small tibial surfaces a potential problem arises during flexion of the knee. During the first 25° of flexion the femoral condyles roll posteriorly over the tibial condyles. To continue flexion the femoral condyles simultaneously start gliding anteriorly to prevent rolling of the femur off the tibial plateau, causing the femur to spin on the tibial articular surfaces. The anterior glide results in part from the ACL tension and the wedge-shaped posterior meniscial surface forces, causing the condyles to roll 'uphill'.

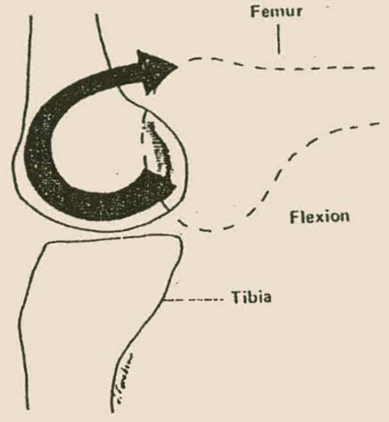

Figure 6:

Schematic illustration of pure rolling of the femoral condyles on a fixed tibia shows the femur rolling off the tibia (Norkin & Levangie, 1992).

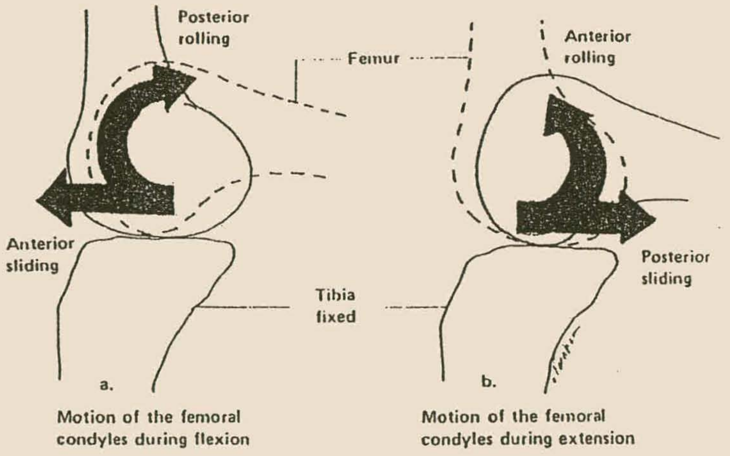

Figure 7:

(a): A schematic representation of rolling and sliding of the femoral condyles on a fixed tibia. The femoral condyles roll posteriorly, while simultaneously sliding anteriorly. (b): Motion of the femoral condyles during extension. The femoral condyles roll anteriorly, while simultaneously sliding posteriorly (Norkin & Levangie, 1992).

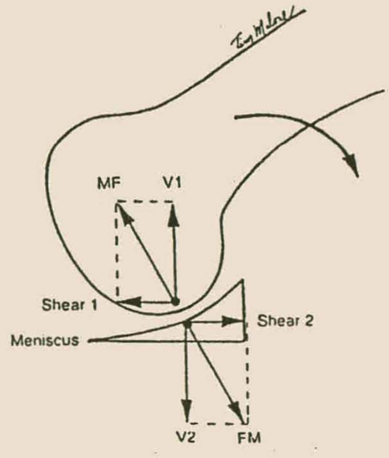

Figure 8:

Schematically represented, the oblique contact of the femur with the wedge-shaped meniscus results in the forces of meniscus-on-femur (MF) and femur-on-meniscus forces (FM). These can be resolved into vertical and shear components. Shear$_1$ assists the femur in its forward glide during flexion while shear$_2$ assists in the posterior migration of the menisci that occurs with knee flexion (Norkin & Levangie, 1992).

Referring to Figures 6, 7 and 8 the oblique forces between the femur and the meniscus (FM) cause an anterior shear (shear 1) and the oblique forces of the meniscus on the femur (MF) create a posterior shear (shear 2). The distorted menisci accompany the femoral condyles through the posterior movement maintaining the congruence provided by the menisci from the fully extended knee.

With extension the condyles are displaced anteriorly on the tibial condyles back to the neutral position, full extension. Initially the femur rolls anteriorly after which the condyles glide posteriorly to continue extension as a spin of the femoral condyles on the tibial condyles. Distortion of the wedge-shaped menisci once again accompany the condyles through extension to neutral position in full extension. Failure of the menisci to remain beneath the femoral condyles and between the tibial and femoral articular surfaces will result in obvious limitation of joint motion causing damage.

Locking and unlocking

Asymmetry of the lateral and medial femoral condyles cause complex intra-articular motion like the rolling and gliding action with extension and flexion. Another of the complex motions is the 'locking' and 'unlocking' of the knee joint essentially caused by the individual odd shapes of the femoral condyles. During the last 30° of extension in a closed kinetic chain (CKC) the lateral femoral condyle has completed its rolling and gliding action before that of the larger medial condyle. This results in the medial rotation of the femur during the last 30° of extension, pivoting on the fixed lateral condyle. The increased tension in the ligaments surrounding the joint during extension assists the medial rotation making it most evident during the last 5°. This 'locking' action is known as the automatic/terminal rotation (Lutgens *et al*, 1992) or the screw home mechanism (Komi, 1992; Gross *et al*, 1996).

With flexion the larger medial condyle starts the movement and laterally derotates the femur. This occurs in both CKC and OKC movements. During OKC movement the tibia laterally rotates during the last 30° of extension and medially rotates during the first 30° of flexion. Any external restraint of this rotation and derotation can result in damage to the joint, ligaments or menisci because of flexion forced oblique into the sagital plane. Flexion of the knee in a CKC movement is accompanied by hip flexion and dorsiflexion of the ankle.

The Patello-femoral Joint

The absence of the patella during knee extension has can result in up to 49% loss in torque production (Kaufman *et al*, 1991). The function of the patella essentially is to increase the moment arm (MA) of the quadriceps via the quadriceps tendon. Although it increases the angle and rotary component of pull, it does so at the cost of anterior shear of the tibia beneath the femur.

The counter action pull is by means of the ACL. During full flexion of the knee the patella assists the least in increasing the moment arm because of its position in the intercondyler notch, with the quadriceps tendon in contact with the femoral sulcus. Extension reverses the sliding down of the patella and with decreasing flexion angles the MA increases. At 60° of flexion the MA is at its largest point with the patella the furthest away from the instant axis of rotation of the tibio-femoral joint. This corresponds with the research, finding the angle of peak torque for the quadriceps muscles group being approximately 60° of flexion (Kannus1990; Kannus *et al*, 1991; Kannus & Kaplan, 1991). This is not only due to the patella but also influenced by the length-tension relationship of the muscles and the contraction type. With a large MA less quadriceps muscle force (and less patello-femoral joint compression) is needed to produce the same torque. This results in higher quadriceps force needed at large and small flexion angles. This effect is most prominent during the last 15° of extension where an increase of 60% in quadriceps force is needed to complete extension, the highest required than anywhere else in the ROM. Even though near full extension the MA is the smallest, the relative size of the MA is critical to torque production in this position and most important (Kaufman *et al*, 1991).

Staying within the smallest patello-femoral joint reaction force (PFJRF) positions during rehabilitative exercise for the knee joint has been a common challenge for the rehabilitation specialist. At flexion angles of 10°-15° during gait the PFJRF reach approximately 50% of bodyweight (Kaufman *et al*, 1991). At 60° flexion, which is ironically the peak torque angle of the quadriceps, the PFJRF is 3.3 bodyweight and at 130° flexion approximately 7.8 bodyweight (Rothstein *et al*, 1998; Brotzman, 1996; Kaufman *et al*, 1991). All other joints of the body undergo the same reaction forces, but within much more congruent joints.

The medial surface under the patella is in contact with the femoral condyles the most, doing so during 30°-70° of flexion. During the first 20° of flexion the lateral and medial inferior border is in contact with the condyles. During 70°-90° the medial contacts decreases and lateral and odd surface contact increases, but general reaction forces decrease. This result in the medial facet near the central ridge mostly degenerated causing patello-femoral pain, even though the medial facet contains the thickest hyaline cartilage in the human body.

The vastus medialis and lateralis (via the medial and lateral retinacular fibers) provide transverse stabilisation and the quadriceps and patellar tendon longitudinal stabilisation to the patella.

Incidence of knee joint and musculature injuries

The anatomically unstable knee joint is viewed as the most vulnerable to injury. The three most common results of trauma to this joint include meniscectomy, ligamentous repair and patello-femoral pain (chondromalacia) (Campbell & Glenn, 1982). Knee ligament rupture is severe and one of the most common traumas to the knee joint (Kannus & Yasuda, 1992; Kannus & Järvinen, 1991). O'Connor (1993) reports of an accident survey at an USA hospital that gave the incidence of knee injuries as one per 1000 of the population per year. Of these injuries, 61% was incurred during sports participation and 10% as result of traffic accidents. More than 50% of ligament injuries were in the 15-30 year age range. Of the running injuries incurred during the 1984 Bern Grand Prix (a 16km race), 27.9% involved the knee joint (Marti *et al*, 1988).

Evident from the review of relevant literature, ligamentous damage to the knee joint has been the focus of a compendium of scientific studies indicating the common injury (Li *et al*, 1996; Osternig *et al*, 1996; Kannus *et al*, 1992, Seto *et al*, 1988; Draganich *et al*, 1989; Baratta *et al*, 1988).

Increasing participation of the general population in athletic activity has correspondingly led to an increase of soft tissue injury. Muscle strain injuries are the most frequent injury in sports (Garret, 1990). The most common site of injury amongst players in the South African National Cricket Team is the thigh area (Smith, 1997). The muscles surrounding the knee joint and mostly involved in knee flexion and extension are the hamstring and quadriceps group. The rectus femoris muscle and all three the hamstring muscles are the most injured with the latter muscle group by far the most commonplace of muscle injury. Burkett (1970) was one of the first to report on the high incidence of hamstring muscle injury. Since the publication of his study the hamstring muscle group has been under the research spotlight in ten-folds of etiological and preventative studies (Burkett, 1970; Liemohn, 1978; Glick, 1980; Heiser *et al*, 1984; Sutton, 1984; Coole & Gieck, 1987; Ryan *et al*, 1991; Worrell & Perrin, 1992; Yamamoto, 1993; Worrell, 1994; Jönhagen *et al*, 1994; Best & Garrett, 1996; Orchard, 1997; Upton *et al*, 1996).

The injury has a commonplace occurrence in especially sprinting, cutting and jumping sports (Yamamoto, 1993; Seto *et al*, 1988). Orchard *et al* (1997) reported a total of 16% loss of Australian Rules football playing and training time missed due to hamstring injury. Although only 14% of all sporting injuries surveyed by Muckle (1982) was due to hamstring injury, 30% of actual match playing and training time was lost because of this injury. Hamstring injury is also one of the most often occurring injuries among water skiers (Salley *et al*, 1996).

Reciprocal Muscle Group Ratios

Introduction

Studying the biomechanics of the knee joint and surrounding musculature during normal flexion, extension, functional movements and exercise, one understands the importance of the interrelationship between the joint mechanism, ligaments and muscles to maintain optimal joint integrity. Trauma to any of these structures result in loss of optimal functional and biomechanical status of the joint (Kaufman *et al*, 1991; More *et al*, 1993; Draganich *et al*, 1989; Baratta *et al*, 1988; O'Connor, 1993; Hagood *et al*, 1990; Seto *et al*, 1988; Kannus *et al*, 1992; Osternig *et al*, 1996).

The muscle groups of both sides of a joint necessarily act reciprocally to produce smooth and co-ordinated movement. When a muscle group produces a desired joint motion it is referred to as the agonist of this action and the muscle group producing the opposite joint action the antagonist. To produce concentric extension of the knee the quadriceps muscle group contracts concentrically acting as the agonist. During this extension the hamstrings relax by the principle of reciprocal inhibition acting as the antagonis. Conversely the hamstrings are the agonist and quadriceps the antagonists of concentric knee flexion. The respective roles of the hamstrings and quadriceps muscle groups in producing knee flexion and extension also require that the antagonist act in an eccentric fashion to decelerate the limb near the conclusion of the observed joint action. During knee extension the coactivation of the quadriceps and hamstrings therefor takes place through opposite contraction modes, the quadriceps concentrically and the hamstrings eccentrically.

The strength relationship of two muscle groups (agonist and antagonist) is known as the reciprocal muscle group ratio (Perrine, 1993; Dvir, 1995; Kannus, 1994; Osternig, 1986; Sapega, 1990). Quantified, this ratio is expressed as the weaker muscle group strength as a percentage of the stronger muscle group's strength, thus dividing the stronger by the weaker and multiplying it by 100 for percentage value. If for instance the peak torque of the hamstrings at 60°/sec is measured to be 120 Nm and the quadriceps peak torque in the same test is 220Nm, the HQR will be 0.55 (55%), the hamstring strength 55% that of the quadriceps strength.

Strength training specialists have long recognised the importance of training both muscle groups producing opposite actions about a joint. In spite of these specific training goals, one muscle group usually tends to be stronger than the other. Although not substantially scientifically proven, it has been postulated that excessive imbalances of the reciprocal muscle group ratios predispose the particular joint and/or the weaker muscle group to injury (Kellis & Baltzopoulos, 1995; Grace *et al*, 1984; Campbell & Glenn, 1982; Stafford & Grana, 1984; Orchard *et al*, 1997). Because of this, the ratios of most major joints of the body have received considerable attention in pre-season screening and rehabilitation of athletes.

The concentric and eccentric hamstrings/quadriceps reciprocal muscle group ratio

Dvir (1995) safely claims that at one time 75% of all papers that dealt with any aspect of isokinetics were based on the knee joint. In fact during the early period of research in isokinetics, and until the late 1970's, the relevant medical and physiological literature was strictly knee related.

It has been said that the hamstrings/quadriceps strength ratio (HQR) is more important than the maximal torque in the assessment of muscle function (Campbell & Glenn, 1982). This ratio has been studied with ever growing interest since isokinetics was introduced by Hislop & Perrine in 1967. Controversy exists, however, concerning the optimal value for the knee joint. The literature on isometric and slow concentric isokinetic tests show that the normal HQR varies from 31% to 90% and the recommended optimal ratio between 50% and 80%, generally accepting 60-67% as the average (Nosse, 1982; Osternig, 1986; Kannus, 1989; Dvir, 1995). Klein & Allman (1969) in Heiser *et al* (1984) were the first to identify the ratio as 60% and have been supported by others. Campbell & Glenn (1982) reports that Steindler (1955) made the early generalisation that absolute knee extension force exceeds knee flexion force by a magnitude of three to two or that the knee flexor force is approximately 67% that of the knee extensor.

The values obtained in most of these studies involved concentric contraction. Only after the introduction of eccentric isokinetics during the late 1970's and early 1980's, did this contraction type attract scientific attention. The largest amount of these studies was conducted during the late 1980's and early 1990's, some time after the introduction. The study of Grace *et al* (1984) seem to be the only study referred to by researchers claiming that there is no correlation between low/incorrect HQR and knee joint or knee musculature injury. Later studies showed that the HQR became more specific in application and identified various test parameters having variable effects on the ratio.

Heiser *et al* (1984) showed that a total of 564 intercollegiate football players (players from the 1978-1982 period) that had undergone preseason isokinetic evaluation and achieved a minimum HQR of 55%, experienced 6 hamstring injuries and no recurrences. The comparing group of 534 footballers having only general conditioning as preseason preparation with no strength prerequisites, experienced 41 hamstring injuries and 13 recurrences. Yamamoto (1993) found a high correlation between the HQR and hamstring injury in 64 collegiate track and field athletes. This correlation between the HQR and not only hamstring injury but anterior cruciate ligament (ACL) injury and rehabilitation has been widely supported (Burkett, 1970; Glick, 1980; Muckle, 1982; Sutton, 1984; Coole & Gieck, 1987; Worrell, 1994; Orchard *et al*, 1997; Osternig *et al*, 1996; Li *et al*, 1996; Osternig *et al*, 1986;Campbell & Glenn, 1982; O'Connor, 1993; Baratta *et al*, 1988).

Nosse (1982) reported that while the clinical use of the 0.60/60% ratio has been widely used, the actual attainment of this value occurred under specific conditions which was isometrically at knee flexion angles of 15° for the hamstrings and 65° for the quadriceps. This sudden move of focus from the ratio itself to the conditions of testing started to reveal more parameters of importance to consider when testing and comparing reciprocal muscle group ratios. Factors that influence this value include the protocol of test (including testing velocity, effect of gravity, contraction type, position tested, warm-up procedures), gender, age and joint position.

The effect of test velocity

The early study of Wyatt & Edwards (1981) compared 100 males and females on peak knee flexor and extensor torque irrespective of joint position. The tests were performed across the velocities of 60°/sec, 180°/sec and 300°/sec. The HQR was found to increase from 0.71 to 0.85 as speed increased to 300°/sec. Morris *et al* (1983) tested 10 healthy varsity track and cross-country athletes isokinetically at 30°/sec, 60°/sec, 180°/sec, 240°/sec, 300°/sec. They concluded in agreement with Wyatt & Edwards (1981) that the HQR was lowest at speeds producing the highest torque giving the average HQR as 0.62 at 30°/sec, increasing with speed to 0.87 at 300°/sec. Stafford & Grana (1984), in evaluating 60 intercollegiate football players at velocities from 90°/sec.-300°/sec, ascribed the increasing HQR (with increasing speed) to the fact that the flexors play a greater role in muscular balance at high speed, while at slow speeds the quadriceps are more dominant. The HQR was also found to increase significantly from 30°/sec to 180°/sec by Hageman *et al* (1988). Similar findings were reported by several researchers concluding that the HQR increases with an increase in testing/movement velocity (Klopfer & Greij, 1988; Colliander & Tesch, 1989; Wyatt & Edwards, 1981).

Effect of gravity effect torque (GET) correction

Winter *et al* (1981) and Schlinkman (1984) were some of the first researchers correcting for the effect of gravity when testing joint motion in the vertical plane. Winter *et al* (1981) developed a reliable means of making such corrections, but an electronic accelerometer and recording device are required. Schlinkman (1984) found that even correcting for gravity the HQR of

342 high school football players increased from 0.54 at 60°/sec to 0.67 at 300°/sec. The ratio with correction of gravity resulted in 8-12% lower ratio when compared to the non-gravity-corrected values. Westing & Seger (1989) corrected for the effect of gravity when they evaluated the isokinetic strength of 20 habitually active females' quadriceps and hamstrings at velocities 60°/sec, 120°/sec, 180°/sec, 240°/sec, 360 °/sec and isometrically at 0°/sec. They found no significant increase of the HQR (mean HQR's: 0.46 concentric and 0.57 eccentric) with increasing testing velocities for both concentric and eccentric HQR.

With testing velocities from 60°/sec to 450°/sec Ghena *et al* (1991) found quite the opposite with a significant increase in the HQR with the increasing angular velocities. Worrell and his associates (1991) support this finding. One of the most resent studies concerning the influence of angular velocity, gravity effect torque (GET) and contraction mode on the HQR, is that of Aagaard *et al* (1995). They found a constant HQR (0.47-0.54) with GET correction and significant increase of HQR without GET correction. As angular velocity increases the contribution of gravity to torque production increases in relation to the decreased force of muscular contraction (Nelson & Duncan, 1983; Barr & Duncan 1988).

Critical reviews (Osternig, 1986; Baltzopoulus & Brodie, 1989;Kannus, 1994; Kellis & Baltzopoulus, 1995; Baltzopoulus *et al*, 1991; Finucane *et al*, 1994; Gleeson & Mercer, 1996) support the correction for GET. The error increase can be explained by the different angular positions of maximum torque with increasing angular velocity (Osterning, 1986; Baltzopoulus & Brodie, 1989). Maximum torque is generated at increased knee joint angle as the velocity of movement increases. The gravitational torque also increases with increasing knee joint angle because the horizontal distance between the centre of mass of the limb-lever arm system and the vertical axis of the dynamometer is increasing.

In order to compute the gravity corrected HQR the gravitational torque is added to the quadriceps torque measurement and subtracted from the hamstrings torque measurement resulting in a decrease of the ratio magnitude. At increased knee joint angles the gravitational torque is minimal and the error is smaller (Baltzopoulus & Brodie, 1989).

With decreasing knee joint angle, the gravitational torque increases resulting in a further increase of the HQR and a greater error. If GET correction is performed during isokinetic tests across a range of angular velocities and the HQR increases, the cause of this might be physiological in the sense of fibre type distribution in the two muscle groups. The hamstring muscle group has been shown to be richer in type II fibres than the quadriceps. This would mean that the hamstrings muscle group is capable of producing higher torque values than the quadriceps group at high speeds (Garrett *et al*, 1984; Jönhagen *et al*, 1994).

Finucane *et al* (1994) established a common error in testing on the Kin-Com® isokinetic dynamometer. Based on the results of this study they recommend that when correcting for GET the lever-arm of the Kin-Com® should be held at near horizontal and not the limb segment at the horizontal position. This procedure could well have been a source of error in previous studies.

Effect of testing position

The first isokinetic testing by Hislop & Perrine in 1967 was performed with the subject in the seated position. Since then three testing positions have been used in knee joint evaluations: seated, prone and supine - the first position by far the most common (Dvir, 1995).

In the seated position the hip angle is slightly reclined at approximately 110°-70° of hip flexion. This position allows testing ROM from a maximal 135° of flexion to 0° of flexion (a fully extended knee being in 0° flexion). It has been indicated by several studies that the 'upright'-position has a differential effect on measuring the hamstrings and quadriceps strength (Currier, 1977; Lunnen *et al*, 1981; Bohannon *et al*, 1986; Figoni *et al*, 1988; Worrell *et al*, 1989; Barr & Duncan,1988; Worrell *et al*, 1990; Ford *et al*, 1994; Young & Brooks, 1995; Dvir, 1995; Perrine, 1993; Chan & Maffulli, 1996; Baltzopoulus & Brodie, 1989; Sapega, 1990).

The studies of Currier (1977) and Lunnen *et al* (1981) suggest that greater isometric knee extension force is generated when the hip is in an extended position (0° flexion) and greater knee flexion force is generated when the hip is in a flexed position (110°-130° flexion). In the seated position the hamstring muscle group is in a lengthened position. In a fully extended hip position, the quadriceps femoris muscle is in a lengthened position (Bohannon *et al*, 1986). Given the fact that a muscle generates higher force in a lengthened position, the findings of Currier (1977) and Lunnen *et al* (1981) is not surprising.

Bohannon *et al* (1986) questioned however if greater dynamic knee extension torque would be generated in an extended hip position and if greater dynamic knee flexion torque would be generated in a flexed hip position. They tested 14 healthy females at 60°/sec on a Cybex® II isokinetic dynamometer while the subjects were in an upright seated (85°) or semi-reclined (30°) position. No mention of GET correction was made. Although expecting greater torque values in the semi-reclined position they found no significant difference (1.7% to 6.6%) in knee extension torque between the upright and semi-reclined seated position. Consistent with the studies of Currier (1977) and Lunnen *et al* (1981) they found significantly greater torque production from the hamstrings in the seated position than the semi-reclined position.

Figoni *et al* (1988) tested 18 healthy male college students at hip angles of 5° and 120° and velocities of 15°/sec and 90°/sec. The peak torque values as well as the torque at knee joint angles of 15°, 30°, 45°, 60°, 75° & 90° were used to determine the various HQR's. The rationale for their study was that peak torque for knee flexion and extension occur at different angles, but in normal function when contracting in opposition, they oppose each other at the same knee angle. They found that both the hip and knee angle interact with the velocity of testing and advise that these two angles be taken in consideration with the velocity of testing. The hip angle also influenced the gravity corrected HQR, with higher ratios at 120° hip angle and lower at 5° hip angle. Their study further showed that the HQR could vary from 0.2 to 2.0, depending on factors such as speed of testing, hip position, knee angle, stabilisation and correction of GET. These factors form complex interactions in their effects on the magnitude of these HQR at selected knee angles.

The mechanism for the reduction in hamstring torque in the supine position seems to be related to the length-tension relationship of muscle. This describes an optimal lengthened position of a muscle at which it can develop maximal force (McArdle *et al*, 1991; Komi, 1992; Luttgens *et al*, 1992). Each of the hamstring muscles, except the short head of the biceps femoris, crosses both the knee and the hip joint. At 0°-10° of hip flexion the hamstrings are in a shortened position and the actin-myosin cross bridging does not occur as efficiently. In the seated position however the hamstrings are in a lengthened position and the more optimal actin-myosin cross bridging occurs. Of the quadriceps femoris muscle group the rectus femoris is the only one of the four muscles crossing both the knee and the hip joint. With three of the three and a half muscles of the hamstrings lengthened in the seated position, one can assume that the beneficial effect is greater than that of the quadriceps where one of the four is lengthened when in the supine position. This may explain why the quadriceps torque did not significantly differ in the two positions tested by Bohannon *et al* (1986) while the hamstring torque significantly did.

Worrell *et al* (1989), performing GET correction, evaluated the hamstring and quadriceps torque of 12 healthy university students (7 male and 5 female) in a seated (110° of hip flexion) and supine position (10° of hip flexion) on a Cybex® II at velocities of 60°/sec, 180°/sec and 240°/sec. Their findings were consistent with others (Currier, 1977; Lunnen *et al*, 1981; Bohannon *et al*, 1986 and Figoni *et al*, 1988). Hamstring peak torque was significantly higher in the seated than in the supine position. Contrary to the earlier studies, they found a significant decrease in quadriceps peak torque in the supine position compared to the values obtained in the seated position. In the supine position the hamstrings are placed in an inefficient shortened position and the rectus femoris in an inefficient lengthened position (Worrell *et al*, 1989). This explanation by the authors was further supported by the HQR that increased from the supine to the seated position at all test velocities. The decrease in hamstring torque was twice that of the quadriceps torque decrease. Worrell *et al* (1989) supports the explanation that three of the hamstring muscles cross the hip joint while only one of the quadriceps muscles cross the hip joint, explaining why the quadriceps were not influenced to the same extent the hamstrings were by hip position.

In an earlier study by Barr & Duncan (1988) the gravity corrected hamstring peak torque of 20 healthy male and female subjects in the prone position were compared to the gravity corrected hamstring peak torque in the supine position. They also compared the gravity corrected values to the gravity uncorrected values. Gravitational influences were illustrated by the finding that uncorrected knee flexor peak torque was higher in the supine position than that in the prone position. Surprisingly they also found that the values in the prone position were significantly higher than those measured in the supine position. Many subjects commented on the relative difficulty of the prone activity. The sensation of increased gravitational resistance could have a psychological effect inducing the subjects to put forth more effort (Barr & Duncan, 1988). Another justification for the different torque measurements involves the influence of the tonic labyrinthine reflex. Stimulation of the vestibular system by the placement of an individual prone results in the facilitation of the flexor musculature (Barr & Duncan, 1988). The findings of Barr & Duncan (1988) also support that of Figoni *et al* (1988) that knee angle of peak torque interact with the velocity of testing as well as the hip angle.

In the later study of Worrell *et al* in 1990, they found similar results to that of Barr & Duncan (1988). The higher hamstring peak torque values in the prone position than the supine values were ascribed to the fact that the tonic labyrinthine reflex as well as the symmetrical tonic neck reflexes act as mechanisms increasing flexor force. Their subjects also reported the relative difficulty in executing the prone test.

The studies mentioned above identify important factors of isokinetic testing and it's validity. Firstly, the effect of gravity and the position of the subject when the correction is performed seem to not only affect the peak torque values, but also the angle of peak torque as well as the HQR. Ford *et al* (1994) support the correction of GET in the supine position. This is because of their finding that hamstring flexibility may confound GET. When in the seated position the hamstrings are further lengthened and if a patient has poor flexibility of this muscle group, the effect of gravity may be enhanced because of the increased tension during the lengthened position. They advise therefor to correct for gravity in the supine position to ensure that the hamstrings are relaxed. Secondly, the findings of these studies pose an important clinical question: should exercise and evaluation occur from a position facilitating maximal torque production or from a position replicating a functional position? The studies of Mann & Hagy (1980), Mann (1981), Mann *et al* (1986) and Montgomery *et al* (1994) analysed the biomechanics of running and sprinting and demonstrated a hip position of 0°-20° flexion during these activities. Momentum during the swing phases take the hip past these angles, but when either the hamstrings or quadriceps are activated from heel strike to toe off, the hip angle is between 20° flexion and 5° extension. With this in mind, evaluation of athletes involved in sprinting and running activities would seem most appropriate from the supine position. Also what should be kept in mind is the fact that the body posture in running is adapted to the purpose of the sport and the position played. When exercising or training the knee flexors and extensors isokinetically, the most efficient position is still to be identified. Should one train in a position where the musculature is in a lengthened position to promote optimal tension development and therefor optimal hypertrophy or should one train in the most functional position possible? This remains a question for research to resolve. The possibility that testing a muscle in optimal position might confound subtle strength deficits, remains another.

Most of the research available on the effect of hip position on isokinetic parameters, evaluated concentric knee flexion and extension only and therefore a third aspect is the effect of hip position on not only concentric but eccentric hamstrings and quadriceps torque and the HQR. Young & Brooks (1995) evaluated 10 healthy university females. Eccentric knee flexion and extension was performed at 90°/sec at hip angles of 90° and 5°. Concentric flexion and extension torque was also measured, but at 180°/sec at the same hip angles. Correction for GET was performed. They found that the eccentric (90°/sec) torque of both the quadriceps and the hamstrings were significantly lower in the supine position than that measured in the sitting position. The concentric (180°/sec) torque of quadriceps were significantly lower in the supine position, but no significant difference was found between the sitting and supine concentric hamstrings torque, supporting the findings of Worrell *et al* (1989). Explanations of their findings are consistent with previous studies (Currier, 1977; Lunnen *et al*, 1981; Bohannon *et al*, 1986; Figoni *et al*, 1988; Worrell *et al*, 1989; Barr & Duncan,1988; Worrell *et al*, 1990; Ford *et al*, 1994). HQR were calculated for both test speeds. The eccentric results showed an increase in the HQR in supine, but a similar trend was not observed on concentric testing.

A fourth factor is the matter of stabilisation of the subject in the chair. Hart *et al* (1984) have shown that adding thoracic strapping improved quadriceps strength significantly. Magnusson *et al* (1992) explored the effect of 'maximal' (thigh and thoracic strapping) and 'minimal' (gripping) stabilisation and found higher scores with maximal and lower scores with minimal stabilisation. Hanten & Ramberg (1988) found no difference in torque production between no stabilisation (only gripping) and using femoral, thoracic and pelvic strapping. However, since gripping can not be applied to all subjects with the same efficiency (Bohannon *et al*, 1986) most isokinetic machines do not offer this option. Therefor stabilisation in the seated position is normally confined to femoral/thigh, pelvic and thoracic segments. Although none of the studies presented data on the effect of stabilisation on peak torque and the HQR, all mentioned the possibility that stabilisation could effect the results of an isokinetic test (Currier, 1977; Lunnen *et al*, 1981; Bohannon *et al*, 1986; Figoni *et al*, 1988; Worrell *et al*, 1989; Barr & Duncan, 1988; Worrell *et al*, 1990; Ford *et al*, 1994 and Young & Brooks, 1995).

Effect of age and gender

Strength is an indispensable precondition for any movement. It is well documented that increase in age has a decreasing effect on muscular strength (Israel in Komi, 1992; McArdle *et al*, 1991). Further, it has been shown that the aging process of the spinal cord and peripheral nerves proceeds relatively slowly in athletic old persons (Israel in Komi, 1992). Israel in Komi (1992) confirms that strength potential reaches the highest level during early adulthood, age 18 to 29yrs. Under normal conditions, middle-aged persons from the age of 30yrs to the age of 60yrs present a continuous decline in muscular strength. The decrement of strength during the course of aging has to be differentiated according to activities, gender and body area.

The most comprehensive study of isokinetic knee flexor and extensor strength, at least in terms of the population size, was Freedson *et al* (1993) in Dvir (1995), who tested 4541 subjects, 1196 women and 3345 men, all between the ages of 18 and 58yrs. Participants were from 20 companies that carried out medium to heavy physical work. Testing at three velocities (60°/sec, 180°/sec & 300°/sec) and not correcting for GET, they found a general tendency of strength loss with increasing age. There was a faster strength loss with age in women, as compared to men. The loss in strength does not necessarily mean that there will be a drop in the HQR. Due the lack

Presuming that the strength loss is of the same proportion in both the quadriceps and the hamstrings, the HQR should not differ. This however needs further investigation. There might be the possibility that the atrophy associated with aging to be more in the quadriceps muscle group than the hamstrings muscle group. Borges (1989) evaluated the isometric and isokinetic strength of knee flexion and extension at three velocities of men and women aged 20-70yrs. No significant difference was found for the isokinetic and isometric values between moderately active and inactive subjects (Tables 5 & 6). A significant decrease in strength between the ages of 20 and 30 years in men and between 40 and 50 years in women was also found. There was a significant decrease in strength for both sexes between the ages of 60 and 70 years.

		12 deg/sec		90 deg/sec		150 deg/sec	
	Age (yrs)	**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
Females	**20**	183 (34)	172 (31)	143 (25)	137 (24)	110 (18)	106 (19)
	30	169 (34)	163 (30)	138 (22)	134 (20)	108 (19)	107 (15)
	40	172 (28)	161 (26)	134 (20)	131 (20)	105 (15)	102 (14)
	50	153 (30)	143 (26)	122 (18)	114 (17)	94 (16)	92 (14)
	60	145 (20)	126 (24)	113 (13)	99 (15)	84 (10)	79 (12)
	70	128 (128)	120 (25)	98 (17)	93 (15)	74 (12)	70 (11)
Males	**20**	289 (44)	269 (47)	231 (32)	217 (27)	180 (24)	179 (22)
	30	258 (45)	243 (47)	207 (38)	196 (35)	158 (34)	160 (28)
	40	148 (29)	238 (42)	203 (27)	197 (31)	158 (24)	155 (26)
	50	226 (51)	220 (45)	186 (36)	177 (92)	145 (27)	143 (30)
	60	223 (48)	212 (40)	179 (34)	169 (32)	142 (28)	136 (22)
	70	188 (36)	183 (37)	143 (24)	145 (30)	113 (22)	113 (21)

Table 5:

Normative peak moments of knee extensors (in Nm) at three angular velocities, based on Borges (1989). Findings express as mean (SD).

Looking at the HQR of the subjects tested by Borges (1989) in Table 7, it is evident that as there is a decrease in the strength of both the hamstrings and quadriceps, the HQR stays relatively the same, more so for the males than for the females. There is a slight decrease in the female HQR with an increase in age.

		12 deg/sec		90 degrees/sec		150 degrees/sec	
Age (yrs)		**Right**	**Left**	**Right**	**Left**	**Right**	**Left**
Females	**20**	100 (20)	95 (20)	68 (21)	66 (17)	49 (19)	49 (19)
	30	90 (12)	88 (12)	61 (15)	58 (13)	46 (14)	46 (14)
	40	93 (20)	91 (18)	62 (14)	61 (13)	46 (14)	46 (14)
	50	76 (24)	75 (20)	52 (13)	51 (13)	36 (13)	36 (13)
	60	77 (14)	74 (17)	53 (12)	47 (13)	38 (11)	38 (11)
	70	65 (12)	59 (13)	39 (13)	38 (13)	28 (8)	28 (8)
Males	**20**	155 (28)	144 (27)	122 (21)	113 (21)	96 (19)	96 (19)
	30	150 (28)	143 (35)	113 (23)	108 (29)	91 (26)	91 (26)
	40	149 (22)	144 (24)	112 (18)	106 (21)	87 (16)	87 (16)
	50	142 (32)	129 (30)	98 (24)	91 (25)	82 (23)	82 (23)
	60	130 (38)	133 (34)	95 (29)	86 (30)	78 (24)	78 (24)
	70	109 (30)	109 (32)	78 (26)	77 (23)	61 (23)	61 (23)

Table 6:

Normative peak moments of knee flexors (in Nm) at three angular velocities, based on Borges (1989). Findings express as mean (SD).

	12 deg/sec			90 deg/sec			150 deg/sec		
Age (yrs)	**R-HQR**	**L-HQR**	**L&R Ave**	**R-HQR**	**L-HQR**	**L&R Ave**	**R-HQR**	**L-HQR**	**L&R Ave**
Females 20	54.6	48.2	51.4	47.6	55.2	51.4	44.5	46.2	45.4
30	53.3	43.3	48.3	44.2	54.0	49.1	42.6	43.0	42.8
40	54.1	46.6	50.4	46.3	56.5	51.4	43.8	45.1	44.5
50	49.1	44.7	46.9	42.6	52.4	47.5	38.3	39.1	38.7
60	53.1	47.5	50.3	46.9	58.7	52.8	45.2	48.1	46.7
70	50.8	40.9	45.9	39.8	49.2	44.5	37.8	40.0	38.9
Males 20	53.6	52.1	52.9	52.8	53.5	53.2	53.3	53.6	53.5
30	58.1	55.1	56.6	54.6	58.8	56.7	57.6	56.9	57.3
40	100.7	53.8	77.3	55.2	60.5	57.9	55.1	56.1	55.6
50	62.8	51.4	57.1	52.7	58.6	55.7	56.6	57.3	57.0
60	58.3	50.9	54.6	53.1	62.7	57.9	54.9	57.4	56.2
70	58.0	53.1	55.6	54.5	59.6	57.1	54.0	54.0	54.0

Table 7:

Right HQR (R-HQR), left HQR (L-HQR) and average of left and right HQR derived from the values obtained by Borges (1989).

Effect of body size

Isokinetic strength has been shown to be related to body size and age in children and young athletes (Molnar & Alexander, 1974; Gilliam *et al*, 1979). Thomas (1984) conducted a similar study testing the isokinetic strength of the knee flexors and extensors of adult females at velocities of 60°/sec and 240°/sec to determine the relationship of the torque generating capabilities to age and body size. He found that age, and to a lessor extent bodyweight and height, can account for torque differences in adult females, regardless of speed of movement. An increase in age tends to cause a decrease in torque output, while an increase in body weight and height increase torque output. His study demonstrated the effect of not correcting for

GET by finding that with an increase in velocity of testing there was a larger decrease in quadriceps torque than in hamstrings torque (Thomas, 1984).

The effect of age, bodyweight and -length/stature is important for the biokineticist, since an accurate reference standard for equalising strength scores is a valuable tool in exercise rehabilitation. Nutter & Thorland (1987) examined the relative importance of body size and composition as determinants of individual differences in isokinetic leg extensor strength in young adult males and females at 60°/sec, 180°/sec and 240°/sec (no mention was made concerning of GET correction). At each of the three velocities both lean bodyweight and bodyweight had a moderate correlation with quadriceps peak torque (Nm/kg of bodyweight). Thigh circumference was also found to have a low to moderate correlation with quadriceps strength at all velocities.

The authors conclude that in trained individuals higher correlations may reflect underlying factors such as training-induced changes in fibre recruitment patterns used within specific muscle groups, greater hypertrophy of fast twitch fibres, increased neurological facilitation, greater muscle mass relative to body weight or greater reliability of measurement. This is important since low to moderate correlations between body size and strength may suggest that additional factors determine differences in strength. These may further include muscle fibre type and distribution, enzyme capacity to replenish ATP and anatomical properties of the joint. Important to remember is muscle contraction under isokinetic conditions (peak torque values and therefor HQR) reflect selective recruitment of fibre types and patterns of neuromuscular co-ordination according to the speed of testing which differ from those of static or isometric contractions or contractions associated with resistance/weight training.

The study conducted by Highgenboten *et al* (1988) evaluated the relationship between knee flexion and extension torque (concentric and eccentric) and body weight. Part of the study also included a comparison of

HQR (concentric and eccentric) between females and males aged 15 to 34yrs. All subjects were non-symptomatic and a total of 127 subjects (54 males and 73 females) were tested at 50°/sec on a Kin-Com® dynamometer and no GET correction was performed. The younger age group of 15-24yrs produced significantly greater concentric flexion and extension torque than the older 24-34yrs group. They also found a significant gender difference, with all male values higher than those of females. Interestingly they found that there was no significant difference between the HQR in relation to age and gender. The mean concentric HQR was found to be 0.5 across all ages in both genders and a higher mean value of 0.58 for eccentric comparisons.

When adjusting peak torque values of hamstrings and quadriceps in relation to body mass the gender difference seem to reduce less in concentric values than the eccentric values (Colliander & Tesch, 1989). Hence, males showed a 23% and 8% greater peak torque per unit of body weight than females for concentric and eccentric modes respectively in the study of Colliander & Tesch (1989). The lack of GET correction could be identified by the finding that the decrease in quadriceps torque as velocity increased was significantly more than that of the hamstrings. As a consequence to this, the HQR was found to increase with increasing velocity, a finding supported by Wyatt & Edwards (1981). Colliander & Tesch (1989) conclude that angular velocity and muscle action influence the HQR more than gender and body mass. Studies supporting the influence of contraction type and even more so the angular position at which torque values are taken from to compute the HQR, may be of more functional value (Figoni *et al*, 1988; Hageman *et al*, 1988; Klopfer & Greij, 1988).

The HQR of males and females seem not to be significantly different even if the concentric torque values are less than that of males and the eccentric values are more comparable. The higher eccentric torque production by females may be because of females utilising stored elastic energy (the visco-elastic properties of muscle involved in eccentric contraction) to a greater extend than men (Colliander & Tesch, 1988).

Klopfer & Greij (1988) found the only way to compare their torque values obtained from the females (n =32) and males (n =23) aging 19yrs to 37yrs (within and between the gender group), was to compute peak torque as a percentage of body mass. Finding similar results and not correcting for GET, Hageman *et al* (1988) advises not to compare male and female values due to the well-documented physiological differences. Kannus & Kaplan (1991) found in their study, as found in previous studies, that hamstrings and quadriceps peak torque values of the men they tested (18-45yrs) were twice as much that of the females of the same age group. The average relationship between the hamstrings and the quadriceps were between 50%-80% in both groups. The group of subjects used in this study therefor represented a healthy, moderately active adult population ranging in age from 18 to 45 years.

Comparing the findings of the above mentioned studies, it seems that correlations between strength and factors age and gender does not have such an important role in the rehabilitation of the strength ratio between the flexors and extensors of the knee joint. Female peak torque values are lower than that of males and peak torque of patients between the age of 18yrs and 30yrs are almost guaranteed to be higher than those above the age of 30yrs. The difference between the genders become smaller when expressing the peak torque values relative to body mass, but still remains. Peak torque values, within the same group of patients or subjects, expressed relative to bodyweight seem to be more accurate in equalising the values for comparison. Despite the differences in peak torque values of the hamstrings and quadriceps amongst different ages and genders, the HQR remains relatively stable. This inevitably means that there is little to no difference across gender and age in the strength relationship between the hamstring and quadriceps muscle groups. (Thomas, 1984; Nutter & Thorland, 1987; Highgenboten *et al*, 1988; Hageman *et al*, 1988; Klopfer & Greij, 1988; Westing & Seger, 1989; Westing *et al*, 1988; Colliander & Tesch, 1989).

The correlation between knee flexion and extension strength, bodyweight and lean bodyweight within the same age group and/or athletic population does however have its place and is widely used. Evaluating the research available on the athletic population, this becomes more apparent. Housh *et al* (1984) tested the isokinetic strength of female adolescent track and field athletes. Comparing absolute strength, the flexion and extension strengths of the throwers were higher than that of the jumpers, middle distance runners and the sprinters. When the relative strengths (compared to bodyweight and lean bodyweight) were compared, no significant strength differences were found between the four athletic groups. In a study by Read & Bellamy (1990) they evaluated the isokinetic quadriceps and hamstrings strength of elite tennis, squash and track athletes. They found significant differences in peak torque within and between groups, but a HQR that remained between 60%-80%.

Literature studying the correlation between the HQR and body weight and lean body weight is scares. This might be due to the fact that even though there is a moderate to high correlation between body weight and/or lean bodyweight and peak torque, this correlation does not carry through to the strength relationship between the hamstrings and quadriceps muscle groups.

The clinical studies of Kannus and his various associates during 1988 to 1994 on especially the injured knee and the muscle strength characteristics added invaluable information to this particular field of sport science. Concerning the strength relationship between the hamstrings and quadriceps muscle groups, one conclusive fact is present in every study conducted by him: This ratio is a too individual measurement to justify recommending general optimal values for it and that the first step in the rehabilitation process of an unstable knee is to attain the HQR of the opposite healthy extremity. From here the optimum HQR can proportionately be attained to the functional use of the hamstrings and quadriceps of the particular patient and for the specific activities (Kannus, 1988a; Kannus, 1988b; Kannus, 1989; Kannus, 1990; Kannus & Järvinen, 1990; Kannus & Järvinen, 1991; Kannus *et al*, 1992; Kannus, 1994).

Relationship between eccentric hamstring strength and concentric quadriceps strength

It is a well known fact that each sport and the specific positions played within the sport, even individual sports where position can relate to the style of play, each individual will need and necessarily have different physical and physiological requirements. In a sport like soccer the physical requirements are very much the same amongst all positions but it differs considerably from that of a front and back line rugby player, a hockey player, a sprinter/hurdler or a jumper. The physical attributes of a lock forward will certainly be different than that of the centre or wing. It is therefor apparent that in some sports all or some positions might require similar and might not require similar physical and physiological attributes.

In top performance sports where large amounts of money are invested in athletes and an injury free season becomes of paramount importance, all available science is used to reduce the risks of injury and preventing large amounts of money to be lost. This practice has been implemented far more extensively in the past 5-10 years and resulted in research being conducted in newer areas of medicine and especially sports science. As mentioned earlier the most of the isokinetic research on specifically the knee joint and its surrounding musculature was done in the late 1960's to early 1970's and then again during the 1980's (Dvir, 1995). Very little additional information about the HQR and knee flexion and extension characteristics was brought under the spotlight. During the later 1990's a sudden development in the functional importance of eccentric exercise and the benefits associated with it lead to some questioning about the functional importance of the known concentric hamstring quadriceps reciprocal strength ratio.

The respective roles of the hamstrings and quadriceps muscle groups in producing knee flexion and extension require that the antagonist act in an eccentric fashion to decelerate the limb near the conclusion of the observed joint action. During knee extension the co-activation of the quadriceps and hamstrings takes place through opposite contraction modes, the quadriceps concentrically and the hamstrings eccentrically. In daily activities, the agonist muscle group (quadriceps) works concentrically to accelerate the limb forward whereas the antagonist group (hamstrings) generate eccentric tension to decelerate the limb and/or prevent joint overloading. This has been shown with electromyography measuring the increased activity of the hamstrings during knee extension (Westing *et al*, 1991). It has been reported that eccentric antagonist/concentric agonist ratio deficits at a given velocity may be related to injury (Bennet & Stauber, 1986).

As mentioned earlier as the test velocity increases the concentric torque decreases and the eccentric torque increases initially but at higher velocities it plateaus. If measured at the same velocity, the order of strength, dependant on contraction mode, is eccentric > isometric > concentric (Elftman, 1966 in Dvir, 1995). The increased moment observed during eccentric contractions, deviates from both the theoretical model and the in vitro findings, shown by the levelling off of the moment-angular velocity curve which takes place even at relatively low velocities. This finding has been confirmed by others (Colliander & Tesch, 1989; Ghena *et al*, 1991; Dvir, 1995). The explanation for this phenomenon posits a negative feedback loop that involves a peripheral and spinal regulation in order to avoid excessive stresses on the muscle itself (Bennet & Stauber, 1986). According to this explanation the central nervous system monitors total tension over the time concerned (impulse) and limits the eccentric potential of the muscle. When this loop fails to operate properly, as might occur in sudden and vigorous stretching of an active muscle, tear of the musculo-tendinous unit could result. If the active muscle is stretched to an extent where no tear occurs but the muscle finds itself in a vulnerable position, there is a possibility that secondary functions of the particular muscle might suffer under these situations. An example can be damage to the anterior cruciate ligament tear where the protective posterior draw of the hamstrings was not sufficient against the anterior or rotary force. This however needs further investigation.

Studies have shown that with respect to single joint testing, particularly the knee, the eccentric/concentric strength ratio of the same muscle group derived from low-medium velocities, is very likely to be 0.95 to 2.0 (Dvir, 1995; Bennet & Stauber, 1986; Albert, 1995). Current knowledge on the effect of velocity increase on the ratio is scares, since the use of high velocities for the study of eccentric muscle performance is not risk free (Albert, 1995). It might be assumed that because the concentric value decrease and the eccentric value increase or stabilise with increasing velocities that the ratio would increase with increasing velocity. Bennet & Stauber (1986) have reported that deviations from this range relates to pathological conditions such as anterior knee pain and that correction of this ratio relieved symptoms as well as removed the presumable cause of the anterior knee pain within as little as 14 days of isokinetic rehabilitation. Since the nature of many athletic and normal movements involve the concentric and eccentric actions, the eccentric antagonist/concentric agonist ratio and the eccentric/concentric strength ratio of the same muscle group, may be more valid indicators of the muscular imbalance than the eccentric or the concentric HQR.

The joint and muscular actions involved in hamstring muscle and anterior cruciate ligament (ACL) injuries involve the quadriceps and more importantly the hamstrings. As mentioned earlier the most common knee joint injury is the ACL tear and the most common muscle injury is the hamstrings muscle tear (Garret *et al*, 1984; Sutton, 1984; Orchard *et al,* 1997; Osternig *et al*, 1996; Hagood *et al*, 1990; Osternig *et al*, 1986; Li *et al*, 1996). Prerequisites for the prevention of hamstring injury have been the subject of many studies. One of the firsts to look at the causative factors of hamstring strains in football players and track athletes was Burkett in 1970. A cable-tension knee flexion and extension test was performed on each subject. The HQR was calculated for each subject and it was found that four of the six subjects (in total 12 subjects were tested) that had a HQR below 0.5 sustained hamstring injury within four weeks after the first test. Unfortunately no mention was made at which angles of knee flexion and extension the strengths were measured and no GET was performed. Liemohn (1978) followed the same protocol as Burkett (1970) but increased the sample size to subjects included sprinters, hurdlers, jumpers and pole-vaulters. Liemohn concludes in agreement with Burkett that there appear to be a host of factors and not just a low HQR, that either singularly or synergistically precipitate and/or potentiate hamstring strains.

These factors became the focus of an abundance of studies during the following years. Table 10 summarises the etiological factors been studied during the period of 1970 to 1997. Lack of hamstring flexibility, eccentric hamstring strength, ipsi-lateral hamstring strength deficits and inadequate warm-up rank top of the list concerning the etiological factors of hamstring muscle injury according to Table 8. The fact that the hamstring is a bi-articulate muscle (crossing two joints) received considerable attention, but this however relates to lack of flexibility, since the mechanism of injury involves the muscle being overstretched across the two joints (knee extension during hip flexion). The lack of functional training, endurance and a low HQR can be associated with lack of hamstring strength, whether concentric or eccentric.

A review of literature identify common mechanisms of hamstring injury:

1. Excessive antagonistic force placed on relaxed/lengthening hamstring, over-stretching the muscle which in turn results to injury (Sutton, 1984; Worrell *et al,* 1991; Worell & Perrin, 1992; Sullivan *et al,* 1992; Jönhagen *et al,* 1994; Worrell *et al,* 1994).

2. When the hamstring muscle is overstretched while fully elongated, the muscle responds with rapid and excessive protective contraction (due to the rapidly altered muscle spindle activity), which is opposed to by the frictional resistance within the muscle framework (Glick, 1980; Sutton, 1984; Coole & Gieck, 1987).

Etiology	Literature
HQR<50-60%	Burkett (1970);Leimohn (1978); Glick (1980); Heiser *et al* (1984); Yamamoto (1993); Orchard (1997)
Lack of hamstring flexibility	Burkett (1970);Leimohn (1978); Glick (1980); Sutton (1984); Worrell *et al* (1991); Worell & Perrin (1992); Sullivan *et al* (1992); Jönhagen *et al* (1994); Worrell *et al* (1994).
Lack of endurance (fatigue)	Leimohn (1978); Glick (1980); Sutton (1984); Worrell Perrin (1992)
Excessive quadriceps strength	Muckle (1982)
Ipsilateral hamstring strength difference>10%	Heiser *et al* (1984); Sutton (1984); Garret *et al* (1984); Worrell & Perrin (1992); Yamamoto (1993); Orchard (1997)
Inadequate warm-up	Heiser *et al* (1984); Sutton (1984); Coole & Gieck (1987); Worrell *et al* (1991); Worrell & perrin 91992);
Lack of eccentric hamstring strength	Sutton (1984); Garret *et al* (1984); Coole & Gieck (1987); Worrell *et al* 91991); Ryan *et al* (1991)Worrell & Perrin (1992); Jönhagen *et al* (1994); Worrell *et al* (1994).
Bi-articulate muscle (hamstrings)	Heiser *et al* (1984); Sutton (1984); Yamamoto (1993) ; Coole & Gieck (1987).
Dual nerve innervation of Biceps femoris	Burkett (1970); Heiser *et al* (1984); Sutton (1984)
Inadequate rehabilitation	Muckle (1982); Sutton (1984); Upton *et al* (1996)
Faulty running technique and skill	Muckle (1982); Sutton (1984)
Lumbar spine abnormalities (lordosis)	Muckle (1982); Hennesey & Watson (1993)
Meniscal problems of the knee joint	Muckle (1982)
Lateral popliteal nerve adhesion	Muckle (1982)
Non-functional training	Heiser *et al* (1984); Sutton (1984); Coole & Gieck (1987); Worrell *et al* (1991); Orchard (1997)
Poor posture	Sutton (1984)
Mg imbalance	Sutton (1984)
Psychological factors	Sutton (1984)
Training experience	Sutton (1984); Jönhagen *et al* (1994)

Table 8: Etiological factors to hamstring muscle group injury

3. The hamstrings contain predominantly type II muscle fibres capable of high intrinsic forces and thus put in positions to do just that, but very seldom they are thoroughly prepared to perform this function. Most injuries occur during the late swing and early take-off phase of running gait when this contraction-change takes place. Most of the injuries also occur during the early or last part of training session, game or season (Sutton, 1984; Heiser *et al*, 1984; Yamamoto, 1993).

4. Injury to the hamstrings mostly involve type II fibres (Garret *et al*, 1984; Coole & Gieck, 1987; Worrell *et al*, 1991; Ryan *et al*, 1991, Worrell & Perrin, 1992; Jönhagen *et al*, 1994; Worrell *et al*, 1994).

5. The functional change from eccentric deceleration to concentric acceleration (Coole & Gieck, 1987; Worrell *et al*, 1991; Ryan *et al*, 1991, Worrell & Perrin, 1992; Jönhagen *et al*, 1994; Worrell *et al*, 1994).

These mechanisms can all be correlated with the etiological factors. Most of the studies concur, but few studies substantiate or prove that these etiological factors predispose one to injury. Most of the studies are unclear as to whether muscle weakness or lack of flexibility (the two most common etiological factors) was caused by the strains or if the weak and/or inflexible muscle induced the strains, since comparisons are made between injured and uninjured subjects (Yamamoto, 1993; Ryan *et al*, 1991). Burkett (1970) and Liemohn (1978) are the only two studies predicting injury from testing data. It is important to remember that this host of factors and mechanisms, and not just strength and flexibility, either singly or synergistically precipitate and/or potentiate hamstring strains. No single reason for injury and no single treatment are available.

The active muscle tension is proportionate to the fibre type distribution and the tear occurs when the tension exceeds the tension maximum of the weakest part of the muscle (Garret *et al*, 1984; Glick, 1980). This happens most in the biceps femoris muscle (Glick, 1980; Muckle, 1982; Sutton, 1984; Garret *et al*, 1984) during heel strike or take-off (toe-off) phase of running gait.

As mentioned earlier the eccentric strength exceeds concentric strength and thus it can be assumed that hamstring injury occurs in type II fibres (Garret *et al*, 1984) during maximal eccentric contraction often during simultaneous knee extension and hip flexion (kicking action, leading leg of hurdlers) and just before or at heel strike.

Friden *et al* (1983) suggested that due to the extreme tension generated, eccentric contraction cause a preferential recruitment of type IIb muscle fibres. Friden *et al* (1983) also demonstrated that eccentric training produces structural changes in muscle fibre architecture and that these changes occur primarily in type IIb fibres. These adaptations produce an optimal overlay between the actin and myosin filaments; create greater muscle fibre stretchability; and reduce the risk of mechanical damage to the muscle, resulting in an increased ability to produce force when these fibres are recruited. This has been supported by others (Albert, 1995).

According to the pattern of motor unit recruitment, a greater number of Type IIb fibres are recruited as the speed and intensity of concentric exercise increase (McArdle *et al*, 1991). Thus by enhancing the force production of type IIb fibres, eccentric training may lead to an improvement in the muscle's ability to produce force eccentrically and at higher speeds concentrically (Ryan *et al*, 1991). Eccentric training of the hamstrings has been indicated as one of the most important prophylactic treatments when injury has occurred in this muscle group and for prevention of recurrence (Heiser *et al*, 1984; Sutton, 1984; Worrell *et al*, 1991; Worrell, 1994; Jönhagen *et al*, 1994)

Flexibility and hamstring muscle strength (the variables most often tested in studies of hamstring muscle strains) must be examined in light of the activity where the injury most often occurs: the ballistic action of sprinting during which the hamstrings are subject to high forces during open and closed kinetic chain movements (Seto *et al*, 1988).

In contrast to walking, where the body is supported by one or both feet constantly in contact with the ground, running involves a serious of co-ordinated jumps during which the bodyweight is supported only intermittently on one foot. Hamstring muscle activity during running/sprinting serves three functions:

1) By contracting eccentrically to decelerate the forward displacement of the lower leg and to stabilise the knee during the forward swing phase,
2) extend the hip during the support phase by means of concentric contraction and
3) to assist the gastrocnemius muscle in paradoxically extending the knee during the take-off phase of the running cycle.

(Elliot & Blanksby, 1979; Mann & Hagy, 1980; Montgomery *et al*, 1994; Mann *et al*, 1986; Mann, 1981; Norkin & Levangie, 1992).

Garret *et al* (1984) refers to eccentric hamstring activity counteracting concentric quadriceps contraction during knee extension. He further reports that a strength imbalance between these two muscle groups, the concentric HQR, has shown to be related to injury. Comparing concentric hamstring strength with concentric quadriceps strength while stating that the actual action is concentric quadriceps eccentric hamstrings, could be one of the reasons why even though an optimal concentric HQR has been achieved, the athlete still has a high rate of recurrence. This error is evident in many other studies (Burkett, 1970; Liemohn, 1978; Glick, 1980; Heiser *et al*, 1984; Sutton, 1984; Coole & Glick, 1987; Ryan *et al*, 1991; Worrell & Perrin, 1992; Yamamoto, 1993; Worrell, 1994; Jönhagen *et al*, 1994; Best & Garrett, 1996).

Worrell *et al* (1991) found no relationship between hamstring injury and concentric HQR or eccentric HQR and ascribed flexibility (incorrect & ineffective stretching) as the single most important factor in treating and preventing injury. Hennessy & Watson (1993) and Sullivan *et al* (1992) support this. The relation between hamstring injury and the HQR seem to be individual hamstring weakness (Worrell & Perrin, 1992; Worrell *et al*, 1994; Orchard, 1997; Best & Garrett, 1996) instead of a strength imbalance, since there is no simultaneous concentric contraction of the hamstrings and quadriceps.

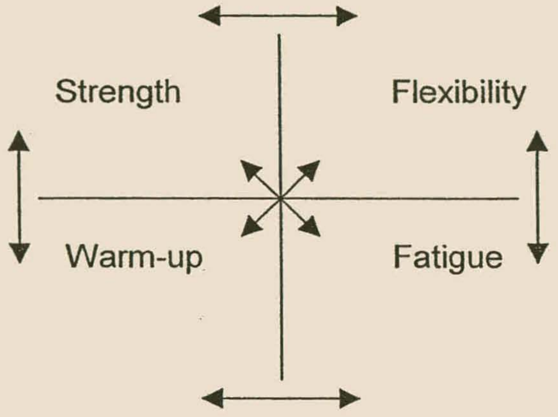

Figure 9:

The theoretical hamstring model proposes that injury can occur as a result of a single factor interacting between several factors. (Worrell & Perrin, 1992).

Literature research could only find two studies concerning the concentric agonist (quadriceps)/eccentric antagonist (hamstrings) strength ratio of which both were very resent. Aagaard *et al* (1995) investigated the concentric and eccentric strength of the quadriceps and hamstrings of 22 elite soccer players at isokinetic test velocities of 30°/sec, 120°/sec and 240°/sec. They state that the 'conventional' HQR merely indicates the degree of qualitative similarity between the quadriceps and the hamstring torque-velocity patterns due to the similar findings of both muscle group strengths across speeds. Dynamic joint movement is characterised by concentric agonist and simultaneous eccentric antagonist involvement, or vice versa (Aagard *et al*, 1995). Such antagonistic co-contraction seem to be an important inherent protective component in especially the knee joint where it has been suggested to reduce the anterior shear of the tibia relative to the femur (Jurist & Otis, 1985; Baratta *et al*, 1988; Kaufman *et al*, 1991; Nisell *et al*, 1989; Renström *et al*, 1986; Solomonov *et al*, 1987; More *et al*, 1993; Draganich *et al*, 1989; O'Connor, 1993). For this obvious need for information on the agonist-antagonist strength relationship they introduced a 'functional' HQR to assist in evaluating dynamic joint stability. They found the concentric quadriceps/eccentric hamstring strength ratio ranged from 0.89 to 1.05 at the faster velocities. Keeping in mind that concentric strength tends to decrease and eccentric strength to increase with increasing velocity, it is not surprising that the ratio increases with increasing velocity. This finding is however an extremely effective example of why and how the different parameters of muscle function synergistically assist in maintaining, in this case, dynamic joint stability. One may go as far as to speculate that according to Newton's law that for every action there is an equal opposite reaction, the 'functional' HQR should aim for a 1.0 relationship since equal eccentric hamstring strength will stop equal, opposite concentric quadriceps strength.

Osternig *et al* (1996) acknowledged the findings of several other studies on the importance of eccentric hamstring activity during knee extension to maintain dynamic joint stability. They tested 14 subjects of which 7 had ACL reconstructed knees and the remaining 7 were healthy. Eccentric and concentric knee flexor and extensor strength was measured at velocities of 15°/sec, 30°/sec, 45°/sec and 60°/sec. The concentric extensor/eccentric flexor ratio increased with the increase in velocity approaching equality at 60°/sec for both the injured and uninjured group. Hagood *et al* (1990) reported that as the knee extension velocity increased to 240°/sec there was a significant EMG activity rise in the hamstring muscle group. This suggests an increase joint stiffness and decrease in laxity as speed of movement increases. This may also suggest that if this mechanism does not work properly, as is the case in ACL deficient knees (Hagood *et al*, 1990; Osternig *et al*, 1996), the knee joint becomes more vulnerable to injury.

The purpose of this particular study is to evaluate in particular the relationship between the concentric strength of the quadriceps muscle group and the eccentric strength of the hamstring muscle group at a preset angular velocity in a healthy, athletic population, since these two strengths play an integral part in the dynamic knee joint stability and muscle function. This relationship has extensively been supported in research, but quantifiable data to assist the rehabilitation specialist in the treatment and prevention of particularly ACL and hamstring muscle injury is lacking (Aagard *et al*, 1995, Osternig *et al*, 1996; Osternig *et al*, 1986; Li *et al*, 1996; Hagood *et al*, 1990; Ghena *et al*, 1991; Westing *et al*, 1991; Jurist & Otis, 1985; Baratta *et al*, 1988; O'Connor, 1993; Draganich *et al*, 1989; More *et al*, 1993)

Chapter Three

Methods and Procedures

Introduction

The purpose of this study was to determine the maximal concentric and eccentric strength of both the hamstring and quadriceps muscle groups. For the adequate determination of these maximal strength values the data was obtained by means of an isokinetic muscle performance evaluation. The evaluations were performed at the Biokinetics Laboratory of the University of Stellenbosch. The underlying premise of the study was that well-conditioned sports people demonstrate strength ratios involving the hamstring and quadriceps muscle groups that correspond with the functional use of these muscle groups during human movement.

Subjects

The sample size of this investigation consisted of 45 athletes all attending the South African Rugby Institute (SARI) in Stellenbosch, South Africa. All subjects were actively involved, training and competing, in the sport of rugby and have been injury free in the lower limbs for a minimum period of 12 months. This population was selected because of the importance of optimal knee-joint, quadriceps and hamstring muscle integrity to assist the pool of factors all essential for top performance. An invitation letter was sent to coaches and players involved inviting them to take part in the study. (Appendix A).

Method and Design

The isokinetic evaluations were performed using an isokinetic dynamometer capable of correcting for the effect of gravity and measuring eccentric and concentric muscle strength. A trained anthropometrist took the anthropometrical measurements. All measurements and details were recorded on a subject information sheet (Appendix B). The isokinetic evaluations containing all necessary values and graphical displays were printed for each subject (Appendix C)

The study followed a descriptive research design involving once off testing of each subject. Isokinetic dynamometry was used to determine the peak eccentric and concentric torques of the involved muscle groups where-after these values were used to determine the functional and contractional strength ratios between the hamstring and quadriceps muscle groups.

Procedures

All subjects were informed of the requirements of the research project in terms of participation in isokinetic measurements and the details were explained. Informed consent was obtained from all subjects before testing (See Appendix D).

Anthropometrical assessment

All anthropometrical measurements were taken before the warm-up procedure that preceded the isokinetic assessments. Each subject was subjected to measurement of their stature and body mass. A detailed description of the various measurements and techniques used in this study is presented (ACSM, 1988).

Stature

Stature was measured from the highest point on the head (vertex) in the medial sagittal plane to the soles of the feet with a Harpenden stadiometer. The subject would stand erect and barefoot with the heels, buttocks and rear of the head, which is held in the Frankfurt horizontal plane, in contact with the vertical stadiometer. With the heels in contact with each other, the fingers and upper limbs fully extended and held tightly against the sides of the body. Before the measurement was taken the subject was instructed to inhale and stretch upward to the fullest extent keeping the head in the Frankfurt position. Ensuring the heels not to raise and the stadiometer branch to make contact with the head, the stature was recorded in centimetres to the nearest millimetre (ACSM, 1988).

Body mass

Body mass was measured using a Seca scale that was calibrated before every measurement. The subject was clothed in a pair of shorts only and measurements were recorded to the nearest 0.1kg.

Isokinetic strength assessment

A Kin-Com ® isokinetic dynamometer (model nr. 125 AP), of which validity and reliability studies have previously been published (Harding *et al*, 1988), was used to measure the concentric and eccentric strength of the quadriceps femoris and hamstring muscle groups. As these two muscle groups are the main musculature responsible for knee flexion and extension, testing of the knee joint musculature involved particular consideration of:

a) Positioning and stabilisation of subject,
b) the alignment of the biological and mechanical axes,
c) position of the resistance pad,

d) gravity effect torque correction and
e) test angular velocities.

Before the test commenced each subject completed the warm-up procedure which started off with 8-10 minutes of cycling on a generic cycle ergometer. During this phase of the warm-up, the tester defined and explained thoroughly to the subject the concept of isokinetic muscular work and concentric and eccentric contractions. The fact that it was to be a maximal muscular strength test was also stressed. This was followed by an approximate 10 minute stretching session during which the left and right hamstring, quadriceps and calf musculature of the subject was stretched according to instructions from and with assistance of the tester.

The isokinetic test was performed with the subject in the seated position with a hip joint angle of approximately 90-110° of flexion and the thighs and thorax were well supported by the seat. This position allowed the knee musculature to be tested through a flexion-extension range of motion (ROM) of approximately 90-110°.

The subject was optimally stabilised around the pelvis and thorax using the stabilisation belts of the Kin-Com®. The thigh of the tested side was stabilised using a thigh-stabiliser. During the test the subject was not allowed to grasp any steady handle and was instructed to cross their arms over the chest area holding onto the shoulders.

The axis around which flexion and extension of the knee rotates is the tibio-femoral joint. The convenient alignment axis that served as the anatomical axis of rotation extends through the lateral femoral epicondyle. With the subject seated on the dynamometer chair, the lateral femoral epicondyle of the side tested was aligned parallel with the mechanical rotational axis of the dynamometer's lever arm. After the axis alignment was completed, the resistance pad was placed at a level immediately superior to the medial malleolus of the tested leg allowing the subject to be able to freely dorsi-flex the ankle maximally and that the strap around the lower leg was not too tight. The placement of the resistance pad did not allow any proximal or distal movement of the pad along the lower leg during flexion and extension of the knee. Gravity effect torque correction was performed as part of the set-up procedure of the dynamometer by weighing the tested segment, which was attached to the lever arm, with the lever arm at a 90° angle to the horizontal. A line-level attached onto the lever arm was used as a level-reference.

Subjects were tested using the overlay function at the standard angular velocity of 60°/sec through a ROM of 90°-110°. The side of gross motor preference was tested first with each muscle group tested individually. The quadriceps muscle group was tested first with the eccentric contraction following the concentric contraction.

Once the positional set-up and axis alignment was completed and the subject comfortably, but firmly stabilised around the thoracic, pelvic and thigh area, the testing ROM was recorded starting at 90°-110° of knee flexion and ending at 0° flexion (full extension). The subject was given 3-5 trials to familiarise with the concentric and eccentric isokinetic contractions. Care was taken that the subject understood the procedures and that the monitor of the computer was clearly visible to him. Misunderstanding test procedures could have resulted in invalid test results. Verbal encouragement was supplied to the subject throughout the test and positive visual feedback given by means of the graphical display of the test on the computer monitor.

The test started with the subject maximally extending the knee as hard and fast as possible until no further extension was possible. The concentric contraction was recorded and after five seconds the tester initiated the eccentric contraction test by instructing the subject to extend the knee as hard as possible and work against the lever arm that was moved down to the starting position by the dynamometer. The eccentric contraction test was saved and inter-contraction rest periods of 30 seconds were allowed. The procedure was repeated five times. The particular contraction result was only saved if the performance was better than the previous best.

After the quadriceps group was tested, the starting position of the test was changed to 0° of flexion and ending position to 90°-110° of flexion. This enabled concentric contraction strength of the hamstring group to be tested first followed by the eccentric contraction. Two minutes rest was allowed before testing of the hamstring muscle group started. The subject concentrically flexed the knee as hard and fast as possible until no further flexion was possible. The concentric contraction was recorded and after five seconds the tester initiated the eccentric contraction test by instructing the subject to flex the knee as hard as possible and work against the lever arm that was now moved up to the starting position by the dynamometer. The eccentric contraction test was saved and inter-contraction rest periods of 30 seconds were allowed. The procedure was repeated five times. The particular contraction result was only saved if the performance was better than the previous best.

After testing the dominant side, the set-up of the dynamometer was changed to enable the testing of the non-dominant side. The same procedures as with the dominant side were followed. At completion of the test the subject was instructed to cycle for approximately 5 minutes after which he stretched the quadriceps, hamstring and calf musculature as standard cooling-down procedures. The final test-results were saved and printed.

Statistical Analysis

The final sample consisted of 45 male rugby players, average age 19.67yrs (SD=2.11) playing the full range of available positions in a rugby team. The isokinetic indices that were used to analyse the results included the concentric and eccentric peak torque of the left and right hamstring and quadriceps muscle groups as well as the bilateral strength differences (as percentage).

The following reciprocal muscle group ratios and contraction-strength ratios were calculated:

1) Left and right concentric hamstring to concentric quadriceps ratio (HQR)
2) Left and right eccentric hamstring to eccentric quadriceps ratio
3) Left and right eccentric hamstring to concentric hamstring
4) Left and right eccentric quadriceps to concentric quadriceps ratio
5) Left and right concentric hamstring to eccentric quadriceps ratio
6) Left and right concentric quadriceps to eccentric hamstring ratio

Quantitative data were analysed using Microsoft Excel Version 7.0 Analysis Tool. The reciprocal muscle group ratios, contractional strength ratios and functional strength ratios were calculated.

Chapter Four

Results and Statistics

Subjects

The final sample of the study consisted of 45 male rugby players playing the full range of available positions in a rugby team. The ages of the subjects ranged from 17 to 29 years with the average age 19.67 years (SD=2.11) (Table 9). The average bodyweight was 84.50kg (Range=68-133kg; SD=12.43) and average body height 179.17cm (Range=163-198cm; SD=8.10).

	Average	Range	Standard Deviation
Age (years)	19.67	17-29	2.11
Bodyweight (kg)	84.50	68-133	12.43
Body Height (cm)	179.17	163-198	8.10

Table 9:

Descriptive subject information

Peak torque measurements and bilateral strength differences

Peak torque measurements of the quadriceps and hamstring muscle groups were performed in the concentric and eccentric mode. The predominant side of gross motor preference was the right side. The average gravity corrected peak torque of the right quadriceps was 252.38 Nm (SD=45.99), ranging from 182 Nm to a maximum of 398 Nm. The left quadriceps average peak torque measured 245.71 Nm (SD=45.88) ranging from 144 Nm to 347 Nm. Comparing the mean peak torques of left and right quadriceps the average bilateral difference resulted in a 2.6% strength difference, while computing the average bilateral difference of all 45 subjects the average results were 10.47%. Both these values are within the normal range of strength differences between the gross motor preference side the non-preferred (Kannus, 1994).

Right concentric hamstring peak toque averaged 161.93 Nm (SD=43.11) with a minimum measurement of 76Nm and maximum of 248Nm. The left hamstring concentric peak torque ranged from 76Nm to 231Nm with an average of 148.76Nm (SD=32.69). The mean bilateral difference was 15.32%. Comparing the average concentric torque measurements of the hamstrings, the difference drops to 8.13%. Kannus (1994) refers to three subgroups of bilateral differences and is listed below in Table 10.

Bilateral Strength Discrepancies	
< 10%	Normal
10-20%	Possibly abnormal
>20%	Probably abnormal

Table 10:

The three subgroups of bilateral discrepancies (Kannus, 1994).

Evaluating the eccentric values, the average right quadriceps peak torque resulted to 334.56Nm (SD=76.25; Range=209Nm-525Nm) and left averaged at 314Nm (SD=60.74; Range=160Nm-427Nm). The average quadriceps bilateral strength difference was 13.08%. Eccentric hamstring measurements showed an average of 198.58Nm (SD=51.46; Range=89Nm-323Nm) for the right side and 188.29Nm (SD=41.62; Range 91Nm-315Nm) for the left. Bilateral difference between the eccentric hamstring strengths of left and right sides averaged 17.14%.

From these results a concerning observation arises in the sense that the hamstring bilateral strength differences, concentric and more so eccentric, are outside the normal range. Concentric hamstring and eccentric quadriceps and hamstring bilateral differences classifies the group as possibly abnormal according to the classification of Kannus (1994). Table 11 lists the muscle strengths measured, averages, standard deviation (SD), minimum and maximum scores and Table 12 the bilateral differences. In accordance with research (Albert, 1995; Kellis & Baltzopoulos, 1995) the eccentric average values were higher than that of the concentric values for both muscle groups (Figure 10).

Concentric	**Mean**	**SD**	**Minimum**	**Maximum**
Right Quadriceps	252.38 Nm	45.99	182 Nm	398 Nm
Right Hamstrings	161.93 Nm	43.11	76 Nm	248 Nm
Left Quadriceps	245.71 Nm	45.88	144 Nm	347 Nm
Left Hamstrings	148.76 Nm	32.69	76 Nm	231 Nm
Eccentric				
Right Quadriceps	334.56 Nm	76.25	209 Nm	525 Nm
Right Hamstrings	198.58 Nm	52.46	89 Nm	323 Nm
Left Quadriceps	314.00 Nm	60.74	160 Nm	427 Nm
Left Hamstrings	188.29 Nm	41.62	91 Nm	315 Nm

Table 11:

Average isokinetic concentric and eccentric strength values, standard deviation (SD), minimum and maximum values (N=45).

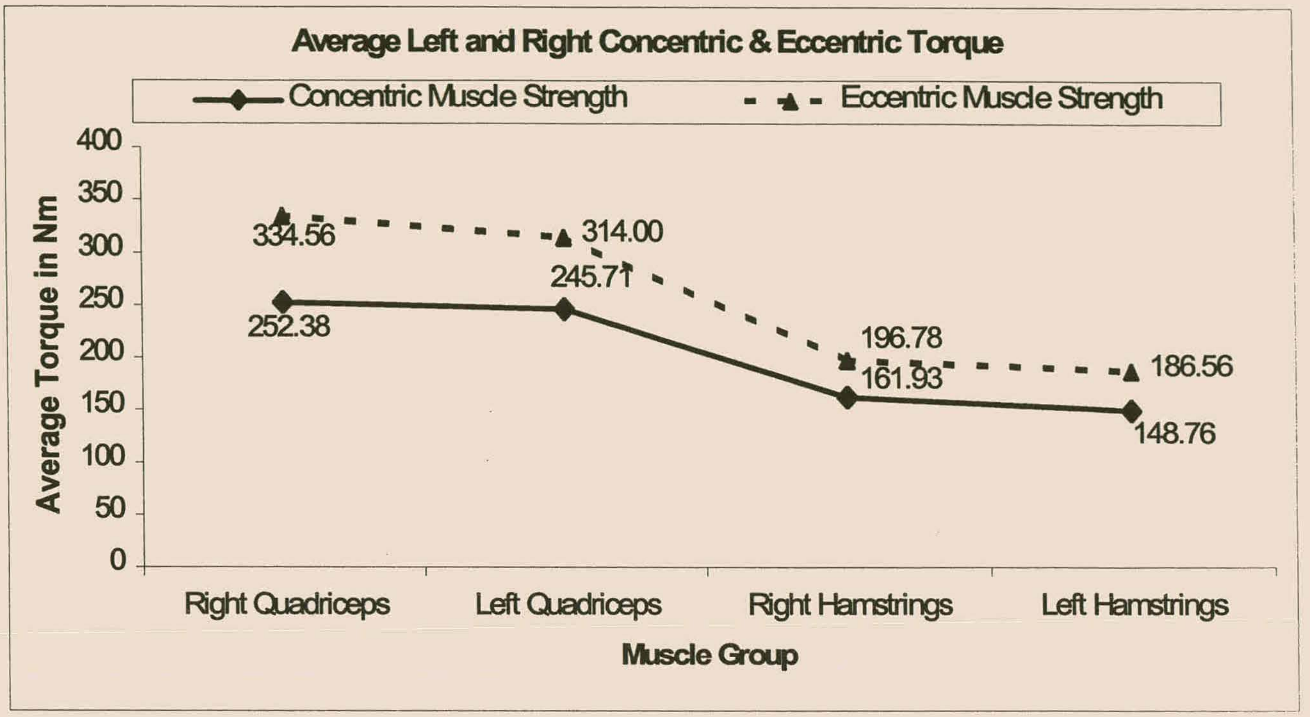

Figure 10:

Graphical display of average hamstring and quadriceps concentric and eccentric peak torque.

Concentric	**Mean**	**SD**	**Minimum**	**Maximum**
Quadriceps	9.54%	9.83	0.4%	44.19%
Hamstrings	14.43%	9.97	0.00%	39.90%
Eccentric				
Quadriceps	10.34%	12.20	0.30%	44.06%
Hamstrings	17.25%	14.55	0.50%	57.56%

Table 12:

Average bilateral difference for concentric and eccentric strengths of the quadriceps and hamstrings, standard deviation (SD), minimum and maximum scores (N=45).

Muscle Strength Ratios

Reciprocal Muscle Group Ratios

The weaker muscle group is expressed as a percentage of the stronger muscle group when referring to the reciprocal muscle group ratio of a particular joint. The hamstring muscle strength is therefore divided by the quadriceps strength and the value multiplied by 100 to arrive at a percentage value.

Table 13 lists the left and right concentric and eccentric reciprocal muscle group ratios as ratios, not percentages. The average right concentric ratio was 0.65 (SD=0.16) with a minimum value of 0.36 and a maximum ratio of 1.03. On the right side the ratio averaged at 0.62 (SD=-0.14), minimum value 0.42 and maximum 1.13.

The eccentric reciprocal muscle group ratio, one that is not referred to as much in research, resulted in very much the same values as that of the concentric values. On the right side the average was 0.60 (SD=0.15) with a minimum value of 0.39 and maximum of 0.99. The left side average ratio was 0.61 (SD=0.15), minimum ratio 0.37 and maximum 1.06. Figure 11 displays the concentric and eccentric values graphically, showing the eccentric value to stay fairly constant bilaterally and the concentric value to drop from right to left.

The values obtained from this study concerning the concentric and eccentric hamstring quadriceps strength ratios relate closely to the average values studied in research (see Table 14). As mentioned earlier, the concentric HQR has been shown to vary between 31% and 90% and the recommended optimum ratio between 50% and 80%, generally accepting 60-67% as the average (Nosse, 1982; Kannus, 1989; Osternig, 1986; Dvir, 1995; Chan & Maffulli, 1996). Due to his joint specific and injury specific rehabilitation orientated studies Kannus (1994) was later of opinion that there exists no optimal HQR. He concluded that this ratio is a too individual measurement/parameter to justify recommending general optimal values and the first step in rehabilitation process of an unstable knee is to attain the HQR of the opposite healthy extremity. From this point functional rehabilitation should be implemented specific to the individuals needs and the rehabilitation process phases onto becoming conditioning specific.

Concentric	Mean	SD	Minimum	Maximum
R Hamstring : Quadriceps	0.65	0.16	0.36	1.03
L Hamstring : Quadriceps	0.62	0.14	0.42	1.13
Eccentric				
R Hamstring : Quadriceps	0.60	0.15	0.39	0.99
L Hamstring : Quadriceps	0.61	0.15	0.37	1.06

Table 13:

Average reciprocal muscle group ratios of left and right side, standard deviation (SD), minimum and maximum scores (N=45).

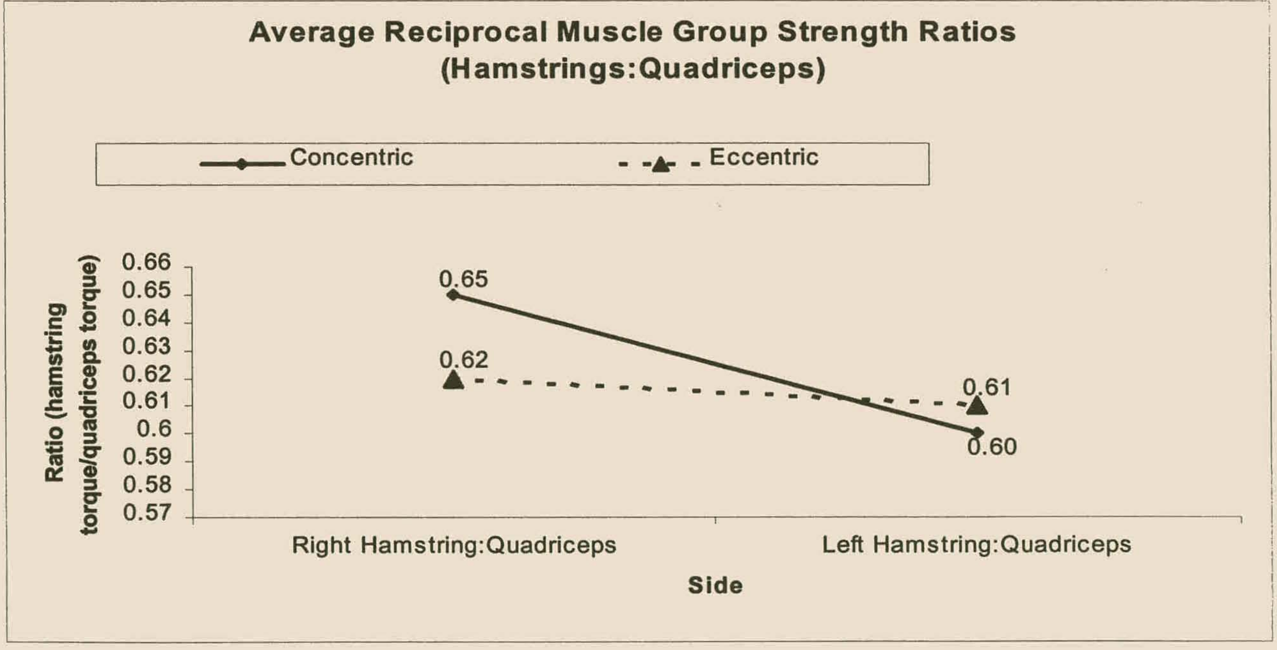

Figure 11:

Average reciprocal muscle group ratios.

References	Concentric HQR
Read & Bellamy (1990)	0.77
Kannus & Kaplan (1991)	0.62
Kannus (1980)	0.62
Kannus *et al* (1991)	0.62
Kannus & Yasuda (1992)	0.59
Kannus (1992)	0.67
Campbell & Glenn (1982)	0.73
Morris *et al* (1983)	0.65
Grace *et al* (1984)	0.59
Highgenboten *et al* (1988)	0.52
Westing & Seger (1989)	0.46
Colliander & Tesch (1989)	0.63
Stafford & Grana (1984)	0.67
Osternig *et al* (1996)	0.64
Aagard *et al* (1995)	0.51
Kannus & Järvinen (1990)	0.60
Ghena *et al* (1991)	0.55
Current research (1999)	0.62

Table 14

A summary of researched concentric HQR for comparative use with actual obtained concentric HQR

Critical Deficit Ratio

Bennett & Stauber (1986) first described this particular ratio in their very successful study concerning the eccentric strength training of the quadriceps in treatment of anterior knee pain. This ratio is simply calculated by dividing the eccentric strength of a muscle group by the concentric strength of the same muscle group. The ratio is therefore a unilateral strength efficacy comparison.

Table 15 lists the particular values calculated. For the right leg the average ratios were 1.26 (SD=0.26) and 1.33 (SD=0.21) for hamstrings and quadriceps respectively. The left side ratios resulted to 1.28 (SD=0.21) and 1.29 (SD=0.17) for the hamstrings and quadriceps respectively. Figure 12 illustrates the average critical deficit of the quadriceps to be higher than that of the hamstrings.

Right	**Mean**	**SD**	**Minimum**	**Maximum**
Hamstrings Muscle Group	1.26	0.26	0.63	1.80
Quadriceps Muscle Group	1.33	0.21	0.98	1.80
Left				
Hamstrings Muscle Group	1.28	0.21	0.88	1.63
Quadriceps Muscle Group	1.29	0.17	0.89	1.67

Table 15:

Critical deficit ratios average scores, standard deviation (SD), minimum and maximum scores.

When the performance of negative work (eccentric) was evaluated in humans, muscles were less active as indicated by EMG readings than during concentric work of the same magnitude (Newman *et al*, 1983). Thus, the central nervous system can exploit the ability of muscle to generate higher tensions during eccentric work and thereby reduce the energy cost by reducing the number of active motor units. Bennett & Stauber (1986) suspected therefor that errors in control of muscle function during the performance of negative work might cause varying degrees of soft tissue damage, especially in those situations where no well-defined orthopaedic disorder (such as anterior knee pain) could be identified. The symptomatic subjects tested by Bennett & Stauber (1986) all presented eccentric torque values of the quadriceps that were 15% or more weaker than the concentric values of the same muscle group. Through rehabilitation the critical deficit ratio was increased to approximately 1.3-1.5 and 80% of the subjects group was pain free after 6-9 isokinetic rehabilitation sessions.

The ratios derived from the values obtained in this study compare well with the predicted optimal values of Bennett & Stauber (1986) and the average of 1.4 as reported by Albert (1995).

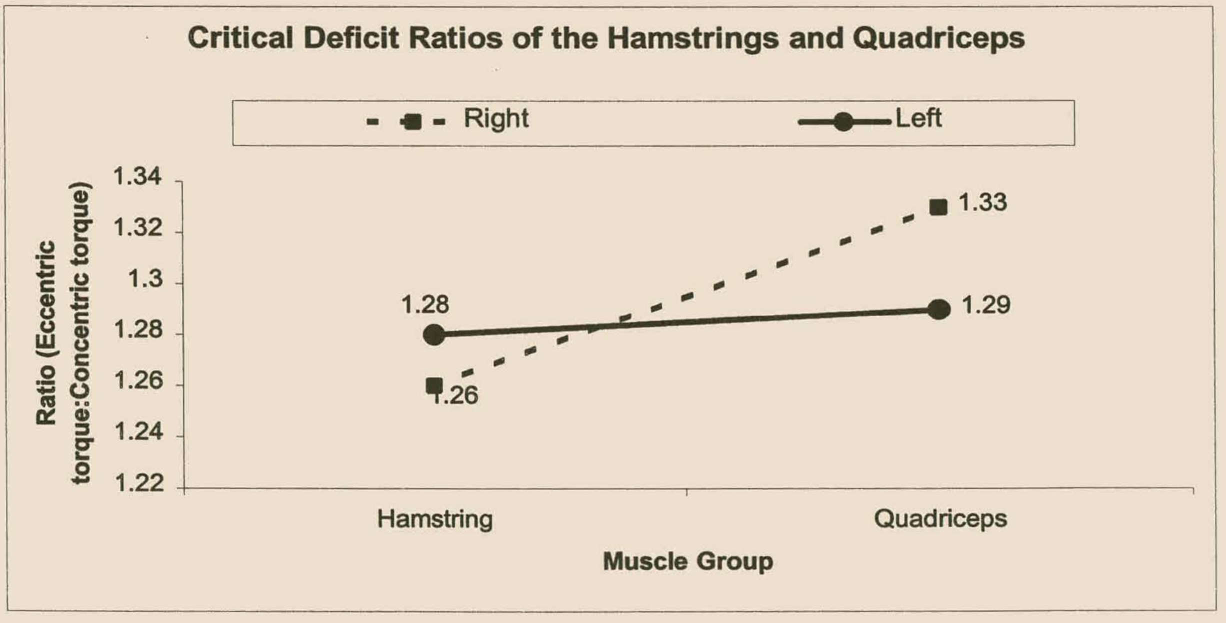

Figure 12:

Critical deficit ratios of the hamstrings and quadriceps.

Functional Dynamic Stability Ratio

The functional dynamic stability ratio evaluates the strength relation between the two muscle contractions that take place simultaneously during human movement. In the evaluation of the knee joint, this ratio is calculated by dividing the eccentric hamstring strength into the concentric quadriceps strength of the same leg (unilateral comparison). The result will therefore include a left and right value and resemble the strength ratio of the muscles and its contractional strengths as applied during knee extension. For the purpose of the study a second dynamic stability ratio was calculated by dividing the eccentric quadriceps strength into the concentric hamstring strength, the action of knee flexion.

Table 16 lists the particular values and Figure 13 graphically displays the calculated values. The ratio between the eccentric strength of the quadriceps and concentric strength of the hamstring showed average values striving towards a 50% ratio on both the left and right side. Interestingly only the maximum values are closest to a 1:1 ratio.

The functional dynamic stability ratio of particular importance in this study resulted to 0.79 (SD=0.16) and 0.77 (SD=0.14) relationship on the right and left side respectively. The total number of subjects with a ratio higher than 0.8 was 22 for the right side and 21 on the left side. There is also a tendency that those subjects with ratios close to 1:1, has very small bilateral strength differences eccentrically and concentrically.

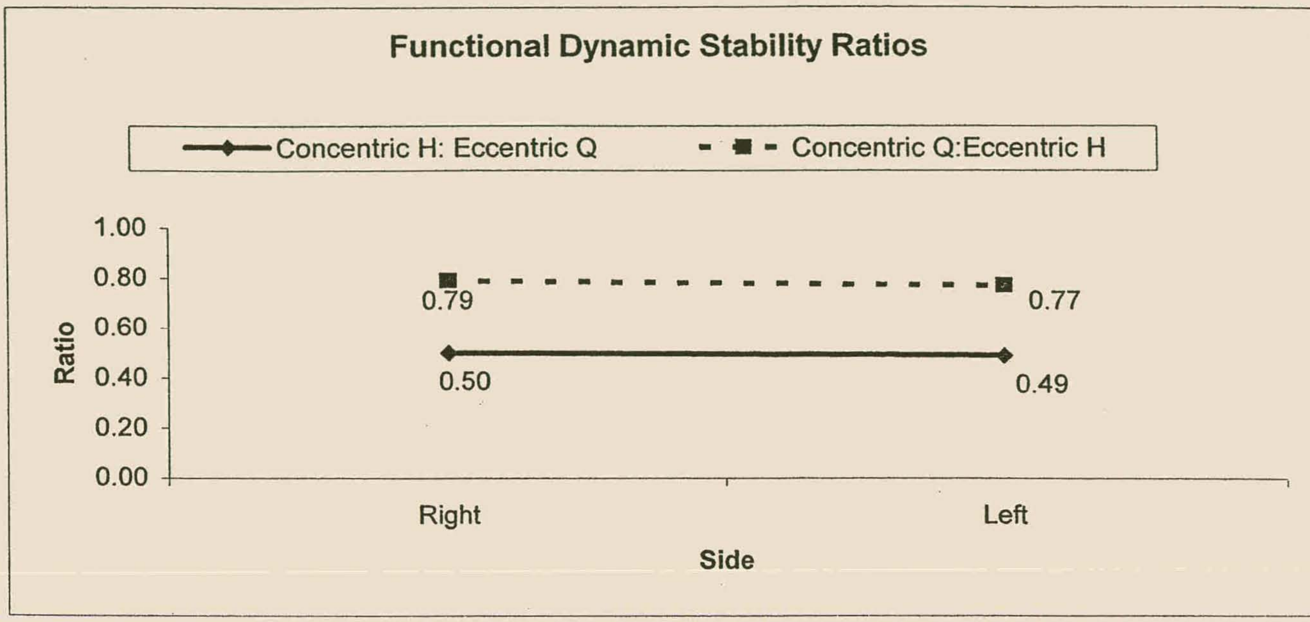

Figure 13:

Functional dynamic stability ratios

Concentric Hamstring : Eccentric Quadriceps	Mean	SD	Minimum	Maximum
Right	0.50	0.16	0.25	0.98
Left	0.49	0.15	0.30	1.01
Eccentric Hamstring : Concentric Quadriceps				
Right	0.79	0.16	0.45	1.17
Left	0.77	0.14	0.49	1.11

Table 16:

Average functional dynamic stability ratios of the right and left leg, standard deviation (SD), minimum and maximum scores.

In their study of ACL injured and uninjured subjects, Osternig *et al* (1996) also found the tendency that the eccentric knee flexor torque approached equal values to that of concentric knee extensor torque in the healthy subjects, but not in the ACL injured subjects.

Aagard *et al* (1995) evaluated the same ratio under investigation in the present study. Their study introduced this ratio to indicate the extent to which the hamstrings are capable of counteracting the anterior shear of the tibia during knee extension and found the ratio to vary between 0.89 and 1.05, in close elation to the findings of the present study (average 0.8; range 0.25-1.17).

Chapter Five

Conclusions and Recommendations

Sport specific conditioning and injury rehabilitation has long been separated due to the perception that "injured" and "uninjured" athletes train differently. Both conditioning and rehabilitation specialists make use of the principles of training including progressive overload (volume, intensity, and frequency), training specificity, individuality and genetic ceiling and detraining (Hawley & Burke, 1998). The present school of thought concerning training and rehabilitation is to make training as functional as possible (Tippett & Voight, 1995.). Simply put, when training muscular strength, the whole movement required must be trained and not just the muscles. Training, and rehabilitation, must therefor always simulate what is required from the actual demands of the particular activity.

A functional dynamic stability strength ratio was investigated by measuring the concentric and eccentric isokinetic hamstring and quadriceps strength of 45 rugby players. The ratio was determined by dividing the eccentric hamstring peak torque by the concentric quadriceps peak torque value. This ratio takes into account that during knee extension the quadriceps contract concentrically and the hamstrings eccentrically simultaneously. The previous method of measuring optimal knee joint muscle function was the reciprocal muscle strength ratio between these two muscle groups' maximum concentric values (Perrine, 1993).

Also investigated was the relationship between the maximum eccentric and concentric strength of the same muscle group. During activities such as running and sprinting the hamstrings and quadriceps undergo maximal contractional changes i.e. at heel strike the hamstrings change from near maximum eccentric contraction to near maximum concentric contraction. These two contractional strengths should therefor also relate in a functional manner. Bennett & Stauber (1986) have previously referred to this ratio as the critical deficit ratio.

Isokinetic test results presented average critical deficit ratios for the hamstring muscle group of 1.28 (SD=0.21) left and 1.26 (SD= 0.26) for the right leg. Similar results were calculated for the quadriceps, with the left leg ratio 1.29 (SD=0.17) and the right leg 1.33 (SD=0.21). Functional dynamic stability ratios calculated averaged at 0.79 for the right leg and 0.77 for the left leg.

Conclusions

Despite the controversy, the isokinetic hamstrings quadriceps reciprocal muscle group ratio has been studied since the implementation of isokinetics. Other popular parameters focus on the bilateral comparison whereas reciprocal muscle group ratios are concerned with ipsi-lateral agonist-antagonist muscle comparisons. At present, research has accepted that there is no optimal value for this ratio and that the healthy/uninvolved limb should be used as control (Kannus, 1994). The hamstring muscle group has been the focus of research for many years, more specifically, its importance as a stabilizer in anterior cruciate ligament deficient knees and its high incidence of injury (Westing *et al*, 1994; Osternig *et al*, 1996, Osternig *et al*, 1986; O' Conner, 1993; Worrell & Perrine, 1992).

Antagonistic co-contraction is an important inherent protective component in especially the knee joint where it has been shown to reduce the anterior shear of the tibia relative to the femur. Despite already proven causative factors, hamstring strains remain to be considered the most common muscle injury (Upton *et al*, 1996).

Information currently available on reciprocal optimal hamstring quadriceps ratios does not appear to have taken into account the notion of functional specificity. The significance of this ratio is to evaluate the synergistic optimal strength of the muscle groups responsible for knee flexion and extension. If one analyses the biomechanics of knee flexion and extension during running and focus on the thigh muscles activated and which contraction type is utilized during what part of the range of motion, one would soon realize that concentric contraction of the hamstring and quadriceps muscle groups never happen simultaneously. The angle at which peak torque is generated during knee flexion also differs from that of knee extension (Kannus & Kaplan, 1991)

The use of non-functional strength parameters in the past may very well have been an underlying cause of premature discharge and possible high incidence of injury recurrence. Isokinetic testing only measures muscle strength under very specific conditions, far from what is demanded from the actual movements involved in the particular activity. If appropriate steps are taken in the rehabilitation of knee musculature and accurate, objective and functional testing used to monitor progress, the process of rehabilitation is bound to become more secure and decrease the incidence of recurrence of injury.

Isokinetic testing is not the most functional method of testing knee muscle function and strength. Despite of this, it still has its place in the rehabilitation process and therefore the procedures and protocols used when testing must be as accurate as possible and nevertheless attempt to be applied as functional as possible.

As mentioned earlier, when investigating the muscle function of a particular joint it only makes sense to investigate it in the actual way the muscles are used in human movement. The hypothesis of this study was in reflection of Newton's 3rd law that states that for every action there is an equal, but opposite reaction. For a powerful knee extension (concentric quadriceps) to be terminated, an equal but opposite action (knee flexion) is required from the hamstrings (eccentric contraction).

Hypothesis 1

The hypothesis that for optimal knee joint and muscle function the eccentric hamstring peak torque and concentric quadriceps peak torque should be equal was not achieved in this study. Despite the fact the subjects were evaluated during their pre-season training period, a value (0.77 left leg; 0.79 right leg) close to that predicted was obtained. According to bilateral differences concerning concentric quadriceps and eccentric hamstring values, 16 subjects presented normal and balanced knee musculature (Table 12). All 16 of these subjects presented bilateral differences of less than 10% and all presented a functional dynamic stability ratio of higher than or equal to 0.8 (80%). According to these results one may assume that there is a tendency of this particular ratio to strive towards a value closer to 1:1. This would mean that the eccentric hamstring strength is equal to the concentric quadriceps strength. Keeping in mind that all subjects were in the middle of their pre-season training programme and not yet 100% conditioned for the particular sport and risk free, this tendency does seem possible. Another possibility for not achieving the predicted values might be the young age of the subjects and the fact that they are not competing at a highly professional level.

Hypothesis 2

Theoretically it seems possible that if the ratio falls beyond a significant range the athlete might be predisposed to possible muscle or ligament injury. A long term study involving injury count and functional ratios is needed to practically concluded that if these two muscle strengths are to be equal, together with optimal critical deficit ratios, the possibility of especially hamstring muscle injury and re-injury would be highly unlikely.

Hypothesis 3

Based on all the researched done it may be concluded that hypothesis 3 was achieved and that the functional dynamic stability ratio can supply valuable information to the rehabilitation specialist in the concentric and eccentric evaluation of the knee musculature.

Recommendations

In view of the conclusions drawn as a result of the investigation, the following recommendations are made. Some of which concern maximal isokinetic testing, while others concern research possibilities.

1. From this study it seems possible that:

   - Effective functional rehabilitation protocols and training programmes must be used specific to the individual injured.

   - More accurate, effective functional testing must be applied and not just clinical test results determining the return to play of an injured patient or qualification into a training group.

This research project dealt with step 2 in applying more accurate and functional muscle strength testing by means of an isokinetic dynamometer. By determining the velocity and the contraction mode of the movement an additional dimension can be evaluated in an athlete's performance profile: different contraction strength at high velocities of movement or power. Precise prediction to hamstring strain can and should be evaluated through the development of specific tests to elicit weaknesses prior to the athlete's active participation. Just as 'specificity of training' has been emphasized to direct conditioning programmes to the demands of a particular sport, 'specificity of testing' should be emphasized to direct evaluation procedures to simulate conditions that may cause a specific injury to an athlete in a particular activity.

A more effective parameter might definitely then be the relationship between the concentric strength of the quadriceps and the eccentric strength of the hamstrings. Concerning the training of the hamstring muscle group, it is not necessarily what contraction type to use to gain the most strength, but to train the muscle using both contraction types maximally in accordance to how it is utilised in human movement.

It therefore seems that the interrelationship between the four crucial factors in preventative and rehabilitative treatment of hamstring injury (Figure 9) is known to the rehabilitation specialist, but the effective functional rehabilitation after initial rehabilitation has been completed is an area for research to explore and experiment further. An adapted plan of action in the rehabilitative process of hamstring injuries was developed and shown in Figure 14.

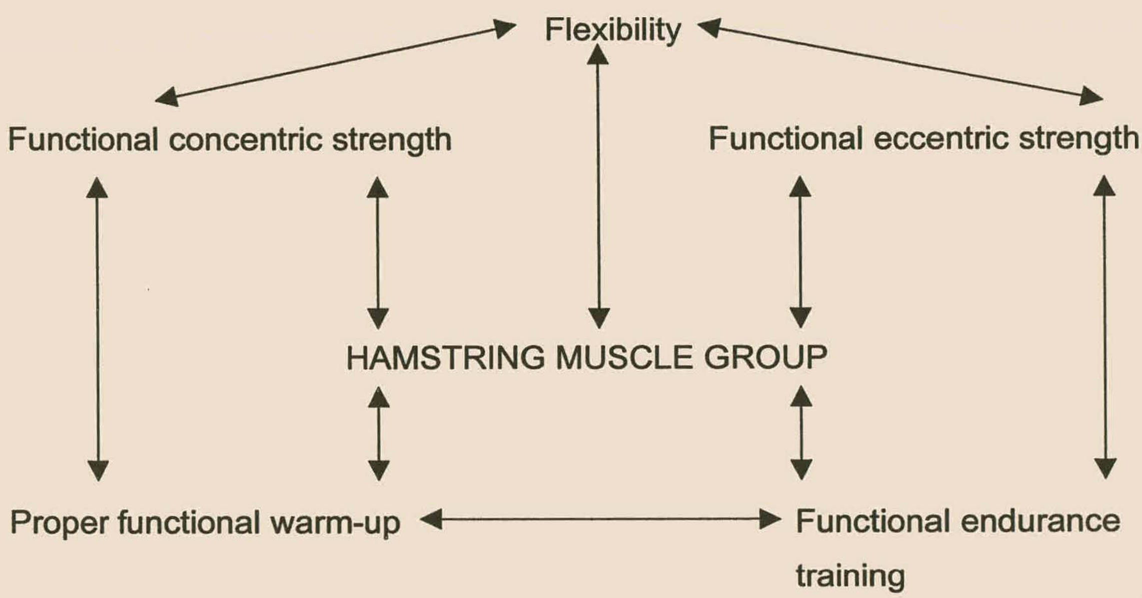

Figure 14:

Adapted theoretical hamstring model proposes that injury could be treated and prevented integrating functional factors flexibility, concentric strength, eccentric strength, warm-up and endurance training (Modified from Worrell & Perrinn, 1992, Figure 9, page 72).

2. Testing muscle performance should form a crucial part of training and rehabilitation and the principles used and the methods followed must

be adapted to be functionally applied to the specific sport or human movement and required demands.

3. To maintain scientific accuracy and generic values to be used by all sports scientists, all isokinetic testing through the vertical plane must correct for the effect of gravity.

4. The findings and research concerning the current study is not limited to only knee flexion and extension or only hamstrings and quadriceps, but can be applied in further research concerning other joints and muscles of the human body.

5. More specific investigation of the particular ratio can be calculated using the torque values at the specific angles of knee movement when eccentric hamstring and concentric quadriceps contractions are simultaneous.

6. Another possible line of research could be of neural nature. The actual control of muscle contraction plays a significant role in optimal muscle function. For example, a large part of hamstring muscle injury happens at heel strike during running/sprinting gait. At this specific position the hamstring muscle group undergoes tremendous maximal contractional strength changes, from nearly maximal eccentric strength to decelerate the lower leg to near maximal concentric strength to accelerate the limb. This sudden change in muscle contraction demands intense neural control and any lack in this control can have a direct effect on muscle function. Training of the actual movement and not individual training of a muscle group becomes a very important part in any rehabilitation and training programme.

7. Isokinetic evaluation should not be used as a tool to determine the termination of rehabilitation and the indication of resuming normal sporting activity. Achieving the desired results from an isokinetic test only indicates the start of intensive functional rehabilitation that

subsequently progresses to a form of pre-season training and in-season training until such time that the injured athlete is properly conditioned concerning all aspects of physical performance, to resume normal sporting activity.

8. Evaluating the results and research available, eccentric strength of hamstring muscles (generally all major muscles and muscle groups) has largely been neglected in strength and conditioning programmes. This contractional strength is of utmost importance in optimal muscle function, propioception and maximal strength and hypertrophy gains.

9. Research needs to explore the possible influence and significant role of pelvic stability in the prevention of hamstring injury.

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APPENDIX A

Dear Athlete/Coach,

I am busy with my Masters degree in Sport Science specializing in Biokinetics. The purpose of my study is to evaluate the strength of the thigh muscles (Quadriceps and Hamstring muscle groups) to make specific strength comparisons and attain certain strength ratios. An isokinetic device will be used to evaluate specific strengths of the muscles. These values may be used, in practice, to prevent injury as well as to rehabilitate an injured knee joint and thigh musculature. It would also be of great help if Coaches could provide me with the names of Athletes under his/her care that might be interested in taking part in the study.

To qualify for the evaluation the athlete must:

1. Have no history of injury to both lower extremities in the past year,
2. Be actively participating at club level or higher in any of the above mentioned sports.

The aim is to test uninjured sports people in order to make the measurements valid for application in the clinical practice. The isokinetic muscle evaluation will involve no cost, just 45 minutes of your time. Each subject will also receive a concise report on the results of their tests.

I can be contacted at the following phone number or Email address all hours: (021) 887 7799, (021) 617768, Email: express@new.co.za and 808 4735 (Biokinetics Laboratory of US) during office hours where you can leave your name and number and I will contact you.

Your participation in this study would be greatly appreciated.

Thank you,

Sean Surmon

APPENDIX B

Functional Hamstring/Quadriceps ratio Thesis Study

Subject Information and Score Sheet

Name: ______________________________ Tel: _______________

Participating Sport: _____________________ Level: _____________

Position: ____________________________

<u>Anthropometry:</u> R L

Age: _______ Gender: _________ Stature: _______ cm Body weight: ______kg

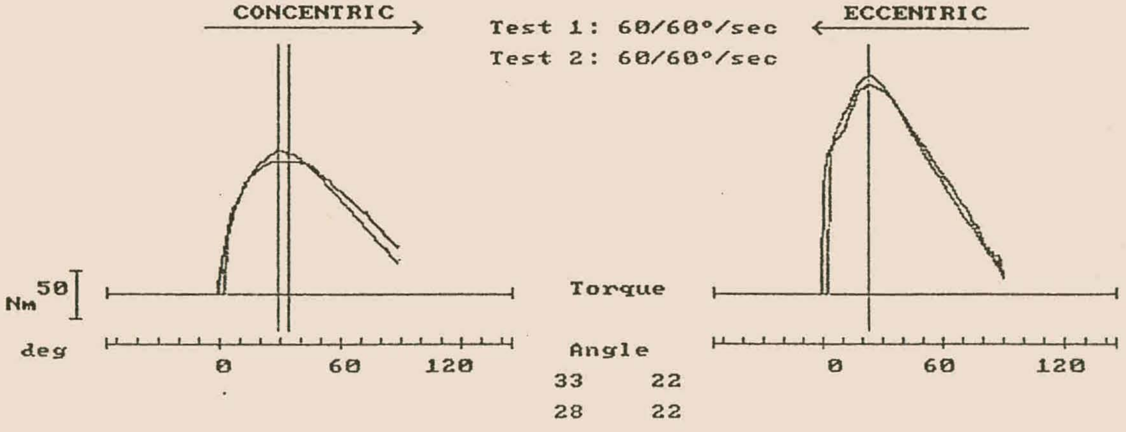
APPENDIX C

KIN-COM TEST RESULT
Version: 5.13

BIOKINETIKA LAB.
DEPT.M.B.K.
UNIVERSITEIT STELLENBOSCH
(021)-8084735

Patient	:
Date	: 30.04.99
Joint	: KNEE
Physician	: SEAN
Diagnosis	: SEAN

Procedures		Test ONE	Test TWO
Date	:	30.04.99	30.04.99
Side	:	RIGHT	LEFT
Muscle Grp.	:	EXT/FLEX	EXT/FLEX
Lever Arm	:	27 cm	27 cm
Angles	:	0 to 90 deg	2 to 90 deg
R-T Gravity	:	14 Nm	18 Nm
Velocity	:	60	60
File	:	205.CHA	205.CHA



Test ONE	:	140 Nm	RIGHT	Test ONE	:	219 Nm
Test TWO	:	149 Nm	LEFT	Test TWO	:	227 Nm
Difference	:	6.8 %		Difference	:	3.9 %

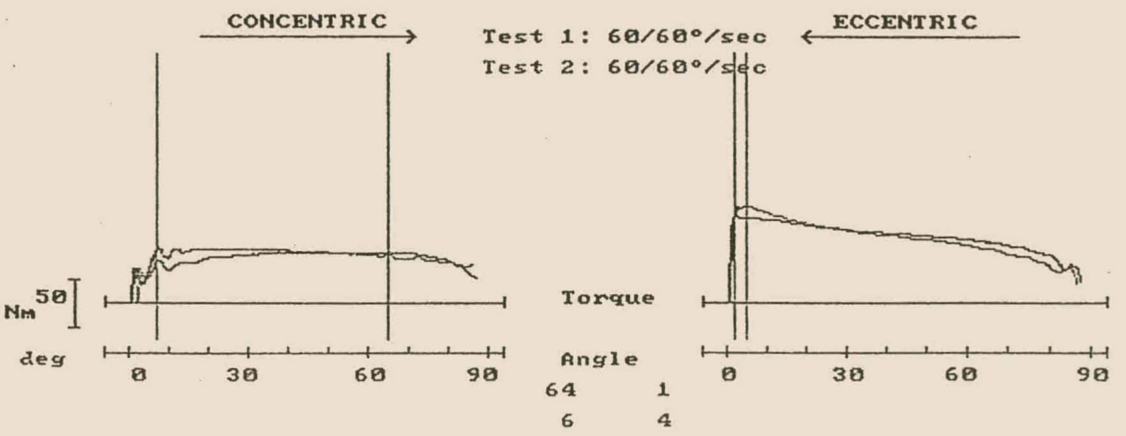
APPENDIX C (continued)

KIN-COM TEST RESULT
Version: 5.13

BIOKINETIKA LAB.
DEPT.M.B.K.
UNIVERSITEIT STELLENBOSCH
(021)-8084735

Patient :
Date : 30.04.99
Joint : KNEE
Physician : SEAN
Diagnosis : SEAN

Procedures		Test ONE	Test TWO
Date	:	30.04.99	30.04.99
Side	:	RIGHT	LEFT
Muscle Grp.	:	EXT/FLEX	EXT/FLEX
Lever Arm	:	27 cm	27 cm
Angles	:	0 to 89 deg	1 to 88 deg
R-T Gravity	:	14 Nm	18 Nm
Velocity	:	60	60
File	:	205.CHA	205.CHA



Test ONE	:	53 Nm	RIGHT	Test ONE	:	89 Nm
Test TWO	:	60 Nm	LEFT	Test TWO	:	101 Nm
Difference	:	13.8 %		Difference	:	13.2 %

APPENDIX D

Functional Hamstring/Quadriceps Ratio Thesis Study

<u>Informed Consent</u>

Name: ____

Please read the following:

1. By entering this thesis study you will perform a battery of one isokinetic knee flexion extension evaluation in both concentric and eccentric contraction mode. This test is a maximal performance test and will be strenuous.
2. You will undertake some anthropometrical measurements for the purpose of the study.
3. The tester may terminate testing at any point if he deems it necessary or appropriate. You may also stop the testing at any time if the level of exertion is too exhaustive.
4. Information you possess about your health status or previous experiences of unusual feelings with physical effort may affect the safety and value of your testing procedure. Your prompt reporting of feelings with effort during the test protocol are also of great importance. You are responsible to fully disclose such information when requested by the tester.
5. The results of your tests are strictly confidential and only the data used in the study.
6. Sean Surmon or the Department of Human Movement Science, Stellenbosch University will not be held liable for any injury obtained during the testing procedures.

I hereby declare that:

- The testing procedures have been explained to me by the tester,
- To the best of my knowledge I am currently free from any existing medical condition/other complaint/injury that would preclude me from full participation in this particular study,
- I give my written consent to Sean Surmon, the tester, to undertake the battery of tests which form part of the above mentioned study.

Subject's signature: ______________________________ Date: ______________________

Sean Surmon: ___________________________________ Date: ______________________

APPENDIX E

Anthropometrical Data of all Subjects Tested

NAME	Age	Weight	Stature	Fat %	LBM
1	19	78.6	163.5	15.8	66.2
2	21	99.4	193.5	8.9	90.6
3	23	80.6	185.0	4.7	76.8
4	18	86.0	179.0	13.5	74.4
5	20	89.0	178.3	13.3	77.2
6	24	71.2	180.0	4.9	67.7
7	20	72	168	11.4	63.8
8	18	85.6	169.0	16.5	71.5
9	18	89.0	190.0	8.4	81.5
10	22	74.6	175.7	4.7	71.1
11	18	78.6	183.0	2.5	76.6
12	19	77.2	177.4	5.2	73.2
13	18	91.2	179.0	8.2	83.7
14	19	82.6	192.1	8.1	75.9
15	18	79.5	184.5	24.9	59.7
16	21	75.2	163	21	38.6
17	19	97.4	188.6	14.9	82.9
18	19	94.6	187.0	9.3	85.9
19	19	78.6	167	20.5	49.3
20	20	77.8	186.2	4.5	74.3
21	19	69.8	165.0	3.8	67.1
22	19	113.4	177.0	24.6	85.5
23	18	132.6	189.5	23.0	102.1
24	19	81.6	183.6	3.0	79.2
25	19	94.3	179.5	19	76.4
26	18	109.4	198.0	12.0	96.0
27	19	90.4	190.0	9.7	81.6
28	19	89.0	185.0	10.9	79.3
29	21	82.6	173.2	9.8	74.5
30	22	80.0	177.5	6.4	74.9
31	18	83.4	180.0	7.2	77.4
32	19	93.4	180.0	11.1	83.0
33	17	71.2	178.6	4.3	68.1
34	29	90	184	13.7	77.7
35	19	76.2	179.3	4.1	73.1
36	19	77.9	175	20.6	52.4
37	19	75.6	181.0	4.6	72.1
38	19	74	176.2	13	64.4
39	24	68.2	168.5	7.6	63.0
40	19	71.4	177	12.6	62.4
41	20	74.8	172.5	14.1	64.3
42	20	88.0	170.8	22.5	68.2
43	18	94.2	182.0	11.8	83.1
44	20	86	176.5	19.1	69.6
45	19	76.6	173.0	9.6	69.2
Average	19.67	84.50	179.17	11.54	73.46
Standard Deviation	2.11	12.43	8.10	6.32	11.42
Minimum	17	68	163	2.50	38.60
Maximum	29	133	198	24.90	102.10

APPENDIX F

Concentric and Eccentric Torque Values of Quadriceps & Hamstring of all Subjects Tested

Subject	Maximum concentric torque values (Nm)						Maximum eccentric torque values (Nm)					
	RQ	RH	LQ	LH	BDQ	BDH	RQ	RH	LQ	LH	BDQ	BDH
1	197	142	243	177	23.4	24.6	230	201	216	230	6.1	14.1
2	291	187	274	201	5.8	7.5	308	198	381	221	23.7	11.6
3	276	210	285	155	3.3	26.2	364	273	385	200	5.8	26.7
4	246	133	189	122	23.2	8.3	302	205	246	195	18.5	4.9
5	289	186	231	192	20.1	3.2	337	180	239	195	29.1	8.3
6	225	92	223	120	0.9	30.4	264	140	258	187	2.3	33.2
7	196	99	237	123	20.9	24.2	285	130	314	196	10.2	50.8
8	238	105	230	101	3.4	3.8	358	147	336	148	6.1	0.7
9	398	157	333	207	16.3	31.8	525	226	365	263	30.5	16.4
10	293	145	282	146	3.5	0.7	482	188	402	151	16.6	19.7
11	251	184	246	166	2.0	9.8	287	255	279	193	2.8	24.3
12	240	165	273	173	13.8	4.8	339	219	300	233	11.5	6.4
13	261	149	253	153	3.1	2.7	273	204	263	154	3.7	24.5
14	247	220	265	160	7.3	27.3	300	200	317	199	5.7	0.5
15	214	220	290	174	35.5	20.9	352	205	290	211	17.6	2.9
16	199	120	149	110	25.1	8.3	219	89	227	101	3.7	13.5
17	264	248	261	194	1.1	21.8	320	232	370	221	15.6	4.7
18	263	184	269	157	2.3	14.7	473	263	379	209	19.9	20.5
19	188	135	164	121	12.8	10.4	272	131	216	140	20.6	6.9
20	258	221	144	162	44.2	26.7	286	218	160	143	44.1	34.4
21	230	124	208	122	9.6	1.6	328	171	306	144	6.7	15.8
22	225	148	213	164	5.3	10.8	326	163	356	220	9.2	35.0
23	317	214	310	142	2.2	33.6	344	262	346	212	0.6	19.1
24	314	189	316	136	0.6	28.0	399	261	427	161	7.0	38.3
25	350	127	296	142	15.4	11.8	501	229	366	231	26.9	0.9
26	333	202	347	217	4.2	7.4	460	271	376	232	18.3	14.4
27	201	157	241	142	19.9	9.6	335	206	356	220	6.3	6.8
28	265	149	264	135	0.4	9.4	432	185	423	193	2.1	4.3
29	249	184	273	152	9.6	17.4	262	166	299	197	14.1	18.7
30	213	121	244	146	14.6	20.7	209	200	275	201	31.6	0.5
31	275	244	283	231	2.9	5.3	326	323	373	315	14.4	2.5
32	319	203	267	122	16.3	39.9	419	311	357	132	14.8	57.6
33	239	236	236	147	1.3	37.7	240	148	263	207	9.6	39.9
34	266	106	290	123	9.0	16.0	428	185	384	187	10.3	1.1
35	258	157	237	132	8.1	15.9	360	152	311	126	13.6	17.1
36	182	120	177	105	2.7	12.5	297	149	271	142	8.8	4.7
37	240	160	245	159	2.1	0.6	330	199	311	192	5.8	3.5
38	253	155	245	124	3.2	20.0	393	189	347	154	11.7	18.5
39	183	116	212	105	15.8	9.5	262	138	290	171	10.7	23.9
40	233	137	223	115	4.3	16.1	335	223	334	185	0.3	17.0
41	187	76	177	76	5.3	0.0	291	126	247	91	15.1	27.8
42	229	122	247	157	7.9	28.7	242	116	305	197	26.0	41.0
43	271	212	252	192	7.0	9.4	353	259	308	216	12.7	16.6
44	241	165	246	144	2.1	12.7	342	198	326	191	4.7	3.5
45	250	161	167	150	33.2	6.8	265	202	230	166	13.2	17.8
Average	252.38	161.93	245.71	148.76	10.47	15.32	334.56	198.58	314.00	188.29	13.08	17.14
Standard Deviation	45.99	43.11	45.88	32.69	10.27	10.66	76.25	51.46	60.74	41.62	9.42	14.13
Minimum	182.00	76.00	144.00	76.00	0.40	0.00	209.00	89.00	160.00	91.00	0.30	0.50
Maximum	398.00	248.00	347.00	231.00	44.20	39.90	525.00	323.00	427.00	315.00	44.06	57.56

APPENDIX G

Reciprocal and Functional Dynamic Muscle Strength Ratios

Subject	Right ConH/ConQ	Left ConH/ConQ	Right EccH/EccQ	Left EccH/EccQ	Right EccH/ConH	Left EccH/ConH	Right EccQ/ConQ	Left EccQ/ConQ	Right ConH/EccQ	Left ConH/EccQ	Right EccH/ConQ	Left EccH/ConQ
1	0.72	0.73	0.87	1.06	1.42	1.30	1.17	0.89	0.62	0.82	1.02	0.95
2	0.64	0.73	0.64	0.58	1.06	1.10	1.06	1.39	0.61	0.53	0.68	0.81
3	0.76	0.54	0.75	0.52	1.30	1.29	1.32	1.35	0.58	0.40	0.99	0.70
4	0.54	0.65	0.68	0.79	1.54	1.60	1.23	1.30	0.44	0.50	0.83	1.03
5	0.64	0.83	0.53	0.82	0.97	1.02	1.17	1.03	0.55	0.80	0.62	0.84
6	0.41	0.54	0.53	0.72	1.52	1.56	1.17	1.16	0.35	0.47	0.62	0.84
7	0.51	0.52	0.46	0.62	1.31	1.59	1.45	1.32	0.35	0.39	0.66	0.83
8	0.44	0.44	0.41	0.44	1.40	1.47	1.50	1.46	0.29	0.30	0.62	0.64
9	0.39	0.62	0.43	0.72	1.44	1.27	1.32	1.10	0.30	0.57	0.57	0.79
10	0.49	0.52	0.39	0.38	1.30	1.03	1.65	1.43	0.30	0.36	0.64	0.54
11	0.73	0.67	0.89	0.69	1.39	1.16	1.14	1.13	0.64	0.59	1.02	0.78
12	0.69	0.63	0.65	0.78	1.33	1.35	1.41	1.10	0.49	0.58	0.91	0.85
13	0.57	0.60	0.75	0.59	1.37	1.01	1.05	1.04	0.55	0.58	0.78	0.61
14	0.89	0.60	0.67	0.63	0.91	1.24	1.21	1.20	0.73	0.50	0.81	0.75
15	1.03	0.60	0.58	0.73	0.93	1.21	1.64	1.00	0.63	0.60	0.96	0.73
16	0.60	0.74	0.41	0.44	0.74	0.92	1.10	1.52	0.55	0.48	0.45	0.68
17	0.94	0.74	0.73	0.60	0.94	1.14	1.21	1.42	0.78	0.52	0.88	0.65
18	0.70	0.58	0.56	0.55	1.43	1.33	1.80	1.41	0.39	0.41	1.00	0.78
19	0.72	0.74	0.48	0.65	0.97	1.16	1.45	1.32	0.50	0.56	0.70	0.85
20	0.86	1.13	0.76	0.89	0.99	0.88	1.11	1.11	0.77	1.01	0.84	0.99
21	0.54	0.59	0.52	0.47	1.38	1.18	1.43	1.47	0.38	0.40	0.74	0.69
22	0.66	0.77	0.50	0.62	1.10	1.34	1.45	1.67	0.45	0.46	0.72	1.03
23	0.68	0.46	0.76	0.61	1.22	1.49	1.09	1.12	0.62	0.41	0.83	0.68
24	0.60	0.43	0.65	0.38	1.38	1.18	1.27	1.35	0.47	0.32	0.83	0.51
25	0.36	0.48	0.46	0.63	1.80	1.63	1.43	1.24	0.25	0.39	0.65	0.78
26	0.61	0.63	0.59	0.62	1.34	1.07	1.38	1.08	0.44	0.58	0.81	0.67
27	0.78	0.59	0.61	0.62	1.31	1.55	1.67	1.48	0.47	0.40	1.02	0.91
28	0.56	0.51	0.43	0.46	1.24	1.43	1.63	1.60	0.34	0.32	0.70	0.73
29	0.74	0.56	0.63	0.66	0.90	1.30	1.05	1.10	0.70	0.51	0.67	0.72
30	0.57	0.60	0.96	0.73	1.65	1.38	0.98	1.13	0.58	0.53	0.94	0.82
31	0.89	0.82	0.99	0.84	1.32	1.36	1.19	1.32	0.75	0.62	1.17	1.11
32	0.64	0.46	0.74	0.37	1.53	1.08	1.31	1.34	0.48	0.34	0.97	0.49
33	0.99	0.62	0.62	0.79	0.63	1.41	1.00	1.11	0.98	0.56	0.62	0.88
34	0.40	0.42	0.43	0.49	1.75	1.52	1.61	1.32	0.25	0.32	0.70	0.64
35	0.61	0.56	0.42	0.41	0.97	0.95	1.40	1.31	0.44	0.42	0.59	0.53
36	0.66	0.59	0.50	0.52	1.24	1.35	1.63	1.53	0.40	0.39	0.82	0.80
37	0.67	0.65	0.60	0.62	1.24	1.21	1.38	1.27	0.48	0.51	0.83	0.78
38	0.61	0.51	0.48	0.44	1.22	1.24	1.55	1.42	0.39	0.36	0.75	0.63
39	0.63	0.50	0.53	0.59	1.19	1.63	1.43	1.37	0.44	0.36	0.75	0.81
40	0.59	0.52	0.67	0.55	1.63	1.61	1.44	1.50	0.41	0.34	0.96	0.83
41	0.41	0.43	0.43	0.37	1.66	1.20	1.56	1.40	0.26	0.31	0.67	0.51
42	0.53	0.64	0.48	0.65	0.95	1.25	1.06	1.23	0.50	0.51	0.51	0.80
43	0.78	0.78	0.73	0.70	1.22	1.13	1.30	1.22	0.60	0.62	0.96	0.86
44	0.68	0.59	0.58	0.59	1.20	1.33	1.42	1.33	0.48	0.44	0.82	0.78
45	0.64	0.90	0.76	0.72	1.25	1.11	1.06	1.38	0.61	0.65	0.81	0.99
Average	0.65	0.62	0.61	0.61	1.26	1.28	1.33	1.29	0.60	0.49	0.79	0.77
Standard Deviation	0.16	0.14	0.15	0.15	0.26	0.20	0.21	0.17	0.16	0.15	0.16	0.14
Minimum	0.36	0.42	0.39	0.37	0.63	0.88	0.98	0.89	0.25	0.30	0.45	0.49
Maximum	1.03	1.13	0.99	1.06	1.80	1.63	1.80	1.67	0.98	1.01	1.17	1.11