NORMATIVE ISOKINETIC TORQUE VALUES FOR REHABILITATION IN SOUTH AFRICA

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SYNOPSIS

Title: Normative isokinetic torque values for rehabilitation in South Africa.

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The goal of effective rehabilitation should always be to restore "normal" function if possible. What is "normal" function? Although many subjective definitions may describe what is "normal", it is the search for objective criteria of what constitutes "normality" that inspires exercise scientists worldwide! The primary aim of this study was to establish **normative** isokinetic torque values in young males, for rehabilitation purposes in South Africa. Four hundred and forty four (444) healthy male subjects participated in the study. A Cybex 340 isokinetic dynamometer was used to measure peak torque, using a quantitative experimental design. No correction was made for the effects of gravity. The following movement patterns were included: ankle plantar/dorsiflexion, knee flexion/extension, shoulder external/internal rotation, shoulder horizontal abduction/adduction, shoulder flexion/extension, elbow flexion/extension (using two different grip positions), and forearm pronation/supination. Descriptive statistics together with percentile scaling were used to develop normative values for the movement patterns studied. Normative values were presented in relative terms and expressed as a percentage in terms of Nm torque per kg body mass (% BM). In addition to the relative isokinetic torque values, the agonist/antagonist ratios were also expressed as a percentage. The percentile scales were also included to be used by clinicians involved in talent identification programmes and the screening of elite athletes. To conclude, normative isokinetic values were developed for young South African males. To enable subjects with large variations in body weight to utilize these **norms**, they were expressed in relative terms (% BM) instead of absolute terms (Nm). The possible benefit of the study was that population-specific and objective normative values were established for rehabilitation purposes and for use in sport science programs.

Key words: Isokinetics, torque, norms, rehabilitation, South Africa

SAMEVATTING

Titel: Normatiewe isokinetiese wringkragwaardes vir rehabilitasie in Suid-Afrika.

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Die herstel van "normale" funksie behoort altyd die doelwit van effektiewe rehabilitasie te wees. Wat is egter "normale" funksie? Alhoewel daar vele subjektiewe definisies gevind mag word wat "normaal" omskryf, is navorsers wêreldwyd op soek na objektiewe kriteria vir "normaliteit"! Die hoofdoel van hierdie studie was om **normatiewe** isokinetiese wringkragwaardes vir rehabilitasie-doeleindes vir jong Suid-Afrikaanse mans te bepaal. Vierhonderd-drie-en veertig (444) gesonde manlike proefpersone het deelgeneem aan die studie. 'n Cybex 340 isokinetiese dinamometer is gebruik om piek wringkrag, deur middel van 'n kwantitatiewe eksperimentele navorsingsontwerp te bepaal. Geen korreksie is gemaak vir die effek van gravitasie nie. Die volgende bewegingspatrone is ingesluit: enkel plantaar/dorsi fleksie, knie fleksie/ekstensie, skouer eksterne/interne rotasie, skouer horisontale abduksie/adduksie, skouer fleksie/ekstensie, elmboog fleksie/ekstensie, en voorarm pronasie/supinasie. Beskrywende statistiek en persentielskaling is gebruik om normatiewe waardes vir bogenoemde bewegingspatrone te ontwikkel. Hierdie normatiewe waardes is uitgedruk in relatiewe terme as 'n persentasie van Nm wringkrag per kg liggaamsmassa (% LM). Verder is die agonis/antagonis verhoudings ook uitgedruk as 'n persentasie. Die persentielskale word ook ingesluit vir gebruik in talentidentifikasie-programme en die sifting van elite atlete. In samevatting is normatiewe isokinetiese waardes ontwikkel vir jong Suid-Afrikaanse mans. Hierdie waardes is uitgedruk in relatiewe terme (% LM) in plaas van in absolute terme (Nm), sodat selfs individue met groot variasies in liggaamsmassa hierdie **norms** kan bebruik. Die moontlike bydrae van hierdie studie is dat objektiewe populasie-spesifieke normatiewe waardes ontwikkel is vir rehabilitasie-doeleindes, sowel as vir sportwetenskapprogramme.

Sleutelwoorde: **Isokineties, wringkrag, norme, rehabilitasie, Suid-Afrika**

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LIST OF ABBREVIATIONS

°:	degrees
°/s:	degrees per second
$:	Dollar
%:	percentage
% BM:	percentage body mass
1RM:	one repetition maximum
A:	angular displacement
ADL:	activities of daily living
ACL:	anterior cruciate ligament
ASD:	average standard deviation
AVG:	average
BM:	body mass
BMR:	body mass ratio
BP:	blood pressure
CI:	contractional impulse
CKC:	closed-kinetic-chain
CON:	concentric
COV:	coefficient of variance
cm:	centimetres
DBP:	diastolic blood pressure
DOMS:	delayed onset of muscle soreness
ECC:	eccentric

ECG:	electrocardiogram
Ext.:	extension
Fig.:	figure
Flex.:	flexion
Ft-lb:	foot-pounds
GC:	gravity corrected
GET:	gravity effect torque
H/Q:	hamstrings divided by quadriceps
HR:	heart rate
IPA:	isometric pre-activation
J:	joules
KE:	knee extension
KF:	knee flexion
kg:	kilogram
LBM:	lean body mass
LIB:	lower isometric bias
m:	metre
MOGAP:	Montreal Olympic Games Anthropometrical Project
n:	number of subjects
N:	Newton
NGC:	not gravity corrected
Nm:	Newton-metres
Nm/kg:	Newton-metres per kilogram body mass
OKC:	open-kinetic-chain

P:	power
PFS:	patella femoral syndrome
ROM:	range of motion
RPP:	rate pressure product
SAAF:	South African Air Force
SAMS:	South African Medical Services
SANDF:	South African National Defence Force
SBP:	systolic blood pressure
STD:	standard deviation
T:	torque or time
TAE:	torque acceleration energy
TAS:	total arm strength
TLS:	total leg strength
UBX:	upper body exercise bench
UMP:	upper moment limit
W:	work

CHAPTER 1: INTRODUCTION AND AIM OF THE STUDY

1.1 INTRODUCTION

The biological system implies **variability**. Chemical reactions and physics are governed by strict laws of nature (like the laws of Newton). However, no one human being is exactly similar in his/her reaction to internal or external stimuli. Thus one of the most burning aspects of biological science is accurate and valid testing. This is especially true when investigating muscle function in terms of strength, power, torque, and endurance.

Scientists use different methods for evaluating muscle function. Measurements used to measure muscular strength for instance, range from manual resistance and gravity testing (Magee, 1992; Kendall *et al.*, 1993; Houglum, 2001), own body mass tests (callisthenics) (Houglum, 2001), isometric tests (Abernethy & Wilson, 2000), isotonic tests like free weights, exercise machines (Houglum, 2001), or dynamometers (Heyward, 1997; Abernethy & Wilson, 2000), cable tension systems (Gray *et al.*, 1962; Housh *et al.*, 1984) to computer-assisted methods like isokinetic muscle testing (Perrin, 1993, Dvir, 1995; Abernethy & Wilson, 2000). Although the reliability, validity, and accuracy of muscle testing have received considerable attention in the past (Watkins *et al.*, 1984; Arnheim & Prentice, 1993; Abernethy *et al.*, 1995), there is still some controversy regarding measurement techniques. The search for objective and quantitative criteria dominates worldwide research efforts regarding the measurement of muscle strength (Abernethy & Wilson, 2000). According to Sale (1991) and Schmidtbleicher (1992), there are four main purposes of strength and power assessments, namely:

- determining the importance and relevance of strength and power to performance;
- developing a profile of the athlete;
- monitoring an athlete's progress in training; and
- monitoring the rehabilitation of injuries.

The **relevance** of strength and power testing in athletes would depend upon the degree of association between strength measurements and performance and the ability of such measurements to discriminate between elite and sub-elite performers (Sale, 1991).

According to Abernethy *et al.* (1995), the development of better strength and power assessment procedures is dependent upon three considerations. Firstly, gaining improved insights into the mechanisms underpinning the acute and chronic adaptations to strength and power training. Secondly, to accurately describe the effect of different training programmes upon strength and power, and lastly, to ensure that measurement techniques are reliable and valid.

Isokinetics has come to the fore and is increasingly being used by researchers and clinicians involved in the testing of muscle function and in orthopaedic rehabilitation (Moffroid *et al.*, 1969; Grimby *et al.*, 1980; Scudder, 1980; Wyatt & Edwards, 1981; Sherman *et al.*, 1982; Murray *et al.*, 1984; Olerud *et al.*, 1984; Watkins *et al.*, 1984; Wong *et al.*, 1984; Grace, 1985; Burnie & Brodie, 1986; Osternig, 1986; Thomee *et al.*, 1987; Ellenbecker *et al.*, 1988; LoPresti *et al.*, 1988; Rutherford, 1988; Baltzopoulos & Brodie, 1989; Heyward, 1997).

The advantages of isokinetics are numerous. The main advantage of isokinetics is that it allows for accommodating resistance, making it a very **safe** method of testing (Perrin, 1993). Since the velocity of movement is limited to a preset maximum angular velocity, the resistance of the device is always equal to the applied muscle torque. A muscular contraction resulting in an angular velocity less than that of the device would thus result in no resistance. If however, the muscular contraction aims to accelerate the limb to an angular velocity higher than the device's preset value, the applied force will be met by an equal and opposite force or resistance (Hislop & Perrine, 1967; Thistle *et al.*, 1967; Baltzopoulos & Brodie, 1989; Perrin, 1993).

Another advantage of isokinetic testing is that it causes **minimal insult** to the musculature (Perrin, 1993). Concentric isokinetic testing results in less muscle soreness and damage than traditional resistance training which incorporates both concentric and eccentric contractions (Talag, 1973; Armstrong, 1984; Jones *et al.*, 1986).

Some key questions arise when evaluating different protocols and forms of dynamometry:

- how reliable is the test?
- what is the correlation between the test score and athletic performance in a specific sport?
- does the test discriminate between the performance of members of heterogeneous and/or homogeneous groups?
- is the evaluation sensitive to the effects of training, rehabilitation and/or acute bouts of exercise? and
- does the test provide insights into the mechanisms underlying strength and power performance (Abernethy *et al.*, 1995)?

Questions have also been raised concerning isokinetic muscle testing (Winter *et al.*, 1981; Sapega *et al.*, 1982; Nelson & Duncan, 1983; Perrin, 1993). Pertinent factors have been highlighted as having a major effect on the reliability of isokinetic testing. These include the specific **isokinetic device** used, the **method** of testing, the reliability of **axis alignment**, machine **calibration**, **damp settings**, **torque overshoot**, the training of the **personnel** who conduct the test, and the validity of isokinetics regarding **functional**, multi-joint movement patterns (Rothstein *et al.*, 1987; Perrin, 1993).

Despite some unanswered questions, isokinetics is currently viewed to be the most reliable, accurate, and objective method of evaluating single-joint muscle strength in human subjects (Baltzopoulos & Brodie, 1989). For this reason, computerized isokinetic testing of muscle strength has become a **very popular** evaluation method amongst exercise and sport scientists, as well as amongst various professions in the medical field (biokineticists, physiotherapists and sports physicians).

Biokinetics is a specialized field in complementary medicine. A biokineticist would typically qualify by completing a three-year university degree, followed by an honours degree. A one-year internship under the guidance of a qualified biokineticist must then be completed in order to register with the Health Professions Council of South Africa (HPCSA). Thus only after five years' theoretical and practical training, the biokineticist may conduct independent rehabilitation. The biokineticist in South Africa is involved in the fields of "Total Wellness", "Sport Science", "Rehabilitation of cardiac and chronic metabolic diseases", like diabetes, as well as in "Orthopaedic Rehabilitation". Biokineticists are specifically involved in **final phase** orthopaedic rehabilitation, that is, after a patient has been treated for acute symptoms by a physiotherapist. Orthopaedic patients are normally referred to a biokineticist by physiotherapists, chiropractors, podiatrists, and medical doctors.

In order to set **realistic goals** for orthopaedic rehabilitation programmes and to evaluate the **effectiveness** of treatment programmes, accurate, objective, valid and reliable measurements of muscle strength and endurance are crucial. Biokineticists are also involved in physical pre-participation examinations of elite athletes. The **absence** of applicable population- and sport specific **norms** hampers the interpretation of collected data. Population specific normative data has to consider age, gender, body mass, activity levels and nationality (Falkel, 1978). Specific norms established in one population group **cannot be extrapolated** to another population group without consideration of the differences between population groups.

Normative isokinetic data relating to the **knee joint** musculature is by far the most prolific (Wyatt & Edwards, 1981; Stafford & Grana, 1984; Sclinkman, 1984; Berg *et al.*, 1985; Poulmedis, 1985; Appen & Duncan, 1986; Fillyaw *et al.*, 1986; Hageman *et al.*, 1988; Highgenboten *et al.*, 1988; Kannus, 1991; Knapik, *et al.*, 1991; Worrel *et al.*, 1991;). An aspect that has received a fair amount of attention is the "desirable" norm for the **hamstrings-quadriceps ratio** (H/Q). The **40:60 ratio** (H/Q: 67%) of hamstrings/quadriceps torque at an angular velocity of 60°/s, has become a widely used norm for different athletes and the general population.

However, this ratio has been **challenged** by various researchers, especially when dealing with athletes like sprinters (Housh *et al.*, 1984; Berg *et al.*, 1986; Alexander, 1990) and tennis players (Ellenbecker & Roetert, 1995). Perrin (1993) states that the general ratio of hamstrings to quadriceps at slow isokinetic velocities is about 60% (37.5: 62.5). The following authors have reported hamstrings-quadriceps ratios at 60°/s of between 54% and 64% (all the torque ratios were corrected for the effect of gravity):

- 54% in the dominant limb of male college track athletes (Appen & Duncan, 1986);
- 54% in the dominant limb of female university soccer players (Fillyaw *et al.*, 1986);
- 54% in the dominant limb of high school male football players (Sclinkman, 1984);
- 60% in the uninjured limb of male and female subjects (Kannus, 1988b);
- 61.5% in the uninjured limb of male and female subjects (Kannus, 1991);
- 64% in the dominant limb of male and female subjects (Kannus, 1988a);
- 64% in male athletes' dominant limb (Worrel *et al.*, 1991).

Research data on isokinetic **shoulder norms** is freely available (Berg *et al.*, 1985; Ellenbecker *et al.*, 1988; Otis *et al.*, 1990; McMaster *et al.*, 1991; McMaster *et al.*, 1992). The most common value to consider when evaluating shoulder function seems to be the external/internal rotation ratio (Brown *et al.*, 1988; Connelly

Maddux *et al.*, 1989; Ellenbecker, 1992). An "ideal' ratio of 66% for external/internal shoulder rotation at 60°/s is commonly reported (Connelly Maddux *et al.*, 1989; Ellenbecker, 1992).

However, despite efforts by various researchers, normative isokinetic data is **largely lacking for the other joints** like the ankle (Fugl-Meyer *et al.*, 1985), elbow (Berg *et al.*, 1985; Griffen, 1987), and wrist joint (VanSwearingen, 1983; Nicholas *et al.*, 1989). Although some normative data exists regarding the hip joint, it is also a joint for which there are still more questions than answers, especially where hip rotation torque is concerned (Smith *et al.*, 1981; Smith *et al.*, 1982; Poulmedis, 1985; Alexander, 1990; Donatelli *et al.*, 1991).

The lack of normative data is problematic for the biokineticist, especially in dealing with patients with bilateral muscle atrophy or bilateral muscle imbalances (Dvir, 1995). Isokinetics may also serve as objective criteria for confirming a clinical diagnosis (Yamamoto, 1993). Again, normative isokinetic data becomes very important, especially when rehabilitating a patient with **bilateral injuries** or conditions (Olerud *et al.*, 1984; Dvir, 1995), or when screening healthy individuals (like athletes) for muscle imbalances. For an athlete to return to his or her sport, the injured limb must have achieved torque values of at least 90% of the uninjured limb (Davies, 1992). Despite the wide use of isokinetics in **South Africa**, clinical decision-making continues to be hampered by inadequate normative data

(Charteris & Goslin, 1986; Krüger *et al.*, 1995). The utilization of **foreign norms** by local Biokineticists may also **not** be **valid** for the South African population. It may result in either an overestimation or an underestimation of an individual's muscle strength (Krüger *et al.*, 1995).

1.2 AIM OF THE STUDY

The aim of the study is to establish normative isokinetic torque values in young South African men for the shoulder, elbow, forearm, knee, and ankle joints.

CHAPTER 2: MUSCLE FUNCTION AND ISOKINETICS

2.1 INTRODUCTION

Before determining a muscle's maximum capacity to produce force, the following physiological aspects must be present. The muscle-tendon unit has to be intact. The muscle has to receive normal innervation from the central nervous system. The musculo-skeletal unit must also be free from pain (Perrin, 1993).

Theoretically, isokinetic movement implies that the limb moves at a constant velocity. Isokinetic muscle contraction or isokinetics is currently a widely used tool in muscle testing and conditioning. It may be used in clinical settings as a therapeutic modality, during physical rehabilitation, and in sport science as a way to improve performance levels.

2.2 DIFFERENT TYPES OF MUSCLE CONTRACTION

2.2.1 Isometric contractions

Various researchers have used isometric muscle testing and have extrapolated dynamic strength from isometric strength (Sale & Norman, 1982; Young & Bilby, 1993). Isometric tests have been popular for a number of reasons:

- they are easily standardized and hence reproducible (Bemben *et al.*, 1992);
- they require very little technique or skill and can thus be used with untrained and trained subjects;
- isometric tests are straightforward to administer and relatively safe for subjects to perform; and
- they require relatively inexpensive equipment (Wilson, 2000).

However, a number of researchers have reported that isometric tests have a poor relationship to dynamic performance measurements (Hakkinen *et al.*, 1986; Murphy *et al.*, 1994; Wilson *et al.*, 1995; Murphy & Wilson, 1996). Murphy *et al.* (1994) reported a 0.38 correlation between isometric rate of force production and seated shot-put, while there was a 0.86 correlation between concentric isoinertial/isotonic testing (using a weight of 30% of 1RM) and seated shot-put. Their findings correspond with that of Pryor *et al.* (1994), who reported that isoinertial testing correlated much more with the seated shot-put, compared to isometric testing (0.80 vs. 0.42).

Wilson (2000) states further that many of the previous studies regarding the relationships between dynamic performance and isometric testing were non-significant and that the correlation coefficients of those findings that showed significance were typically in the order of r=0.5. This implies that only approximately 25% of the variance was common. This is supported by Fry *et al.*

(1991), Abe *et al.* (1992); Wilson *et al.* (1993), Baker *et al.* (1994), Wilson & Murphy (1995), and Wilson *et al.* (1995).

Wilson *et al.* (1995) examined the relationship of isometric, isokinetic, and vertical jump tests to cycling performance (peak power output produced in six seconds). While the isokinetic and vertical jump tests showed a significant relationship (r=0.51-0.73) to cycling performance, there was a very poor relationship between the isometric test and cycling performance (r=0.38). Thus the isokinetic and vertical jump tests were capable of discriminating between subjects with different cycling performance levels. In support, Wilson & Murphy (1995) found that isometric tests were not significantly related to sprint performance over 30 metres and could not discriminate between sprinters of differing ability.

The rationale for the superiority of dynamic tests over isometric tests to predict dynamic performance levels is based on the neural and mechanical differences between the different contractions (Wilson, 2000). Thus dynamic muscular tests may be superior to isometric tests when evaluating dynamic performance, because they invoke a neural response that has greater similarity to the performance of interest. There are also large mechanical differences between isometric and dynamic muscular actions. Dynamic contractions make use of substantial quantities of elastic strain energy, while isometric actions do not benefit from it (Komi & Bosco, 1978; Wilson *et al.*, 1991).

Isometrics benefit from musculo-tendinous stiffness, whereas dynamic contractions (isotonic and isokinetic) do not. Muscle stiffness reflects the capacity of a muscle to absorb or dissipate forces such as the stress of force production from muscle activity. The effect of muscle stiffness is most relevant in the midrange of motion where there is significant overlap of actin and myosin, rather than at the ends of ROM (Hutton, 1992). Wilson *et al.* (1994) reported a correlation of 0.72 between musculo-tendinous stiffness and isometric rate of force development and 0.63 between stiffness and maximum isometric force. The isometric rate of force development represents the rate of force development over the initial 60-100 ms of a maximal isometric contraction. Hutton (1992) reported that isometric and eccentric exercises lead to a decrease in muscle stiffness and that concentric exercises increased muscle stiffness. Conceptually, a stiffer musculo-tendinous unit would enhance isometric force production, compared to a more compliant system. Stiffness will also determine, to some extent, how effectively and rapidly internal forces generated by the contractile component are transmitted to the skeletal system (Wilson, 2000).

Motor unit recruitment patterns differ for the performance of different tasks by the same muscle as well as when changes in the direction of force application occur (Ter Haar Romeny *et al.*, 1982; Ter Haar Romeny *et al.*, 1984). There are also definite differences in activation patterns between isometric and dynamic contractions at the same joint angle (Tax *et al.*, 1990; Nakazawa *et al.*, 1993).

Therefore, it would appear that dynamic tests are superior to isometric tests in predicting success in dynamic performance tasks. Hence, it is strongly recommended that dynamic muscular tests be used when evaluating functional athletic performance (Wilson, 2000).

The major disadvantage of isometrics is the fact that strength gains are restricted to no more than 20° within the angle at which the training took place (Houglum, 2001). Optimal strength gains are achievable at intensities above 66% of 1RM. Training at 35% to 66% of 1RM may produce some strength gains, but at a slower rate and the main effect will be an increase in muscle endurance (Houglum, 2001).

2.2.2 Isotonic or isoinertial contractions

Most functional movement patterns involve the acceleration and deceleration of a constant mass (i.e., a limb or an external object). Thus the majority of functional movements involve the development of isotonic or isoinertial force (Murphy *et al.*, 1994).

"Isotonic" may be the wrong word to describe traditional weight lifting movements for instance, since the muscle tension constantly changes with changes in joint angle and speed of movement. Thus the term **"isoinertial"** (i.e., involving constant mass), may better describe these movements (Abernethy & Wilson, 2000;

Houglum, 2001). Isoinertial loading implies a constant resistance to motion rather than merely a constant resistance or load throughout a weight-lifting task. Isoinertial strength correlates highly with dynamic sport performance (Wilson *et al.*, 1993; Abernethy *et al.*, 1995)

Performance in traditional weight-lifting tasks may provide only a limited diagnosis of an individual's capacity for developing functional isoinertial strength, since weight-lifting only supplies unidimensional feedback, based only on the muscle's capacity to either overcome or yield to a given load (Logan *et al.*, 2000). Isotonic exercise stresses the muscle maximally only at its weakest point in the ROM (also referred to as the "sticking point"). This implies that the greatest resistance that can be used during concentric isotonic exercise is equal to the maximum amount of weight that can be moved through the weakest point in the ROM (Perrin, 1993; Heyward, 1997). Under faster dynamic conditions, the momentum of the weights lifted may cause the subject to overcome the "sticking point" more easily and this leads to an even less effective muscle contraction intensity.

An eccentric contraction can produce about 30% more force than a concentric action (Wilmore & Costill, 1999). It is believed that the muscle's non-contractile elements provide the additional forces during eccentric muscle contraction. However, it takes more energy to perform a concentric muscle contraction compared to an eccentric contraction. Although it requires more energy to perform a concentric contraction, there does not seem to be any difference in strength gains between concentric and eccentric muscle training (Houglum, 2001).

The **force-velocity curve** (Figure 2.1) also demonstrates that as the contraction speed of a concentric activity increases, the muscle's ability to generate force declines. In a sense, the opposite is true for eccentric exercise: as speed of contraction increases, the force increases initially, then levels off or decreases (Houglum, 2001).

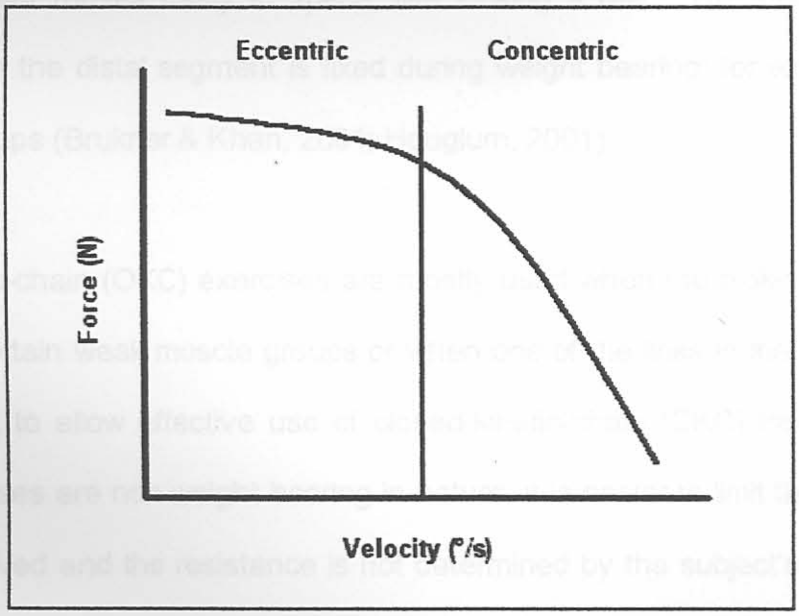

Figure 2.1: Force-velocity curve

Eccentric muscle contractions also have a greater likelihood of delayed onset of muscle soreness (DOMS), compared to concentric muscle action (Houglum, 2001).

The exact causes for this phenomenon is still unclear, but some believe that it may be the result of a combination of damage occurring to the muscle membranes and a secondary inflammatory response within the muscle's non-contractile components (Wilmore & Costill, 1999).

2.2.3 Open- and closed kinetic-chain contractions

A kinetic chain is a series of rigid arms linked by moveable objects and is identified in terms of the distal segment of the extremity. The kinetic chain is **open** when the distal segment moves freely in space, like kicking a ball. The kinetic chain is closed when the distal segment is fixed during weight bearing; for example when doing push-ups (Brukner & Khan, 2001; Houglum, 2001).

Open-kinetic-chain (OKC) exercises are mostly used when the biokineticist wants to isolate certain weak muscle groups or when one of the links in the kinetic chain is too weak to allow effective use of closed-kinetic-chain (CKC) training. Since OKC exercises are non-weight bearing in nature, it is easier to limit the size of the forces involved and the resistance is not determined by the subject's body mass. However, because the forces are small, one should guard against fast movements during OKC exercises (Houglum, 2001). CKC exercises have various advantages (Houglum, 2001).

OKC exercises are very functional in that they mimic actions like standing up, walking, and climbing stairs. The compression of the joints and the co-activation of opposing muscle groups during CKC exercises enhance stabilization (Brukner & Khan, 2001). Compare for example, the large shear forces involved during the last 30° of knee extension (OKC) to the stability observed during the squat (CKC) where the shear force is counteracted by co-contraction of the hamstrings (Houglum, 2001)! Another advantage to CKC exercises is the training of one's proprioceptors: keeping one's balance during a one-leg half-squat for example. The use of proprioception is largely absent during OKC exercises.

Osternig *et al.* (1986) investigated the myographic activity of the quadriceps and hamstrings muscle groups during isokinetic assessment at 100°/s and 400°/s. They found that hamstrings **co-activation** increased substantially during the last 25% of knee extension. In contrast, the quadriceps' antagonistic activity remained low during knee flexion. Although the authors could not explain this phenomenon fully, the test protocol used (they assessed knee flexion and extension torque from continuous reciprocal contractions) could have played a role in their findings (Perrin, 1993).

To conclude, CKC exercises are usually safer and more functional in nature than OKC exercises, which are predominantly used to isolate weak muscle groups. It would therefore be beneficial if isokinetic exercise could offer both open- and closed-kinetic-chain exercise modes.

2.2.4 Isokinetic contractions

2.2.4.1 Defining "isokinetics"

The Greek term **"isokinetic"** means, ***"having the same (iso) motion/movement (kinetic)"***. The concept ***"isokinetic"*** refers to constant velocity of movement and variable resistance (Hinson *et al.*, 1979; Perrin, 1993; Dvir, 1995; Houglum, 2001). Isokinetic dynamometry is concerned with measuring dynamic muscle performance at a constant angular velocity and variable or accommodating resistance (Dvir, 1995).

Machines used for isokinetics are referred to as "isokinetic dynamometers" or "isokinematic dynamometers". These machines attempt to accommodate to the torque applied by the subject, without any change in angular velocity, thus offering a variable resistance through the whole range of motion (ROM). Muscle torque (Nm) is the product of muscle force (N) applied at a perpendicular distance (m) from the axis of rotation (Hislop & Perrine, 1967; Gilliam *et al.*, 1979; Osternig, 1986; Perrin, 1993).

2.2.4.2 The history and uses of isokinetics

As with many other historical events, the different versions of the origin of isokinetics may vary or sometimes be challenged. However, the different written sources accessed, reveal the following.

The concept of "**isokinetics**" was developed by James Perrine and introduced to the scientific community in 1967 by Hislop & Perrine (Hislop & Perrine, 1967; Davies, 1992; Perrin, 1993) and in 1967 by Thistle *et al.* (Thistle *et al.*, 1967; Perrin, 1993).

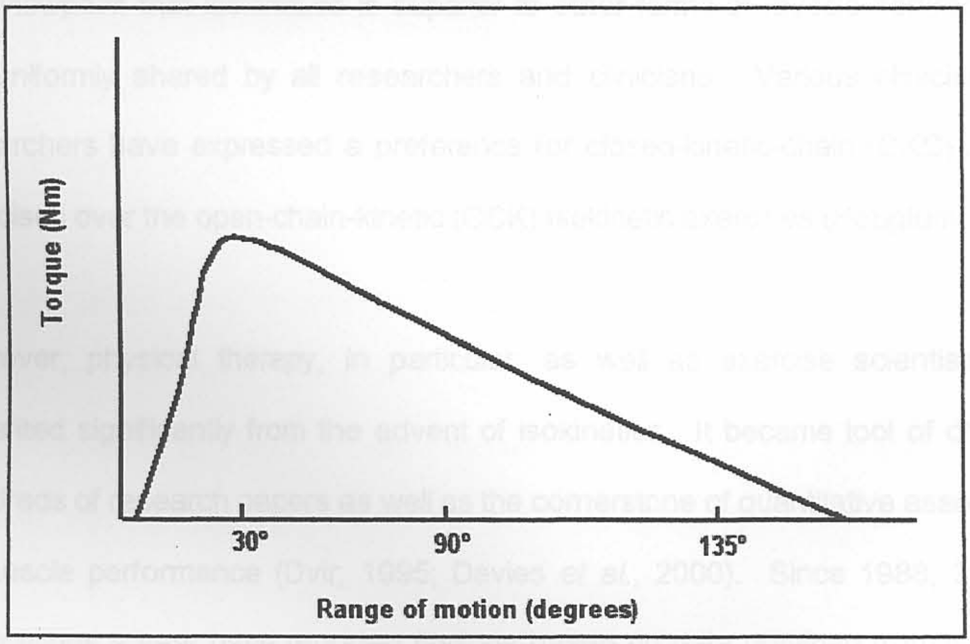

Figure 2.2: A standard torque curve of concentric knee flexion.

They reported on some of the advantages of isokinetic exercise. The length-tension relationship and overall effectiveness of muscle contraction are greatest near the midrange of ROM and are least near the beginning and end of the ROM (Perrin, 1993). This is illustrated by the isokinetic torque curve of concentric knee flexion (Figure 2.2).

Isokinetic exercise is considered by a large number of authors to have several advantages over other types of exercise like isometrics and isotonics, especially when dealing with injured individuals (Thistle *et al.*, 1967; Wilk *et al.*, 1991; Davies, 1992; Perrin, 1993; Ellenbecker, 1995).

The viewpoint that isokinetics is superior to other forms of muscle contraction, is not uniformly shared by all researchers and clinicians. Various clinicians and researchers have expressed a preference for closed-kinetic-chain (CKC) isotonic exercises over the open-chain-kinetic (OCK) isokinetic exercises (Houglum, 2001).

However, physical therapy, in particular, as well as exercise scientists have benefited significantly from the advent of isokinetics. It became tool of choice in hundreds of research papers as well as the cornerstone of quantitative assessment of muscle performance (Dvir, 1995; Davies *et al.*, 2000). Since 1988, 30 to 40 publications a year have reported findings based on data obtained from isokinetic dynamometers. The widespread use of isokinetics allowed researchers to exchange protocols and normative data (Davies *et al.*, 2000).

Various uses for isokinetic dynamometers have been stated previously:

- to collect normative values;
- to classify muscle performance as normal or abnormal;
- to collect and analyse torque curves;
- to establish the efficacy of various treatment regimens or training programmes;
- to quantify muscular work or effort during training;
- to investigate possible correlating factors, like muscle cross-sectional area and peak muscle torque;
- to assess the extent of disability in insurance claims (Keating & Matyas, 1996); and
- to assist in diagnosing musculo-skeletal disorders.

Isokinetic assessment of athletes provides valuable information that may be used to improve their performance levels (Davies, 1992; Dvir, 1995; Chan & Maffulli, 1996; Davies *et al.*, 1997). Data collected in the pre-season screening may be used as a baseline for future measurements of progress (Davies *et al.*, 2000), and it may serve as goals during rehabilitation after an injury.

Assessing **human performance** in the laboratory setting has always been controversial, no matter how closely the particular test or protocol resembled the real event. Some research indicates that there is no correlation between isokinetic testing and functional performance, and that it is not "specific" to athletic performance (Anderson *et al.*, 1991; Greenberger & Paterno, 1995; Wrigley, 2000). However, other researchers report conflicting results (Poulmedis *et al.*, 1988; Alexander, 1990; Anderson *et al.*, 1991; Klentrou & Montpetit, 1991; Mognoni *et al.*, 1994; Mookerjee *et al.*, 1995; Roetert *et al.*, 1996; Blazevich & Jenkins, 1998).

More than 60 studies have investigated the correlation between isokinetic strength and athletic performance, and numerous studies ***do*** demonstrate a positive correlation between isokinetics and functional performance (Tegner *et al.*, 1986; Wiklander & Lysholm, 1987; Sachs *et al.*, 1989; Barber *et al.*, 1990; Noyes *et al.*, 1991; Wilk *et al.*, 1994; Blazevich & Jenkins, 1998).

The following researchers have all reported correlations of 0.5 or higher between isokinetic strength and athletic performance measures. Bosco *et al.* (1983), Ashley & Weiss (1994), Newberry *et al.* (1997), and Pincivero *et al.* (1997a) have reported a significant correlation between isokinetic strength measurements and jumping. Berg *et al.* (1985), Alexander (1990), Anderson *et al.* (1991) and Blazevich & Jenkins (1998) have also reported a significant correlation between isokinetic strength and sprinting. Similar results have been reported for swimming (Ciccone

& Lions, 1987; Klentrou & Montpetit, 1991; Mookerjee *et al.*, 1995), throwing (Pedegana *et al.*, 1982; Roetert *et al.*, 1996), kicking (Poulmedis *et al.*, 1988; Mognoni *et al.*, 1994), and other sports like flat water kayaking (Fry & Morton, 1991), ice skating (Mascaro *et al.*, 1992), and tennis (Cohen *et al.*, 1994).

The only true test of validity however, is not face validity, but criterion-related validity! This is assessed by directly testing the relationship between scores on the test of which the validity is in question (i.e. isokinetic dynamometry) and athletic performance (i.e. "time" or "distance" achieved). The relevance of strength for a given sport should also be based on the ability to discriminate between elite and sub-elite performers (Wrigley, 2000).

Not all sports require muscle strength for peak performance. Most sports lie on a continuum when the importance of strength is considered. At the one end, one finds **strength-dependent** sports that demand high levels of strength for success (i.e. weight lifting, wrestling and hammer throw). On the other end of the continuum, one find **strength-independent** sports (i.e. long distance running, practical target shooting and snooker), which do not demand high levels of muscle strength for achievement. Between these two extremes lie the **strength-related** sports (hockey, tennis and sailing), for which strength is important but not critical for success (Wrigley, 2000).

Data collected during isokinetic dynamometry is used to plot peak torque, torque-angle curves, work, power and time-based indexes, to make comparisons between agonists and antagonists and between contra-lateral limbs (Marshall & Taylor, 1990; Taylor *et al.*, 1991).

Isokinetic machines or dynamometers make use of electronic servomotor control systems and hydraulic chambers. Although most isokinetic dynamometers have computer-based software for performing the torque calculations, some of the older models rely on a thermal writing system. Both concentric and eccentric muscle contraction may be assessed by using the modern isokinetic dynamometers (Bloomfield *et al.*, 1995). These machines thus allow the subject to work maximally through the whole ROM, in contrast to isotonic resistance methods that stress the joints maximally only at one specific joint angle (Perrin, 1993).

Isokinetic devices allow individuals to exert maximum voluntary muscle force up to a preset angular velocity. Up until the moment when the velocity of the subject's limb reaches that of the device, the device records no torque. Only after the subject's limb exceeds the preset velocity, does the dynamometer offer an equal counterforce. It is important to note that the limb, rather than the muscle is moving at a constant velocity. A constant rate of muscle shortening is not necessarily accompanied by a constant limb velocity, according to Hinson *et al.* (1979). They stated *"the term isokinetics may be reserved to denote the type of muscular* *contraction which accompanies a constant angular rate of limb movement rather than a constant rate of muscular shortening"*.

Isokinetic dynamometers objectively measure a subject's muscular force, work, power, and endurance, while being able to disengage if the subject experiences pain or severe fatigue (Anderson *et al.*, 2000). Examples of isokinetic machines include the Akron, Ariel, Biodex, Cybex, Kin-Com, Lido, Merac, Orthotron and Rev systems (Perrin, 1993; Brukner & Khan, 2001).

2.2.4.3 Contra-indications for using isokinetics

Isokinetic testing and exercise is contra-indicated in accordance to the guidelines set by the American College of Sports Medicine (ACSM, 1995). Additional contra-indications include:

- severely limited ROM;
- severe pain;
- severe effusion;
- acute ligament sprain;
- acute muscle/tendon strain;
- soft tissue healing constraints; and
- unstable joint fracture or joint (Davies, 1992).

When working with open-kinetic-chain isokinetics, the biokineticist has control over parameters like ROM, speeds, translational stresses (by different shin pad placements), varus and valgus forces, and rotational forces. When the individual progresses to closed-kinetic-chain exercise or testing, the biokineticist has less control of these variables, which increases the potential risk of injury (Davies, 1992; Davies, 1995; Davies *et al.*, 1995; Davies & Zillmer, 1999). In this case, the biokineticist should weigh up the possible dangers to the benefits associated with performing the specific evaluation.

2.2.4.4 Indications for using isokinetics

Isokinetic testing is indicated for determining a subject's torque capabilities. The results may be used to determine a subject's ability to return to competitive sport following an injury, or it may be used in the process of injury prevention, where each subject's values are compared to that of a suitable database. Thus isokinetics is often used to measure muscle imbalances. Another reason to make use of isokinetic testing is to measure an athlete's potential for a specific sport. Certain testing protocols may be used to measure the muscle fibre composition of an athlete. Isokinetic testing is also used to measure the success of a rehabilitation program.

Isokinetic training is especially indicated in cases where the biokineticist requires the subject to isolate a certain muscle group for training (for example, the hamstrings group). It is also very useful to regain muscle strength after a period of immobilization and atrophy, since the exercises are mostly non-weight-bearing and takes place under very strictly controlled conditions (Dvir, 1995). Since isokinetics allows one to train maximally through a large part of the ROM, it may lead to larger strength increases; this may be especially crucial to elite athletes, who are looking for that something extra to increase their performance levels.

2.2.4.5 Advantages of using isokinetics

Isokinetics has several **advantages** over other types of muscle contraction. Probably the biggest advantages of isokinetics is the fact that the muscle can contract maximally through the whole ROM **without a high risk of injury** due to the accommodating resistance of an isokinetic dynamometer (Perrin, 1993; Bloomfield *et al.*, 1995; Garrick & Webb, 1999). Isotonic exercise in contrast, stresses the muscle maximally only at its weakest point in the ROM (also referred to as the "sticking point"). This implies that the greatest resistance that can be used during concentric isotonic exercise is equal to the maximum amount of weight that can be moved at the weakest point in the ROM (Perrin, 1993; Heyward, 1997).

However, isokinetics may also be used at **sub-maximal levels**. This facility is particularly important in the early phases of rehabilitation, where the patient's injury is recent and the patient has too much pain to permit a maximum contraction (Houglum, 2001).

Because there is **no fixed resistance** to move through the weakest point in the ROM (as with isotonic exercise), isokinetics facilitates a maximum voluntary contraction through the entire ROM (Perrin, 1993). Figure 2.3 compares the force output and percentage of muscle capacity used during maximal isotonic and isokinetic exercise respectively.

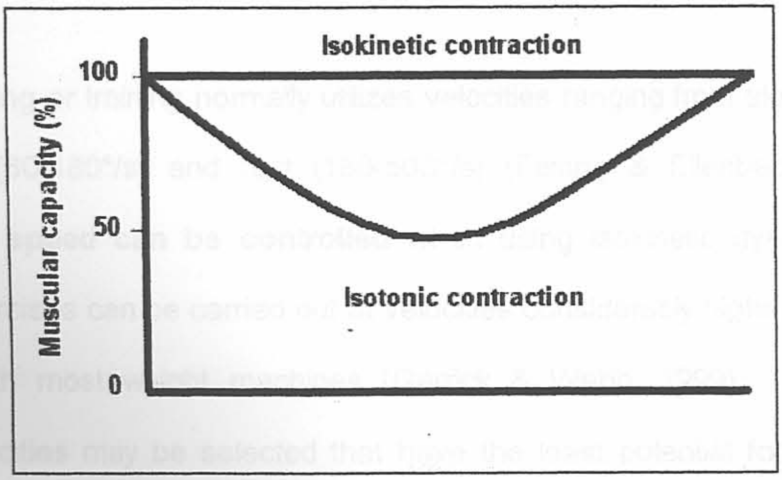

Figure 2.3: The percentage of muscle capacity utilized during isokinetic and isotonic contractions, respectively.

Another important aspect to consider is the velocity at which exercise is performed. Under faster dynamic (isotonic) conditions, the momentum of the weights lifted may cause the subject to overcome the **"sticking point"** more easily and this leads to a less effective muscle contraction intensity. This aspect was partly addressed by designing variable resistance equipment that utilized an elliptical cam. The cam was designed to provide the smallest resistance at the weakest points in the ROM (early and late in the ROM) and the greatest resistance where the muscle is at its optimal length-tension and mechanical advantage (usually midrange). Examples of machines offering variable resistance training include the Eagle Pulstar, Keiser, Nautilus, and Polaris systems (Perrin, 1993; Bloomfield *et al.*, 1995).

Isokinetic testing or training normally utilizes velocities ranging from slow (1-60°/s), intermediate (60-180°/s) and fast (180-500°/s) (Feiring & Ellenbecker, 1996). Because the **speed can be controlled** when using isokinetic dynamometers, isokinetic exercises can be carried out at velocities considerably higher than those attainable with most weight machines (Garrick & Webb, 1999). Additionally, exercise velocities may be selected that have the least potential for joint insult, especially during rehabilitation. Faster velocities cause less compressive forces in a joint than slow velocities (see Bernoulli's Principle). This is advantageous when treating a patient suffering from patella-femoral joint pain for instance (Perrin, 1993).

Isokinetic training and testing provides the biokineticist with **valuable information** regarding the client's torque at various joint angles, as well as the amount of work and power achieved during a set of repetitions. In contrast, isotonics and isometrics only provide the biokineticist with data regarding the maximum force produced (kg), the rate of force development (Young & Bilby, 1993), the distances attained with objects of various masses (for example, shot-put), and the amount of repetitions performed (Perrin, 1993; Young & Bilby, 1993).

Most isokinetic machines also offer the biokineticist the option of **limiting the limb's ROM** in order to **avoid painful angles** or to protect the joint from injury. Most modern isokinetic dynamometers have the ability to limit the ROM by means of mechanical or automatic "ROM stops". This feature is especially effective in the treatment of certain pathological conditions, for example anterior cruciate ligament repairs, patella femoral syndrome, and bursitis (Perrin, 1993).

Isokinetic dynamometers produce **reliable, objective, and reproducible results** during testing and training and involves the use of set protocols (Brown, 2000).

The dynamometer's computer records the muscle's output at every angle of the joint's ROM. The computer also makes it possible to store the data for future use. Another feature of the computer-based system is its ability to **present the data**

graphically within an instant; this is ideally suited for giving feedback to clients. During training, the computer's visual readings provide for **immediate feedback**, thus increasing motivation on the part of the client and supplying the biokineticist with all the relevant information to monitor the client's effort. This feature also improves goal setting for each session. Because the data is stored, progress from session to session can be monitored (Houglum, 2001).

By using isokinetics, it is possible for the biokineticist to **isolate certain muscle groups** for testing. If only closed-kinetic-chain testing was performed on a subject, the biokineticist could have missed a pre-existing isolated weakness (Davies *et al.*, 2000).

Isokinetics offers a **wide range of training options**. By varying the repetitions, sets, rest times, contraction modes and velocities, different muscular properties can be developed, for example, strength and endurance as well as concentric and eccentric muscle contractions (Houglum, 2001).

The **shape of the torque curve** may provide insights into angle-specific weaknesses in the ROM that could be addressed to improve performance (Davies, 1992). Although some clinicians may claim to predict a variety of joint and muscle pathologies from torque curves (Hoke *et al.*, 1983), there exists little or no scientific evidence to support this practice (Dvir, 1995). However, torque, work, and power measurements have been shown to be useful in making clinical decisions regarding muscle function (Perrin, 1993; Dvir, 1995; Davies *et al.*, 2000).

Certain protocols are used to improve **muscular control**; this may be used during muscle re-education therapy and in a wide variety of orthopaedic conditions (Houglum, 2001).

Since there is a **physiological overflow of strength** while training at a particular speed, isokinetic training also increases strength at speeds below and above the training speed (User's Guide: Norm testing and rehabilitation system, 1996).

Ballistic movements are **eliminated** since the dynamometer stops as soon as the subject ceases to produce force (User's Guide: Norm testing and rehabilitation system, 1996).

2.2.4.6 Disadvantages of using isokinetics

Isokinetics also has some distinct **disadvantages** when compared to isometrics and isotonics. Isokinetic equipment is **very expensive** compared to traditional weights and resistance machines and thus not readily accessible. A reliable dynamometer costs over $40,000 (Houglum, 2001). Furthermore, it takes up a substantial amount of space and may thus be impractical for practices with limited floorspace.

Most isokinetic devices **do not offer closed-kinetic-chain exercise**. This makes them non-functional, especially for the lower extremity (Houglum, 2001). Muscle co-ordination and co-contraction of stabilizers that is present in a closed-kinetic-chain exercise like the step-up, is largely absent during an isokinetic contraction. As with most open-kinetic-chain exercises, isokinetics make use of mainly **non-weight-bearing positions** (Perrin, 1993).

Isokinetics tend to be **time consuming**, especially if a client needs to exercise more than one joint in one session (Houglum, 2001), whereas isotonics permits exercise of multiple joints simultaneously. The application and interpretation of isokinetics **require highly trained personnel** that may be difficult to recruit depending on the location of the Centre (Perrin, 1993).

Reliable isokinetic assessment is also **limited to isolated muscle groups** through the cardinal ranges of motion (Perrin, 1993).

Even though an athlete or patient has not yet attained isokinetic measurements that correspond to that of the uninjured limb, the biokineticist cannot always regard the athlete as still disabled. Likewise, achievement of bilateral muscle balance and normative isokinetic values, do not mean that the athlete is completely cured (Garrick & Webb, 1999). Aspects like proprioception, coordination and sport-specific tasks should guide the biokineticist in making a final decision on the person's physical readiness.

Even at the fastest speeds, isokinetics **does not mimic functional speeds**. Throwing for example, results in forearm speeds of greater than 9000°/s (Braatz & Gogia, 1987). During a tennis serve, elbow extension may reach speeds between 982°/s and 1700°/s (Dillman, 1991; Kibler, 1994), and wrist flexion speeds of up to 315°/s (VanGheluwe & Hebbelinck, 1986).

Proper alignment of the exercised joint to the axis of rotation of the dynamometer is crucial to avoid **unwanted shear forces** and torques in the joint (Houglum, 2001).

Some patients struggle to grasp the technique required for effective isokinetic training or testing (own experience). Thus **careful instructions** should be given to all people before commencing to test or train isokinetically. The active or eccentric mode may be dangerous if not used with the utmost care (Davies *et al.*, 2000).

Failure in performing routine **calibration**, may lead to inaccurate results and thus inaccurate recommendations or diagnosis. Stabilization during isokinetics is not always sufficient to ensure isolation of a muscle group. Patients are inclined to

substitute and the clinician should therefore be very strict and observant during the application of isokinetics (Brown, 2000).

2.3 SUMMARY

The different types of muscle contractions each has its own role to play in human function, whether it is for posture, respiration, locomotion, or sports activities. The search for the optimum method of improving muscle function has led to the advent of isokinetics, a contraction characterized by a constant movement velocity and at a variable resistance. Isokinetics has distinct advantages, but also some important disadvantages, when compared to other types of muscle contraction like isotonics or isometrics. Although isokinetic dynamometers are expensive, the two features of isokinetics that stand out are its safety and accurate feedback. Furthermore, the development of closed-kinetic-chain isokinetic dynamometers, like the Lido Linea, has opened up a completely new window of applications for isokinetics (Davies *et al*., 2000).

CHAPTER 3: ISOKINETIC TESTING

3.1 INTRODUCTION

Since the advent of isokinetics, it has become the most **popular** method for evaluating muscle strength, mostly because of its validity, objectivity, and repeatability (Baltzopoulos & Brodie, 1989; Anderson *et al.*, 2000). However, not since the X-ray machine has one single testing apparatus been as **abused** as the isokinetic dynamometer (Brown, 2000). Isokinetic testing also brings a new **terminology** that is unique to this mode of testing and training.

3.2 ISOKINETIC TERMINOLOGY AND INTERPRETATION

Muscle performance may be classified as normal or abnormal (Davies *et al.*, 2000), or as normal, but not sufficient for a specific task, that is, a rugby player's knee extension torque may be normal when compared to the general population, but not large enough for the high demands of competition.

When interpreting isokinetic exercise, the biokineticist needs to be able to analyse a lot of information to make the correct clinical decision or interpretation. For this reason, the biokineticist should have a firm grasp of the terminology associated with isokinetics.

It is important to consider all aspects of the isokinetic test results. To consider peak torque (Nm) in isolation, may lead to the biokineticist missing vital information regarding a client's status.

3.2.1 Peak torque

Torque is a force that produces or aims to produce a rotation about a point or axis, and it is equal to the product of perpendicular force applied and the length of the lever arm. In isokinetics, torque is measured in **Newton-metres (Nm)** or foot-pound (ft-lb). One Nm equals 0.74 ft-lb and one ft-lb equals 1.36 Nm. Some isokinetic dynamometers like the Cybex range of machines measure torque directly at the axis of rotation, while other makes, like the KinCom, measurements force distally and then calculates the torque by multiplying the force with the lever arm.

Peak torque is the most commonly reported parameter and it represents the single highest point on the torque curve. Sapega (1990) constructed the following guidelines for classifying **"abnormality"** between two bilateral muscle groups (for example, left and right quadriceps muscle groups) in "normal" subjects:

"normal":	deficits up to 10%;
"possibly abnormal":	deficits between 10 and 20%, and
"probably abnormal":	deficits greater than 20%.

In subjects where one extremity is **expected** to be weaker due to a previous injury or disuse, the following criteria are used:

- "normal": deficits up to 10%;
- "probably abnormal": deficits between 10 and 20%, and
- "almost certainly abnormal": deficits greater than 20% (Sapega, 1990).

These criteria are partly supported by Malone *et al.* (1980) who stated that bilateral differences larger than 10% to 15% are to be considered for asymmetry. In support of this, Knapik *et al.* (1991) reported that female collegiate athletes, who had bilateral knee flexor strength differences of 15% or more, were at increased risk for lower extremity injury.

3.2.2 Average torque

Average torque represents the average of the sum of each repetition's peak torque. However, this data is not always available from all makes of isokinetic devices.

Wessel *et al.* (1992) suggested that when testing limbs with a relatively large mass (for example the hip and trunk musculature), it might be more accurate to consider the average torque instead of the peak torque. However, the author is of the opinion that comparing the "work" (J) done by each limb, instead of peak torque (Nm) would solve this problem. Furthermore, when compared, peak torque and average torque displayed a strong correlation in both concentric and eccentric contractions (Dvir *et al.*, 1989).

3.2.3 Peak torque relative to body mass (% BM)

In order to compare two individuals' peak torque values with one another, it is useful to express the respective torque values as a percentage of body mass (Nm/kg), so that possible differences in body mass do not lead to inaccurate findings (Davies, 1992). It is also advisable to consider this value (% BM), when comparing an individual's values with that of a normative database.

Other isokinetic values, like work and power, are also expressed as a percentage of body mass, for example: *"Power (BMR) % BM"*.

3.2.4 Angle-specific torque

Angle-specific torque is measured in degrees. The angle of peak torque is the specific angle in the ROM that corresponds to the peak torque value. Angle of peak torque in concentric knee extension, is normally given as approximately 60° of knee flexion at a velocity of 60°/s. However, this angle may vary as a function of the isokinetic velocity (Rothstein *et al.*, 1987), because of different athletic training programmes, or due to an injury. An increase in the isokinetic velocity normally results in a delay in reaching the peak torque (Dvir, 1995). Ivey *et al.* (1985) demonstrated that angle of peak torque may vary greatly between subjects when evaluating the shoulder joint.

It is sometimes helpful to consider the torque at a specific joint angle, as well as to establish the angle of peak torque production (for example, in patella femoral syndrome cases). A lot of research still needs to be done in this regard, especially in pathological conditions such as hamstrings strains. The angle in the ROM where peak torque occurred may also be of clinical value. A client that is recovering from a ligament repair procedure may exhibit different angles of peak torque for the affected limb compared to that of the unaffected limb, due to the muscle's inability to rapidly produce force or because of joint pathologies.

3.2.5 Work

Work is the product of torque and distance moved and is measured in joules (J). Thus work values may change if either one or both of the following two parameters change: torque and/or ROM (Davies *et al.*, 2000). Graphically, work is the area beneath the torque-position curve, or alternatively the average torque ($T_{average}$) times the angular displacement (A): **Work = $T_{average}$ x A** (Dvir, 1995).

The total work (J) may be useful in a variety of cases. For instance, two limbs may have identical torque values, but vary greatly when considering the amount of work (J) done. A bilateral variation in work done may indicate a limitation in ROM or some joint pathology like patella femoral syndrome (PFS) for example, where a certain ROM may be painful.

3.2.6 Power

Power is work done per unit of time and measured in watts (W), or joules per second (J/s). In isokinetics, peak power is the product of peak torque and average velocity. If a subject moves with the dynamometer through the maximum ROM, the only way of increasing power is to produce a higher torque value (Davies *et al.*, 2000), or to have a shorter acceleration and/or deceleration time.

If: **Power (P) = Work done (W) / Time taken (T)**

Then: $\mathbf{P = T_{average} \times A / T}$

Thus: $\mathbf{P = T_{average} \times V}$

Where **V** is the angular velocity and **A** is the angular displacement (Dvir, 1995).

By plotting **peak and average power** at different velocities, it may be possible to determine the optimal velocities where a subject can produce his or her maximum force (Davies, 1992). Training programmes may then be tailored around these findings (that is, whether to perform slow or fast contractions during resistance exercises).

Average power is the total work performed, divided by the time it took in seconds (Davies, 1992), or the product of average torque and angular velocity.

3.2.7 Contractional impulse (CI)

Contractional impulse is the product of the average torque multiplied by the time in which it acts: **$CI = T_{average} \times T$.** CI is measured in Nm.s (Dvir, 1995).

Studies by Sale (1991) and Dvir *et al.* (1991) have shown the significance and possible clinical application of CI in both patients and athletes, but this variable is not widely used by clinicians.

3.2.8 Torque acceleration energy (TAE)

Torque acceleration energy is a measure of the **"explosiveness"** of a muscle contraction and is defined as the total amount of work performed in the first 1/8th of a second of the contraction (Davies *et al.*, 2000).

TAE may be one of the most important parameters when evaluating isokinetic data (Davies *et al.*, 2000), since several studies have demonstrated that TAE deficits may correlate with joint pathologies like knee sprain, ACL-deficient knees (Kannus & Jarvinen, 1989; Kannus & Latvala, 1989; Wojtys & Huston, 1994; Huston & Wojtys, 1996;), and muscular dystrophy.

Manske & Davies (in review) have reported that TAE can be improved to within 10% of the uninvolved side through training.

In contrast to the above, Rothstein *et al.* (1987) stated that the validity of TAE measurements should be questioned, since it is not based on *"Newtonian mechanics".* Clinicians should thus not make use of TAE in their clinical evaluation, but if they did decide to use TAE to measure the muscle's explosiveness, they should only use slow velocity testing. This is probably due to the longer acceleration time observed during faster (larger than°/s) isokinetic testing.

3.2.9 Force decay rate

Force decay rate is a measurement of the downward slope of the torque curve. It reflects the subject's ability to exert maximum force through the entire range of motion (Davies *et al.*, 2000). Currently, there is no widely accepted method to calculate this parameter (Davies *et al.*, 2000). However, Ellenbecker (1998) states that the downward slope of a torque curve should follow a convex or flat line. If the curve's downward slope displays a concave shape, the force decay rate is probably too large and could signal possible muscle weakness. If a subject is weak towards the end of the ROM, or if the subject does not give a maximum effort through the entire ROM, the torque curve may exhibit a rapid **force decay rate**. This is characterized by a torque curve that slopes down rapidly following the achievement of the peak torque.

3.2.10 Fatigue index

The fatigue index is the percentage difference between the maximal and minimum amount of work performed in a set, or the work performed at the start of a set compared to the work performed at the end. By comparing the work performed at the start of a set of repetitions to the work done at the end of the set, one can calculate a subject's **fatigue index** or **endurance ratio**. A common protocol for determining a subject's endurance ratio, involves terminating the test when the torque drops below 50% of the peak torque measured at that specific velocity. Another protocol involves the use of a predetermined number of repetitions (for example, 30 repetitions) or time (Davies *et al.*, 2000). The endurance ratio as well as the total amount of work performed, is then used for bilateral comparisons, sport-specific normative comparisons (Burdett & VanSwearingen, 1987; DeNuccio *et al.*, 1991), baseline data at pre-season, and for diagnostic purposes in patients. Although there is no rule governing the number of contractions to use for endurance testing, the repetitions have varied between 10 (Barnes, 1981) and 150 (Elert & Gerdle, 1989; Gerdle *et al.*, 1989). Twenty to thirty repetitions are commonly used to determine endurance ratio.

3.2.11 Coefficient of variance (COV)

The coefficient of variance represents the standard deviation (STD) as a percentage of the average/mean torque measured. The COV for a single set of data is a statistical measure of how closely the data points are grouped. In this way, a set of repetitions may be quantifiably evaluated for reproducibility and accuracy of data collection (User's Guide: Norm testing and rehabilitation system, 1996). When several isokinetic repetitions are performed, there should be a COV of less than 15% for clinical use and less than 10% for research purposes (Brown *et al.*, 1993; Brown & Whitehurst, 2000; Davies *et al.*, 2000).

When performing an isokinetic evaluation, the biokineticist should encourage a maximal and consistent response. The difference between the lowest value and the highest value should be less than 10% (Davies *et al.*, 2000). If there is an average points variance or COV larger than 10% to 15%, the biokineticist may conclude that the subject did not give a consistent effort, or that the subject experienced some pain or discomfort while performing the test, or that the subject was not well familiarized with the testing procedure or process. The COV value should be viewed with caution when performing endurance testing (that is, more than 10 to 15 repetitions), because the COV will be inflated as a function of the increasing repetitions. Furthermore, testing at high speeds or using unwindowed data, may also increase the COV (Brown & Whitehurst, 2000).

3.2.12 Average standard deviation (ASD)

The average standard deviation is the square root of the average statistical variance. It is a measurement for analysing the consistency of a subject's effort during each contraction. For every angle in the ROM, there is a level of variance. By dividing the sum of the variance of every angle throughout the ROM by the total ROM, the average standard deviation (ASD) is obtained. Large ASD's may indicate inconsistent efforts or malingering by the subject.

3.2.13 Speed-specific data

Each subject may have different force-producing capabilities at different movement velocities. As velocity increases with concentric isokinetics, the torque or force normally decreases (according to the "force-velocity curve"), however with eccentric isokinetics the opposite might be true. Eccentric torque may actually increase with increased velocity according to Davies *et al.* (2000) and then plateaus or decreases as the velocity rises even further. However, other researchers differ on this phenomenon and they have reported no increases in eccentric peak torque over a spectrum of velocities in male subjects, while the opposite was true for their female subjects (Colliander & Tesch, 1989).

Whether peak torque rises or remains stable across increasing speeds appears to be dependent on subject gender, training condition, muscle group, and joint position (Westing *et al.*, 1988; Colliander & Tesch, 1989). The fact remains however, that subjects should be tested at a variety of isokinetic velocities, called **"velocity-spectrum" testing**. The reason for velocity-spectrum testing is to determine whether the subject is ready to perform a variety of functional tasks required during normal **activities of daily living (ADL)** and/or to return to his/her particular sport.

3.2.14 Acceleration time or time rate of torque development

Acceleration time is the time taken to achieve a predetermined variable, like peak torque or a specific joint angle in the ROM (Davies *et al.*, 2000). Acceleration time or time rate of torque development may be especially useful in the testing of athletic populations, since a rapid rate of force development is crucial in various sports events (javelin throwing, tennis, sprinting, rugby, and wrestling, for example). Acceleration time may also be used in evaluating neurological function in orthopaedic patients who have undergone surgery or sustained an injury. This is done to determine the function of the subject's neuromuscular integrity. Acceleration time may also be an indicator of explosive strength or power.

3.2.15 Agonist/antagonist ratios

This ratio is obtained by dividing the subject's antagonistic peak torque value or work, by the agonistic value. The "hamstrings/quadriceps ratio" is probably the best-known agonist/antagonist ratio. Knapik *et al.* (1991) reported an increased risk for lower extremity injury in collegiate female athletes who demonstrated a knee flexor/extensor ratio of 75% or less at a concentric angular velocity of 180°/s.

By considering the **antagonist/agonist ratio**, the biokineticist aims to address the important aspect of muscle balance or imbalance. This ratio may identify weaknesses in certain muscle groups, exposing the subject to the risk of injury (Burdett & VanSwearingen, 1987; Scoville *et al.*, 1997; Aagaard *et al.*, 1998). The **eccentric antagonistic/concentric agonistic ratio** is currently very popular, but the concentric antagonistic/concentric agonistic ratio is currently not regarded as sport-specific (Scoville *et al.*, 1997; Aagaard *et al.*, 1998).

Another question raised about antagonist/agonist ratios, refers to the concept of **"interval-scaled data":** the zero level on the torque curve does not represent a true absence of muscularly generated torque. Thus the actual torque curve represents the resistive torque generated by the dynamometer to keep a limb segment from accelerating (Rothstein *et al.*, 1987). However, this viewpoint is not shared by Dvir (1995), who stated that the zero level moments are never considered, since they represent equivalent forces to that of grade III, in manual muscle testing. The author tends to agree more with Rothstein *et al.* (1987), especially at high angular velocities (larger than 180°/s), where the gravitational forces become larger relative to the torques generated. Thus to minimize the above-mentioned phenomenon, the author suggests testing at slower speeds, in non-gravitational positions (horizontal), and without performing gravitational correction.

3.2.16 Isomap procedure

The **"isokinetic moment angular position" or "Isomap"** is a graphical representation of the torque at each angle in the ROM. The Isomap procedure was developed by Biodex for computerized data analysis through a multi-dimensional approach (Davies *et al.*, 2000). Although not widely used, this new procedure may expand our knowledge regarding isokinetic behaviour of muscles in future.

3.2.17 Eccentric/concentric ratio

To obtain this value, a subject's eccentric knee extension torque for example, is divided by the concentric knee extension torque value. This ratio then reflects the muscle's ability to function under both eccentric and concentric conditions.

Many functional activities make use of an **eccentric/concentric** activation pattern. For example, in throwing there is firstly an eccentric contraction in the internal shoulder rotators during the cocking phase, followed immediately by a concentric contraction during the acceleration phase (Scoville *et al.*, 1997). At slow isokinetic speeds, the eccentric torque is usually 30% larger than the concentric torque (Wilmore & Costill, 1999).

The **eccentric hamstrings/concentric quadriceps** ratio, developed by Aagaard *et al.* (1998), has become popular amongst biokineticists when screening for possible muscle imbalances in elite athletes during the pre-season evaluation. However, the correlation between injury occurrence and this ratio has not yet been proven.

3.2.18 Total leg strength (TLS)

To calculate TLS, several isolated OKC tests of the lower extremity are performed and the data is then summated to develop a composite score of the whole kinetic chain (that is ankle, knee, and hip joints). The same may be done for the upper extremity, namely: total arm strength (TAS) (Davies *et al.*, 2000). Previous research results indicate very low correlations (0.15-0.44) between knee extension torque (OKC) and leg press strength (CKC) (Dvir, 1995). The author reported correlations of 0.34 and 0.28 between leg press and knee extension and leg press and knee flexion, respectively.

Several researchers have published information on the concept of **TLS** (Nicholas *et al.*, 1976; Gleim *et al.*, 1978; Boltz & Davies, 1984). The validity of calculating TLS or TAS and comparing it to CKC exercises like leg press and bench press, is still under review and should not be used blindly.

3.2.19 Average and maximum range of motion

A subject's maximum ROM is normally determined before conducting the test. During the evaluation, the dynamometer calculates the average ROM by dividing the total number of degrees moved by the number of repetitions performed. If the maximum possible ROM for knee flexion/extension is not achieved consistently during the test, parameters like work, power and fatigue index may not be accurately used for bilateral comparisons. Work and power measurements are dependent on the ROM (W = T x D; P = W/T) (Brown & Whitehurst, 2000).

3.2.20 Windowing of data

This involves cutting out those portions of a test where free limb acceleration or deceleration occurs (Brown, 2000; Davies *et al.*, 2000). The portion of the torque curve that is left is then referred to as the **"load range"** or **"true" isokinetic movement**. Some of the latest dynamometers may actually perform this function through its software (for example, the Cybex Norm).

During an isokinetic contraction, there are parts of the ROM where the limb does not move at the predetermined isokinetic velocity. This normally occurs during the acceleration phase at the start of the movement and during the deceleration phase, normally near the end of the movement. It is referred to as "free limb acceleration or deceleration". Acceleration is not a fixed velocity and therefore it cannot represent isokinetic movement. Consequently, some researchers recommend **"windowing"** the data, to select only the "pure" isokinetic portion of the ROM, called the **"load range"**, for analysis (Davies *et al.*, 2000).

3.2.21 Damp setting and velocity overshoot

The damp setting is an indication of the amount of filtering that takes place during an isokinetic contraction. It is very similar to the filters that are employed when conducting an ECG recording. Dampening of the isokinetic data is used to eliminate **"overshoot";** the conspicuous spike that may occur at the beginning or end of a contraction (Dvir, 1995). This spike has been referred to as the **"impact artefact"** (Winter *et al.*, 1981), the "torque overshoot" (Sapega *et al.*, 1982), the "impact torque" (Sale *et al.*, 1987), or the "moment overshoot" (Dvir, 1995).

Some modern dynamometers overcome the overshoot phenomenon by employing **"ramping"** and/or **"windowing of data"** (Farrel & Richards, 1986; Brown, 2000). Ramping is a computer-generated acceleration of the lever arm that allows smooth acceleration to the preset angular velocity (Farrel & Richards, 1986). In most Cybex dynamometers the problem of overshoot artefacts are overcome by not calculating the peak torque within the first 1/8 second (windowing the data) and by employing ramping (User's Guide: Norm testing and rehabilitation system, 1996). During the "windowing of data", the acceleration and deceleration phases of the repetition is eliminated and only the load range data is preserved. This technique has been shown to increase the reliability of testing substantially (Brown, 2000).

The velocity overshoot increases with increasing contraction velocity. At slow speeds such as 60°/s, the overshoot is mild, compared to faster speeds (larger than 180°/s) (Brown, 2000).

3.3 PRINCIPLES OF ISOKINETIC TESTING

When performing isokinetic testing, it is of great importance to control for certain variables. Failure to control/standardize these variables, may affect the reliability of isokinetic testing. Therefore, certain strict principles should be adhered to during isokinetic testing.

3.3.1 Pre-testing procedures

Certain procedures should always precede an isokinetic test in order to optimise the testing process and data collected. **Indications and contra-indications** for participation in isokinetic exercise testing should be adhered to at all times (Kleiner, 1990; ACSM, 1991; Davies, 1992; Richter, 1992; Timm, 1992; Dvir, 1995; Kleiner *et al.*, 1999).

After establishing the **purpose** of testing, the appropriate protocol is selected. Subjects have to be educated regarding the test to improve compliance. It is also important for the subjects to understand the purpose of the testing and how it would benefit them personally (Davies *et al.*, 2000).

The isokinetic equipment should be properly maintained and the dynamometer **calibrated** on a regular basis, in accordance to the manufacturer's guidelines, and all personnel involved should be **qualified** and trained in the use of isokinetics (Davies *et al.*, 2000).

3.3.2 Safety procedures

The biokineticist is responsible for the well-being of each subject. It is therefore imperative to conduct a thorough **medical history** of each person, before any testing takes place (this is done to identify relative or absolute contra-indications for isokinetic testing). All subjects must also complete a written **informed consent**, after having received a thorough explanation of the testing procedure (Davies *et al.*, 2000).

Clinicians should consider the **cardiovascular health/readiness** of their subject, before conducting an isokinetic test. Douris (1991) studied the cardiovascular responses to isokinetic exercise in 10 experienced weight trainers. He reported significant increases in heart rate (HR), systolic and diastolic blood pressure (BP), and rate pressure product (RPP = SBP x HR/100), following one minute of knee flexion/extension isokinetic exercise at maximal effort. This was true for 30°/s, 120°/s, and 300°/s. Generally, the cardiovascular system was increasingly affected with increased training velocities. However, even at 30°/s the SBP rose from 133 mmHg to 188 mmHg; the DBP rose from 79 mmHg to 98 mmHg; the HR rose from 79 bpm to 137 bpm, and the RPP rose from 106 to 260. Negus *et al.* (1987) compared the cardiovascular responses between maximum cycle ergometry and a velocity spectrum isokinetic protocol. They concluded that systolic BP rose more during the isokinetic protocol than during cycle ergometry. These studies serve to caution all biokineticists when utilizing isokinetics in elderly individuals and clients with compromised cardiovascular systems.

The biokineticist should always ensure that the subject performs an applicable **warm-up** routine before testing; this should include an aerobic warm-up and light stretching (Davies *et al.*, 2000). The subject should then be stabilized on the apparatus, while paying careful attention to the **correct alignment** of the joint's **axis of rotation** to that of the dynamometer (Perrin, 1993).

The biokineticist must carefully **document all aspects** (for example, lever arm length and gravitational correction) of the test for legal reasons and to ensure accurate repeat testing (Wilk & Andrews, 1993).

3.3.3 Test speed selection

It is generally recommended that subjects be tested across a **spectrum of isokinetic velocities**. The subsequent results could then be used to design a more scientific training programme compared to having the data of only one test velocity available. Testing across a velocity spectrum may also indicate specific pathologies in the injured individual (Davies, 1992).

One big misconception regarding the assessment of peak torque is that slow isokinetic test velocities reflect strength and that faster test velocities represent power and endurance. Perrin (1993) stated that: ***"Determination of torque, work, and power is independent of test velocity."*** However, it is by changing effort and number of repetitions that the different muscle fibres are preferentially recruited during isokinetic testing and training (Perrin, 1993).

3.3.4 Test repetitions

When evaluating a subject's ability to produce peak torque, it is advisable to use approximately five repetitions. When evaluating muscular power, less than 10 repetitions are normally required, and when testing muscular endurance, more than 20 repetitions are commonly used (Burdett & VanSwearingen, 1987; DeNuccio *et al.*, 1991; Davies, 1992). The important factor to bear in mind is which type of muscle fibre is predominantly recruited by the test and which energy pathway is called upon for the specific test protocol.

3.3.5 Rest intervals during testing

Although Davies *et al.* (2000) proposed a rest interval of 90 seconds between each set of repetitions, and three minutes between sets when power-profile testing is performed, other researchers have employed different rest intervals (Sherman *et al.*, 1982; Ariki & Davies, 1985; Pincivero *et al.*, 1997b). Longer rest periods (> 60 seconds) are used for optimal strength and power development. Shorter rest periods (< 60 seconds) are utilized for improving muscular endurance and hypertrophy (Pincivero *et al.*, 1997b). Rest intervals should be tailored according to:

- the type of contraction (concentric or eccentric);
- the number of repetitions (for example, different rest times for bouts of five versus 30 repetitions);
- the isokinetic velocity (slow-velocity testing/exercise require longer rest periods compared to the same number of repetitions at a faster isokinetic velocity);
- the intensity of effort and
- the overall volume and intensity of the test or exercise session.

3.3.6 Range of motion (ROM)

Most tests should be performed through the full possible ROM, however, there may be instances where it is important to limit the ROM (Davies *et al.*, 2000). For example, when testing a patient with anterior cruciate ligament (ACL) pathology early on during the rehabilitation period (Botha, 1997), it may be safer to limit the ROM. Another reason for limiting the ROM for testing, may be to mimic movement pattern of a specific sport (Davies *et al.*, 2000).

The size of the ROM may have a significant effect on the isokinetic performance. Narici *et al.* (1991) demonstrated that a larger ROM resulted in approximately 9% higher torque values when evaluating concentric knee extension torque. They attributed this to the longer time available for tension development and a greater level of neural activation (possibly due to a larger pre-activation stretch).

3.3.7 Feedback

Several studies have indicated that providing some form of feedback (visual or verbal) may enhance isokinetic torque production and test performance (Figoni, & Morris, 1984; Baltzopoulus *et al.*, 1991). The biokineticist should thus be consistent in giving or withholding feedback, especially in the view of obtaining reliable values when retesting a subject (Davies *et al.*, 2000). The effects of feedback becomes more pronounced when the isokinetic test velocity decreases (Figoni & Morris, 1984; Dvir, 1995) and during eccentric isokinetic muscle testing.

3.3.8 Subject positioning

Ideally a subject should be positioned as closely as possible to his/her sporting position when performing isokinetic tests. By changing a subject's position, it may alter factors like muscle length-tension relationship and the kinaesthetic input into the joint (Davies *et al.*, 2000). While it is obvious that a longer lever arm length would give the subject a greater advantage, this advantage is discounted because the subject's limb also acts as a lever arm (e.g. consider the insertion of the patella tendon onto the tibial tubercle). As the input arm is lengthened, the point at which resistance is applied to the subject's limb is placed farther from the axis of rotation of the joint. This puts the subject's joint at a greater lever disadvantage. Thus any advantage on the dynamometer is negated by an exactly equal disadvantage of the subject's joint complex (User's Guide: Norm testing and rehabilitation system, 1996).

3.3.9 Order of testing

Although researchers (Kovaleski *et al.*, 1992; Kovaleski & Heitman, 1993a) do not agree regarding the velocity order when performing isokinetic testing, it would seem that velocity progression order may affect test results, especially when subjects are not well-familiarized with isokinetics and when performing tests at low and high speeds (Brown & Whitehurst, 2000).

When evaluating a subject at more than one isokinetic velocity, it is usually advisable to start with the slowest velocity and to progressively move to the faster velocities. According to Griffen (1987), this progression will facilitate motor learning and increase the reliability of measurement, especially in subjects with limited experience in isokinetic testing (Wilhite, *et al.*, 1992). Certain joint pathologies may require a different approach: subjects suffering from patello-femoral syndrome (PFS), may find progression from a faster to a slower velocity more comfortable, due to the decreased compression forces experienced at higher isokinetic velocities.

There should also be consistency on whether to test the uninvolved- or involved limb first (Davies *et al.*, 2000). Testing the uninvolved limb first, allows the subject to familiarize him-/herself with the equipment and movement required. This decreases apprehension and increases the reliability of the test (Davies *et al.*, 2000). Once a policy has been established, it should be followed consistently. Eccentric testing should always be conducted last to prevent the effects of fatigue on the concentric evaluation. There should also be an adequate rest period between the initial concentric evaluation and the subsequent eccentric evaluation, to allow the muscles to replenish their energy stores before the next bout of testing.

3.3.10 Skill and training of the tester

The biokineticist or sport scientist conducting the test should have adequate training and experience in isokinetic testing and exercise, as well as a sound knowledge of exercise physiology and exercise science. In South Africa, the biokineticist qualifies as an independent practitioner after **four years of academic training and a one-year practical internship** period. It is advisable that other practitioners who wish to become involved in isokinetic testing and training, should undergo thorough theoretical and practical training.

For purposes of consistency, the same person should perform the retesting of a subject (Davies *et al.*, 2000).

3.3.11 Reciprocal testing

Reciprocal testing implies that both the agonist and the antagonist are being tested simultaneously. For example, knee extension and flexion are evaluated simultaneously, as opposed to testing only knee extension with a passive return to the starting position (Brown, 2000). Physiological factors playing a role here include: length-tension relationships, neural activation, functionality, and muscle memory aspects (Figoni, & Morris, 1984; Grabiner, 1994). Reciprocal testing is thought to enhance force generation by activation of the antagonist's motor units (Grabiner, 1994; Brown, 2000).

3.3.12 Force or torque limits

Some dynamometers make extensive use of minimum and maximum force limits (for example, the KinCom), while others (for example, the Cybex range) rarely require it. Optimally selected torque limits may enhance reproducibility of tests, but poorly selected levels may compromise accurate results. Force limits may also interfere with high-speed concentric and eccentric isokinetics and even make it dangerous. Once the force limit is exceeded, the dynamometer starts to move at the predetermined speed and it takes a period for the dynamometer to decelerate when no more force is being elicited. This could force a patient into a painful ROM; this is especially true of the KinCom dynamometer at speeds exceeding 180°/s (Brown, 2000).

3.3.13 Load range

Isokinetic exercise involves three main phases of movement: an acceleration phase to reach the pre-selected velocity, the true isokinetic phase or load range, and the deceleration phase. The higher the selected isokinetic velocity, the smaller the load range or true isokinetic phase. Thus there is an inverse relationship between load range and isokinetic velocity (Brown *et al.*, 1995; Brown & Whitehurst, 2000). Ostemig (1975) was the first to point out this inverse relationship. He demonstrated that load range decreased from 92% to 16% between isokinetic speeds of 50°/s and 400°/s. This implies that high-speed isokinetics may have such a small load range that it may become ineffective as far as an "isokinetic" training goes, especially in small joints like the wrist, ankle, and elbow (Taylor *et al.,* 1991; Brown & Whitehurst, 2000).

3.4 FACTORS THAT MAY INFLUENCE ISOKINETIC RESULTS

Many factors may influence the results of an isokinetic test/measurement. For example, age, gender, weight, height, and athletic background may have a pronounced effect on the results of the isokinetic test (Keating & Matyas, 1996).

3.4.1 Gender

Even when male and female subjects are matched for age and activity levels, males generally exceed the forces/torques generated by females.

Thomas (1984) evaluated 97 "healthy" women with an average age of 35 years. An isokinetic speed of 60°/s was used to measure knee flexion and extension torques on a Cybex II dynamometer (values were not corrected for gravity). The author reported concentric values of 89 Nm (151 %BM) and 52 Nm (88 %BM) for knee extension and flexion respectively, and a flexion/extension ratio of 60%. Wyatt & Edwards (1981) in turn investigated 50 "healthy" men with an average age of 40 years. They also utilized a Cybex II dynamometer and conducted their concentric tests at 60°/s without any gravity correction. Their results were as follows: knee extension torque was 183 Nm (236 %BM) and 130 Nm (168 %BM) for knee flexion. The reported flexion/extension ratio was 72 %. Comparing the two sets of data, differences between the knee flexion and extension torques of men and women were between 60% and 51%. Analysis of work done by other researchers (Gross *et al.*, 1989; Krüger *et al.*, 1992), who considered gravity corrections, yielded smaller differences in peak torque values, when comparing women to men (between 27% and 39% difference).

Previous researchers indicate that men are able to generate higher torque levels than women (Thomas, 1984; Gross *et al.*, 1989; Krüger *et al.*, 1992). The proposed explanation is that men have a larger percentage of fat-free mass than women do. The role of testosterone and other hormones may also explain some of the observed effects. Therefore, separate norms should be developed for each gender (Davies *et al.*, 2000).

3.4.2 Age

Isokinetic dynamometers have not been designed for very young **children**. In some cases, the proportions of the dynamometer may even prohibit the biokineticist from proceeding with a certain test. Ideally, isokinetic tests should be performed on older children (> 12 years), whose body dimensions are more suited to that of the isokinetic apparatus in use. Sometimes it is possible to make modifications to the dynamometer's set-up in order to accommodate smaller children (for example, using the upper extremity input arm for knee extension and flexion testing) (Henderson *et al.*, 1993).

Although previous test reliability studies reported high reliability (Molnar *et al.*, 1979; Burnett *et al.*, 1990; Merlini *et al.*, 1995; Van den Berg-Emons *et al.*, 1996) for isokinetic testing in children, a lot of research still needs to be done in this regard. Intra-class correlations and the associated standard errors of measurement need to be incorporated in future studies, and reliability studies for eccentric isokinetic testing needs to be undertaken (Weir, 2000).

When evaluating isokinetic strength in children, it is important to account for differences in body size and gender when interpreting the results. The most popular method is to divide the torque value by the subject's body mass (BM), although other methods have also been used (Weir, 2000). Some authors have used height or muscle cross-sectional area instead of BM (Gilliam *et al.*, 1979; Kanehisa *et al.*, 1995), or fat free BM (Docherty & Gaul, 1991). Apart from the practice to divide the torque value by body mass, allometric scaling has shown some promise in correcting for differences in torque between subjects that differ in size (Weir *et al.*, 1990; Kanehisa *et al.*, 1995).

Many studies have shown that older children are stronger than younger ones, even after adjusting for differences in body size (Housh *et al.*, 1989; Balague *et al.*, 1993; Roemmich & Sinning, 1997).

The **ageing** individual's isokinetic testing or training should warrant special attention, due to the physiological effects of ageing. Ageing affects all organ systems of the human body, and the muscular system is no exception (Israel, 1992). Atrophy and absolute loss of type II (fast twitch) fibres have been observed with the ageing process (Larsson, 1983; Hopp, 1993). Lexell *et al.* (1988) and Rogers & Evans (1993) reported that age-related muscle atrophy begins as early as 25 years of age and that at the age of 50, approximately 10% to 25% of the muscle cross-sectional area is lost. Thereafter, the atrophy rate increases until almost 50% of the muscle cross-sectional area is lost by the age of 80. Rogers & Evans (1993) reported that this translated to a loss of strength of about 15% by the age of 60 to 70 years, after which the loss in strength was approximately 30% per decade. These findings were also supported by other researchers (Larsson & Karlsson, 1978; Grimby *et al.*, 1980; Larsson, 1983; Lexell *et al.*, 1986).

The following functional changes associated with the ageing process were observed in skeletal muscles. A decrease of 10% per year after the age of 60 was observed in muscle endurance, maximal voluntary contraction, and velocity of contraction of the quadriceps muscle group (Pendergast *et al.*, 1993). Graves *et al.* (1994) and Birren *et al.* (1979) demonstrated that motor performance also decreased in conjunction with losses in muscle strength due to ageing. Ageing muscles also displayed significantly slower reaction times and prolonged speed of contraction during testing (Birren *et al.*, 1979; Graves *et al.*, 1994).

Several research studies have reported significant **isokinetic strength losses** associated with the ageing process. Concentric isokinetic strength losses of between 35% and 47% have been reported between male and female subjects in their second decade compared to subjects in their seventh to eighth decade (Murray *et al.*, 1980, Clarkson *et al.*, 1981; Johnson, 1982; Murray *et al.*, 1985; Harries & Bassey, 1990; Stanley & Taylor, 1993).

Gross *et al.* (1989) reported on isokinetic concentric strength differences between women aged 30 and 69 years, respectively. They reported a 37% and 22% difference in knee extension and flexion torque at 60°/s, between the two groups.

Freedson *et al.* (1993) reported differences of 25% and 27% for concentric knee extension and flexion, respectively at 30°/s, when comparing women aged 30 years of age to women aged 55 years. Weldon *et al.* (1988) studied 1282 female subjects between the ages of 9 & 73 years. They tested concentric isokinetic values in the knee, shoulder, elbow, and ankle and reported that isokinetic torque increased from the age of 9 years to the age of 30 years, but then decreased incrementally with increasing age after 30.

Thus it appears from the above studies that isokinetic strength showed similar declines with ageing, compared to that reported for isometric and isotonic strength.

3.4.3 Body mass (BM)

By dividing a person's isokinetic torque values by body mass (BM), one normalizes the test results to his or her size in order to interpret the values more accurately (Davies, 1992). As mentioned previously in section 3.4.1, some authors have used height or muscle cross-sectional area instead of BM (Gilliam *et al.*, 1979; Kanehisa *et al.*, 1995), or fat free BM (Docherty & Gaul, 1991) to normalize isokinetic torque for body size, while allometric scaling has shown some promise (Weir *et al.*, 1990; Kanehisa *et al.*, 1995).

3.4.4 Stature/height

Although several researchers have investigated the effect of height/stature on isokinetic strength (Alexander & Molnar, 1973; Asmussen, 1973; Kanehisa *et al.*, 1995), the relationship between a subject's height and isokinetic performance however, is still inconclusive (Davies *et al.*, 2000).

3.4.5 Activity level and athletic background

Subjects that reported participation in athletics and other strenuous sports, were generally stronger, more powerful, and had better endurance than their sedentary counterparts. A 31% difference in concentric peak torque (at 30°/s) of the ankle plantar flexors was reported between competitive athletes and inactive subjects of similar age (Fugl-Meyer, 1981). Even when BM was accounted for, there was still a difference of 27% between the two groups. When comparing the concentric torque values reported for collegiate athletes by Nunn & Mayhew (1988), and for students (Lucca & Kline, 1989), their results showed a difference of 30% for knee extension, and 17% for knee flexion peak torque values at 60°/s between the two groups, with the collegiate athletes showing consistently higher peak torques. The collegiate athletes reported a mean hamstrings to quadriceps ratio of 68%, compared to 65.5% for the student population of Lucca & Kline (1989). In both cases, no correction was made for the effects of gravity.

Thus norms developed for athletic populations should not be applied to sedentary populations (Davies *et al.*, 2000).

3.4.6 Limb dominance

Existing strength differences between limbs may have important implications. When monitoring the progress during **rehabilitation**, the injured limb is often compared to the non-injured side (Henderson *et al.*, 1993; Perrin, 1993). Thus clinicians should be aware of possible differences that existed between limbs before the injury took place. Failure to consider possible **pre-existing bilateral differences**, might lead to erroneous conclusions regarding the progress or success of the rehabilitation programme (Perrin, 1993).

Subjects who participated in **symmetrical lower extremity** activities like cycling and running, do not always show significant differences in isokinetic strength (Perrin, 1993). Although unilateral differences of less than 10% have been reported in lower limb isokinetic strength of soccer players (Agre & Baxter, 1987; Capranica *et al.*, 1992), other researchers have found conflicting results. Chin *et al.* (1994) reported a 36% difference in knee extension torque between the dominant and non-dominant limbs in junior (age = 17.3 years) soccer players at 240°/s. They also reported a moderate difference between the dominant and non-dominant hamstrings, namely 10% at 240°/s. In contrast, Holmes & Alderink (1984) found no significant strength differences between the dominant and the non-dominant limbs for knee extension and flexion torque at 60°/s and 180°/s in high school children. Hageman *et al.* (1988) reported only a 6% difference in peak torque values between the dominant and the non-dominant knee extensors at 30°/s of non-disabled male subjects, while Wyatt & Edwards (1981) found a 4.6% difference in knee extensor torque at 60°/s and a 5.1% difference in knee flexor torque, of non-disabled men.

Athletes competing in **asymmetrical upper extremity** events like javelin throwing, have stronger dominant upper limbs (measured as differences in peak isokinetic torque). The difference may be as much as 15%, at velocities between 60°/s and 180°/s (Perrin *et al.*, 1987). McMaster *et al.* (1991) and McMaster *et al.* (1992), reported differences between 18% and 27% in peak isokinetic torque in the dominant internal shoulder rotation, in national water polo players and competitive swimmers, compared to the non-dominant side, at 180°/s.

Previous research indicated significant differences of up to more than 15% between the dominant and the non-dominant sides when evaluating the **upper extremities** (Perrin *et al.*, 1987; McMaster *et al.*, 1991; McMaster *et al.*, 1992), especially when considering elite athletes who perform unilateral upper limb sports like tennis (Wrigley & Strauss, 1989). The opposite seems to be the case when considering the **lower extremity**; except for athletic populations who partake in asymmetrical lower extremity sports like soccer, most individuals do not show differences larger than 10% between the peak torque of the dominant and the non-dominant lower limbs (Agre & Baxter, 1987; Capranica *et al.*, 1992; Chin *et al.*, 1994).

Thus the effects of dominance on bilateral peak torque should always be considered when screening for muscle imbalances in athletes or when conducting rehabilitation programmes in an orthopaedic setting (Perrin, 1993; Davies *et al.*, 2000).

3.4.7 Subject positioning

Due to length-tension relationships and joint biomechanics, isokinetic torque production will vary if changes occur in the positioning of the subject. For example, when performing knee extension and flexion in the seated position versus the prone position, different results will be obtained (Davies *et al.*, 2000).

Bohannon *et al.* (1986) investigated the effects of two different positions on knee flexion and extension peak torque at 60°/s. The two positions were: (1) upright sitting at about 95° of trunk flexion, and (2) semi reclined at about 30° of trunk flexion. They concluded that knee extension torque did not differ significantly between the two test positions, but that knee flexion torque was significantly greater in the upright position (approximately 8%). These findings were consistent with the research of Felder (1978) and Lunnen *et al.* (1981).

Hageman *et al.* (1989) studied the effects of two different positions (45° gleno-humeral abduction versus 45° gleno-humeral flexion) on shoulder internal and external rotators, at 60°/s and 180°/s. They reported that peak torque values were significantly higher in the abducted position during concentric and eccentric external and internal shoulder rotation.

Previous research thus indicates that the positioning of the subject may have a significant effect on torque production. Subject positioning should thus be standardized and meticulously recorded during isokinetic testing and training.

3.4.8 Contraction mode

Eccentric muscle contractions usually generate larger torque values than concentric contractions. This is attributed to the additional involvement of the non-contractile tissues (elastic components) during eccentric contractions. However, these differences are dependent on the movement velocity (Davies *et al.*, 2000).

3.4.9 Range of motion (ROM)

In order to reach the predetermined angular velocity, the limb has to accelerate from 0°/s, and to reverse the movement at the end of the ROM, the limb has to decelerate back to 0°/s. Thus the true isokinetic ROM or the **load range**, is always smaller than the maximum ROM. There is normally an inverse relationship between angular velocity and the load range: an increased angular velocity implies a smaller load range.

The size or magnitude of the selected ROM may influence the isokinetic test results as mentioned previously (3.3.6). By setting "hard" stops, at each end of the ROM, the biokineticist can ensure that all subjects transverse the same total ROM (Brown & Whitehurst, 2000).

3.4.10 Damp setting

At angular velocities below 90°/s, varying the damp settings (between low, medium or high) does not appear to significantly change the peak or average torque values (Rathfon *et al.*, 1991). However, the extent of the effect of dampening, on higher isokinetic velocities, are not known at present (Dvir, 1995).

3.4.11 Isometric pre-activation (IPA)

Isometric pre-activation (IPA) was introduced in most KinCom machines as a safety measure and to overcome the problem of overshoot. It had a positive effect on average torque, but did not seem to result in higher peak torques (Dvir, 1995). Isometric pre-activation remains controversial and therefore some manufacturers of isokinetic dynamometers have not included this feature in their designs (User's Guide: Norm testing and rehabilitation system, 1996).

3.4.12 Minimum and maximum force

The minimum force or lower isometric bias (LIB) normally serves as a complement to isometric pre-activation in some dynamometers. The LIB is the minimum force that has to be maintained in order for the dynamometer to proceed with the movement at the preset angular velocity (Dvir, 1995). An important factor to take cognizance of is the fact that dynamometers differ in their concentric modes of operation. The lever arm KinCom-type dynamometer moves at the preset velocity once activated, while a dynamometer like the Cybex, allows movement up to a maximum preset velocity. The constant velocity supplied by some dynamometers, is potentially dangerous, especially at high angular velocities and when low LIB values are used (Dvir, 1995). Isokinetic dynamometers are classified according to their velocity control mechanism. For example, some dynamometers use an electronic servomotor, others a hydraulic valve, or a mechanical braking system, while some utilize a magnetic braking system to control its velocity (Perrin, 1993).

The feature that involves limiting the maximum force that a contraction may elicit, is called the upper moment limit (UML). The UML may be activated to ensure the safety of vulnerable structures, like a recently reconstructed ACL. Thus the simultaneous use of LIB and UML, may be beneficial in non-maximal efforts, or for the purpose of fine motor performance analysis or training, and during early phases of the rehabilitation programme (Dvir, 1995).

3.4.13 Feedback

Feedback may be described in terms of form, amount, delay, and content (Peacock *et al.*, 1981; Dvir, 1995).

Peacock *et al.* (1981) demonstrated that isometric peak torque was significantly enhanced by combined visual and auditory feedback. However, this effect was not produced by using either of the methods separately. Figoni & Morris (1984) examined isokinetic performance with and without visual feedback and found a beneficial effect of about 12% at a slow velocity (30°/s), but no benefit at a faster velocity (300°/s). These findings have been confirmed by other researchers

(Baltzopoulos *et al.*, 1991; Hald & Bottjen, 1987). Thus the beneficial effects of visual feedback may be limited to slower isokinetic velocities (Dvir, 1995).

Wilk *et al.* (1991) investigated the effects of verbal feedback and encouragement. They found that aggressive verbal feedback and encouragement resulted in their subjects becoming fatigued earlier. They concluded that verbal feedback should be moderate in intensity and consistent in nature.

Thus any feedback given to a subject should be consistent from one test to the next and from one subject to another (Brown & Whitehurst, 2000).

3.4.14 Stabilization

Subjects should be properly stabilized before conducting an isokinetic evaluation or training session. This will eliminate compensatory movements that may interfere with the intended movement pattern and aid the correct alignment of the joint in question. However, Hanten & Ramberg (1988) reported no significant difference between maximal stabilization procedures and minimal stabilization at a wide range of angular velocities (30°/s to 200°/s) for concentric and eccentric knee extension.

This finding is in contrast with that of Hart *et al.* (1984) who reported significantly greater concentric torque values, regardless of the velocity, when subjects were allowed additional trunk stabilization. Other researchers share their view (Nosse, 1982; Smidt & Rogers, 1982).

3.4.15 Gravity correction (GC)

Failure to report on the gravity correction status of an isokinetic evaluation, will result in erroneous conclusions and interpretation of results (Brown & Whitehurst, 2000). Winter *et al.* (1981) reported mechanical work errors ranging from 26% to over 500% during knee flexion/extension exercise tests at 60°/s and 150°/s.

Researchers are strongly advised to correct for the effects of gravity if high-speed tests are to be conducted. As contraction speed increases, the concentric torque decreases, but gravity stays the same. Thus the relative proportion of the gravitational force increases in relation to the measured force output. This will not only lead to erroneous peak torque values and endurance ratios, but also to incorrect agonist/antagonist ratios (User's Guide: Norm testing and rehabilitation system, 1996).

Fillyaw *et al.* (1986) concluded that failing to correct for gravity effect torque (GET), would significantly decrease knee extension torque values and increase knee flexion torque values. This would lead to erroneous knee flexion/extension ratios. These authors also stressed the importance of correcting for GET in patients with reduced torque output, where the GET is a greater percentage of the measured torque.

One problem with correcting for the effects of gravity however, is the fact that it is a complex procedure, which requires the subject to relax completely. Some subjects are unable to relax one or both of their limbs. This leads to an inaccurate determination of bilateral torque values.

3.4.16 Effects of eccentric exercise

Maximal eccentric contractions may lead to a subsequent decrease in muscle tension development and strength. Research indicates that this muscle weakness is noted immediately after the eccentric exercise bout and it may last up to one week. This aspect should be considered when conducting research or isokinetic testing that involves eccentric protocols, and when designing rehabilitation programmes (User's Guide: Norm testing and rehabilitation system, 1996).

3.5 SOURCES OF ERROR IN ISOKINETIC DYNAMOMETRY

Numerous authors have commented on the reliability, validity, and efficacy of using isokinetics as part of testing and training. Today, isokinetic testing is regarded as a very accurate method for evaluating muscle performance (Farrel & Richards, 1986; Burdett & VanSwearingen, 1987; Wilhite, *et al.*, 1992; Brown *et al.*, 1993; Davies, 1995; Davies *et al.*, 1997; Davies & Zillmer, 1999).

However, the following **sources of error** have been highlighted in the use of isokinetics:

- acceleration and deceleration phases (Sapega *et al.*, 1982);
- the effects of gravity (Winter *et al.*, 1981);
- alignment of the dynamometer's axis to that of the joint (Herzog, 1988); and
- failure to calibrate the dynamometer on a regular basis (at least once a week).

Modern dynamometers make it possible to eliminate the first two sources of error largely, but the third source of error is probably the most problematic, unless one is dealing with the knee joint. The shoulder joint is particularly problematic and poor reproducibility for test-retest has been reported (Magnusson *et al.*, 1990).

If the object is evaluation of the maximal force of the contractile elements of a muscle, then only concentric contractions should be evaluated. During an eccentric contraction, the tension being generated is actually the combination of the contractile and the non-contractile elements within the muscle that are being pulled apart. Thus eccentric contractions at slow to moderate speeds are nearly always larger (approximately 30%), than the corresponding concentric contractions (User's Guide: Norm testing and rehabilitation system, 1996; Wilmore & Costill, 1999).

The largest source of error in the use of isokinetics however, is incorrect application and interpretation by the clinician (**human error**). This may be prevented by more comprehensive training of clinicians and by regular workshops conducted by "isokinetic experts".

3.6 NORMATIVE VALUES FOR INTERPRETING AN ISOKINETIC TEST

"Norm" is the abbreviated form of the word ***"normal"***. In the context of measurement and evaluation of physical properties like muscle strength, it denotes the *average* or *mean* performance of a group of individuals under similar circumstances. The plural form ***norms,*** refers to the availability of the mean, standard deviation, and percentile ranks for various performances of a comparative group, or reference group (Kirkendall *et al.*, 1979).

The use of normative data is **controversial**; however if it is utilized in an appropriate manner, it can be used as a valuable guideline for testing and for developing strength, for conditioning, and for rehabilitation programmes (Goslin & Charteris; 1979; Thompson *et al.*, 1985; Davies *et al.*, 2000).

The idea of setting or prescribing a norm or standard for any one individual or groups of individuals, will usually **evoke criticism** or emotional responses. The preoccupation with norms by some uninformed individuals must be condemned and discouraged. Norms and standards for isokinetic values could be **useful tools** when used by informed professionals, who are able to intelligently discriminate between the performances of different individuals, in different population sub-groups. The utilization of norms may be extremely useful if they are **viewed in context**, client individuality is recognized, and realistic goals are set for each individual (Krüger et al, 1995).

When constructing an isokinetic test protocol, an important decision to make is whether to use a norm-referenced or criteria-referenced test. The type of standard selected would probably depend on the nature of the decisions the biokineticist needs to make after completion of a specific test. When evaluating sporting performance, a norm-referenced score may not apply to the elite athlete. Similarly, criteria-referenced scores developed for athletes may not be realistic for the average individual recovering from an injury sustained in a motor vehicle accident.

In each individual case the following question should be asked: "What is the ***critical score*** that should be achieved in order to fulfil the specific individual's requirement?" For the average person, a percentile score of 50 might be required, whereas the elite athlete might only be satisfied with a score above the 95th percentile (Kirkendall *et al.*, 1981).

Norms can be prepared as percentile ranks, standard scores, T scales, or 6-σ scales. The most common method for reporting on isokinetic norms is to express the norm in terms of torque relative to body mass (% BM) (Kirkendall *et al.*, 1981).

3.6.1 Guidelines for constructing and utilizing norms

Dvir (1995) states that if norms are used, they should be related to **gender, age, and activity level**. To ensure that norms are based on a representative population, they have to be based on a **large number** of scores. It is desirable to have **more than 200** cases when developing norms, although some researchers require a sample equal to 10% of the specific population. In a very large population group (for example, 40 million people), this would not seem practical. However, large number of scores will enhance the reliability of rank ordering.

Although some studies have utilized very **small sample groups**, they may indicate **valuable trends** and actually serve as pilot studies for subsequent future research.

The most appropriate norms for comparing performances must be **local** and as specific as possible to the parameter tested. It is also important to supply all relevant information regarding the test **protocol** for which the norms were developed so that subsequent clinicians may follow **identical procedures** in their evaluations. The criteria used in developing the test must be addressed in detail and validation procedures must be described. The methods of establishing content validity and actual reports of validity and reliability studies should be included, as well as the age, sex, race, and cultural background of the population (Kirkendall *et al.*, 1981).

It is important to take **body mass** and **gender** into account when establishing normative data, since positive correlations exist between body mass, gender, and peak torque (Falkel, 1978, Gilliam et al, 1979). To eliminate the effect of body mass on peak torque, Thorstensson *et al.*(1977) suggested expressing peak torque in Nm/kg body mass (relative torque value), instead of Nm (absolute torque value). By using this method, individuals of different sizes may be compared.

Different researchers have embarked on the mission to establish normative data for different muscle groups. However, biokineticists should exercise caution when attempting to extrapolate test data from one isokinetic dynamometer to another or from one population group to another. Thompson *et al.* (1989) demonstrated significant differences between values obtained from two **different isokinetic dynamometers** (for example, the *Biodex Model b-2000* and the *Cybex II Plus*).

When reviewing the literature on isokinetic norms, how should one approach it? The author made use of certain selection criteria during the literature research. For data to be considered as normative, the following criteria had to be met:

- sample group preferably larger than 50 to 100;
- similar isokinetic dynamometers;
- same gender;
- similar age and activity level;
- body mass corrected torque values;
- peer-reviewed published research articles or publications;
- velocity-specific norms;
- similar set-up, for example, body position: prone or supine; and
- similarity regarding gravity correction.

The following sections (3.6.2 to 3.6.6) are the result of the literature research and may provide some useful normative data for male subjects. No attempt has been made to arrive at one absolute or ideal norm, since such a practice would have been stripped of any scientific basis.

3.6.2 Normative isokinetic values for shoulder flexion and extension

At **60°**/s, concentric shoulder flexion and torques varied from 62 Nm to 65 Nm, and shoulder extension values varied from 80 Nm to 122 Nm. Torque relative to bodyweight (% BM) varied between 80% and 76% for shoulder flexion, and between 97% and 150% for shoulder extension (Ivey *et al.*, 1985; Cahalan *et al.*, 1991). These two authors reported flexion/extension ratios of between 53% (Cahalan *et al.*, 1991) and 77% (Ivey *et al.*, 1985). Both these researchers used a **Cybex II** dynamometer, **did not correct for gravity**, used **healthy males** between the ages of 21 and 50 years, and their sample consisted of 36 (Ivey *et al.*, 1985) and 26 (Cahalan *et al.*, 1991) subjects. When the author pooled (n=62) the data, the following values were obtained: shoulder flexion 64 Nm (78% BM), shoulder extension 101 Nm (123% BM), and a flexion/extension ratio of 65%.

The abovementioned authors also conducted some research at **180°**/s on the same subjects, utilizing the same protocol. The pooled data resulted in the following values: shoulder flexion 47 Nm (57% BM), shoulder extension 70 Nm (86% BM), and a flexion/extension ratio of 68%.

Cahalan *et al.* (1991) also included **300°**/s in their research with the following resulting values: concentric shoulder flexion was 36 Nm (44% BM), shoulder extension was 64 Nm (79% BM), and the flexion/extension ratio was 56%.

3.6.3 Normative isokinetic values for shoulder horizontal abduction and adduction

Weir *et al.* (1990) conducted research on **104 male high school wrestlers** between the ages of 16 and 18. They used a **Cybex II** dynamometer and the dominant side was evaluated. The damp setting was two (2) and **no gravity correction was made**. Test speeds of **30°/s, 180°/s, and 300°**/s were used. The resultant values were as follows. Concentric shoulder horizontal abduction was 68 Nm, 51 Nm and 35 Nm at 30°/s, 180°/s, and 300°/s, respectively. Horizontal adduction measured 74 Nm, 53 Nm, and 35 Nm. Torque relative to BM yielded the following: shoulder horizontal abduction was 100% BM, 73% BM, and 52% BM at 30°/s, 180°/s, and 300°/s, respectively; horizontal shoulder adduction was 106% BM, 76% BM, and 51% BM. The shoulder horizontal abduction/adduction ratios varied from 93% at 30°/s, to 96% at 180°/s, and to 103% at 300°/s.

3.6.4 Normative isokinetic values for shoulder internal and external rotation

Ivey *et al.* (1985); Connelly Maddux *et al.* (1989), and Cahalan *et al.* (1991) conducted research at **60°/s and 180°**/s using the **Cybex II** dynamometer. They **did not correct for the effects of gravity** and their subjects were **63 males** between the ages of 21 and 50 years. Subjects were positioned with their shoulders in **90° of abduction**. They reported the following values: concentric shoulder internal rotation torque varied between 49 Nm and 42 Nm, at 60°/s and 180°/s, respectively. External shoulder rotation torque varied between 30 Nm and 24 Nm. Torque relative to BM for internal shoulder rotation was 60% BM and 51% BM, and between 36% BM and 29% BM for external shoulder rotation. The external/internal shoulder rotation ratio measured 61% and 58%, at 60°/s and 180°/s, respectively.

Wang *et al.* (2000) studied **10 elite male volleyball players**, with an average age of 20 years, using a **KinCom** dynamometer. Both shoulders were included in the evaluation. The following results were reported: the external/internal shoulder rotation ratios at **60°**/s **and 120°**/s varied between 67% and 69% for the dominant limb, and between 98% and 97% for the non-dominant limb. The **eccentric** shoulder external/internal rotation ratio varied between 74% and 84% for the dominant limb and between 93% and 84% for the non-dominant side at 60°/s and 120°/s, respectively.

Cahalan *et al.* (1991) reported the following values for the dominant shoulder of 26 male subjects at **300°**/s. They used a **Cybex II** dynamometer and did not correct for gravity. Concentric shoulder internal rotation was 34 Nm (42% BM), external shoulder rotation was 14 Nm (17% BM), and the shoulder external/internal rotation ratio was 41%.

3.6.5 Normative isokinetic values for shoulder abduction and adduction

Smith *et al.* (1981) and Weir *et al.* (1992) conducted research on **wrestlers** and **elite ice hockey players**, respectively. They both used a **Cybex II** dynamometer and did not correct for gravitational effects. The pooled sample consisted of 68 male subjects with an average weight of 76 kg and an average age of 21 years. They reported the following values at **60°/s and 180°/s.** Shoulder abduction torque was 73 Nm (97% BM) at 60°/s and 56 Nm (72% BM).at 180°/s. Shoulder adduction torque was 92 Nm (119% BM) and 68 Nm (88% BM) at 60°/s and 180°/s, respectively. The shoulder abduction/adduction ratios measured 82% at 60°/s and 84% at 180°/s.

The following data was presented by Ivey *et al.* (1985) and Cahalan *et al.* (1991) using a **Cybex II** dynamometer for **44 male** subjects between the ages of 21 and 50 years. Concentric shoulder abduction values were between 48 Nm (57% BM) at **60°**/s, and 38 Nm (45% BM) at **180°**/s, while the shoulder adduction values were 85 Nm (103% BM) at 60°/s, and 74 Nm (91% BM) at 180°/s. They also reported the following shoulder abduction/adduction ratios: 56% at 60°/s and 51% at 180°/s. These authors **did not correct for the effects of gravity**.

Wilk *et al.* (1992) studied the shoulders of **50 professional male baseball pitchers** using a **Biodex** dynamometer. The average age was 25 years, the average BM 91 kg, and the average height 188 cm. No visual feedback was given and **no correction was made for gravity**. They compared the values of the dominant side to that of the non-dominant side. The angular velocities used were 180°/s and 300°/s. At **180°/s** the following values were reported: shoulder abduction torque was 75 Nm (83% BM) and 80 Nm (87% BM) for the dominant and non-dominant side, respectively. Shoulder adduction was 94 Nm (103% BM) and 86 Nm (94% BM) at 180°/s, and the shoulder abduction/adduction ratio was 80% for the dominant side and 93% for the non-dominant side.

At **300°/s** they reported a concentric shoulder abduction torque of 59 Nm (64% BM) and 53 Nm (58% BM) for the dominant and non-dominant sides, respectively. Shoulder adduction torque at 300°/s was 76 Nm (83% BM) and 74 Nm (81% BM), and the shoulder abduction/adduction ratio was 78% for the dominant side and 72% for the non-dominant side.

3.6.6 Normative isokinetic values for knee flexion and extension

Krüger *et al.* (1992) investigated dominant knee flexion and extension at **60°**/s, in **536 inactive Caucasian males**, using a Cybex II dynamometer. The average height, body mass (BM), and age of the subjects were 177 cm, 79 kg, and 25 years, respectively. Their isokinetic values **were all corrected for the effects of gravity**. Average concentric knee flexion was 127 Nm (183% BM), and knee extension was 238 Nm (338% BM). These authors reported a knee flexion/extension ratio of 54%.

Gross *et al.* (1989) also investigated dominant knee flexion and extension at **60°/s** in **49 males**, between the ages of 15 and 50 years (the average age was 31 years). Their subjects had an average height of 174 cm and an average weight of 73 kg. The authors used a **Cybex II** dynamometer and **corrected for the effects of gravity**. They reported values of 134 Nm (184% BM) for knee flexion, 198 Nm (272% BM) for knee extension, and the knee flexion/extension ratio was 68%. However, when only the values of the 30-year old group were considered, a knee extension value of 240 Nm (307% BM) was reported, knee flexion was 153 Nm (196% BM), and the knee flexion/extension ratio was 64%. The values reported for the 15-year old group yielded a knee extension value of 152 Nm (264% BM), a knee flexion value of 108 Nm (189% BM), and a ratio of 72% between flexion and extension. The different torque values from this study between different age groups serve as a caution to compare non-population specific torque values.

Ghena *et al.* (1991) used a **Biodex B-2000** to investigate concentric and eccentric knee flexion and extension at **60°/s** in **male, university athletes**. The dominant side was selected and values were **corrected for gravity**. The average age, height and weight were 20 years, 182 cm, and 76 kg, respectively. Their values were as follows: **concentric** knee flexion (142 Nm and 186% BM), knee extension

(260 Nm and 340% BM), and knee flexion/extension ratio (55%). They also reported on **eccentric** values. Eccentric knee flexion was 166 Nm (218% BM), eccentric knee extension 257 Nm (337% BM), and the eccentric knee flexion/extension ratio was 65%. The eccentric knee flexion/concentric knee extension ratio was 64%.

Schlinkman (1984) reported very similar values at **60°/s** compared to that of Krüger *et al.* (1992) and Ghena *et al.* (1991). Their values were 127 Nm and 179% BM for knee flexion, 235 Nm and 338% BM for knee extension, and a flexion/extension ratio of 54%. They used a **Cybex II** dynamometer and **corrected for the effects of gravity**. Their subjects consisted of male, **high school football players** (n=342) with an average age of 16 years. Thus it may seem that the subjects from the study of Krüger *et al.* (1992), although reported to be inactive, might have been quite active during their high school years.

Highgenboten *et al.* (1988) also investigated **eccentric** knee flexion and extension at **60°/s**, but they used a **KinCom** dynamometer. They tested both the left and the right side and the data that will be presented is the average of the two sides. It is **unclear** from their publication **whether they corrected for the effects of gravity**. Their sample group consisted of 54 **males** with an average age of 25 years and an average weight of 75 kg. Their values were slightly lower than that of Ghena *et al.* (1991), probably because the age of their sample group was higher and did not exclusively consist of athletes. Eccentric knee flexion was 106 Nm (141% BM), eccentric knee extension 216 Nm (288% BM), and the eccentric knee flexion/extension ratio was 52%.

Wyatt & Edwards (1981) were the only researchers that the author came across who **did not correct for the effects of gravity**, and who fitted the criteria for a **normative** database. However, it must be stated that several other researchers (Lucca & Kline, 1989; Nunn & Mayhew, 1988; Holmes & Alderink, 1984) conducted non-gravity corrected studies on groups smaller than 50 subjects, but they were not considered for this text.

Wyatt & Edwards (1981) conducted their research on **"healthy" male subjects** with an average age, height, and weight of 29 years, 179 cm, and 78 kg. These authors used a **Cybex II** dynamometer for their study. They reported the following values: concentric knee flexion (130 Nm & 168% BM), knee extension (183 Nm & 236% BM), and a ratio of 72% for knee flexion/extension.

It is clear that the ratio of 72%, reported by Wyatt & Edwards (1981) is much higher than that of the abovementioned researchers, who took the effects of gravity into consideration (Krüger *et al.*, 1992; Schlinkman, 1984). It was only the knee flexion/extension value reported by Gross *et al.* (1989) of 68%, that did not agree with these low ratios (54%). When comparing the data of Krüger *et al.* (1992) and that of Gross *et al.* (1989), a possible explanation lies in the fact that the subjects of Krüger *et al.* (1992) displayed much higher knee extension torques compared to Gross *et al.* (1989) (238 Nm vs. 198 Nm). Even when the torque values are expressed relative to body mass, the trend still holds (338% BM vs. 272% BM). Seen together with the fact that the knee flexion values were fairly similar (127 Nm vs. Nm, and 183% BM vs. 184% BM), one might conclude that the subjects of Krüger *et al.* (1992) were more athletically inclined.

When one compares the findings of the author at **60°/s** (**non-gravity corrected torques**), the following was found: concentric knee flexion (159 Nm & 222% BM), knee extension (236 Nm & 331% BM), and a flexion/extension ratio of 68%. Apart from the flexion/extension ratios of the author (68%) and the 72% reported by Wyatt & Edwards (1981) that seem quite similar, the knee flexion and extension values are quite different (flexion: 222% BM vs. 168% BM and extension: 331% BM vs. 236% BM). This comparison should caution all biokineticists and clinicians involved in orthopaedic rehabilitation to use population-specific normative databases.

Numerous studies have been conducted on the knee flexion and extension torque of males at **other angular velocities** (see Table 3.1).

Table 3.1: A summary of previous studies on the knee flexion and extension torque of males at angular velocities other than 60°/s.

Authors	Ext. % BM	Flex. % BM	Ratio	GC	Dynamo-meter	Subjects	Age	BM kg	n
12°/s	CON								
Borges, 1989	348%	198%	57%	Yes	Cybex II	Mixed	30	76	76
30°/s	CON								
Knapik & Ramos, 1980	200 Nm	115 Nm	58%	No	Cybex II	Infantry soldiers	24	74	352
Freedson *et al.*, 1993	238%	153%	66%	No	Cybex II	Medium-heavy work	35	82	3345
90°/s	CON								
Borges, 1989	280%	152%	54%	Yes	Cybex II	Mixed	30	76	76
Borges, 1989	246%	132%	54%	Yes	Cybex II	Mixed	45	78	139
Knapik & Ramos, 1980	138 Nm	90 Nm	65%	No	Cybex II	Infantry soldiers	24	74	352
120°/s	CON								
Ghena *et al.*, 1991	287%	165%	58%	Yes	Biodex B-2000	University athletes	20	76	100
Ghena *et al.*, 1991	341%	220%	65%	Yes	Biodex B-2000	University athletes	20	76	100

Authors	Ext. % BM	Flex. % BM	Ratio	GC	Dynamometer	Subjects	Age	BM kg	n
180°/s	**CON**								
Gross *et al.*, 1989	184%	158%	87%	Yes	Cybex II		31	73	49
Knapik & Ramos, 1980	88 Nm	60 Nm	68%	No	Cybex II	Infantry soldiers	24	74	352
Freedson *et al.*, 1993	131%	104%	81%	No	Cybex II & Cybex II+	Medium-heavy work	35	82	3345
Wyatt & Edwards, 1981	170%	131%	78%	No	Cybex II	“Healthy”	29	78	50
Smith *et al.*, 1981	175%	141%	81%	No	Cybex II	Ice hockey players	24	83	43
240°/s	**CON**								
Schlinkman, 1984	191%	126%	66%	Yes	Cybex II	High school male football	16		342
300°/s	**CON**								
Ghena *et al.*, 1991	191%	116%	61%	Yes	Biodex B-2000	University athletes	20	76	100
Freedson *et al.*, 1993	89%	82%	96%	No	Cybex II & II+	Medium-heavy work	35	82	3345

Authors	Ext. % BM	Flex. % BM	Ratio	GC	Dynamometer	Subjects	Age	BM kg	n
Wyatt & Edwards, 1981	115%	94%	83%	No	Cybex II	"Healthy"	29	78	50
Schlinkman, 1984	161%	108%	67%	Yes	Cybex II	High school football players	16		342
450°/s	CON								
Ghena *et al.*, 1991	148%	120%	80%	Yes	Biodex B-2000	University athletes	20	76	100

For the purpose of this text, only knee flexion and extension torques at 60°/s were considered, but the present author is well aware of the trend that Biokineticists and other clinicians include higher angular velocities into their test protocols. It is therefore hoped that the above table will be of practical use.

3.6.7 Normative isokinetic values for ankle plantar and dorsiflexion

Before the study by Krüger *et al.* (1995), very little normative data existed regarding the ankle musculature. Krüger *et al.* (1995) stated that previous researchers negated testing the ankle's plantar and dorsi flexor strength as well as the strength of the ankle invertors and evertors, possibly due to methodological problems such as the isolation of the invertors and evertors in order to reproduce accurate measurements (Gleim *et al.*, 1978).

Isokinetic testing of the ankle joint's plantar and dorsiflexion may be conducted with the knee straight or bent at 90°. In the 90° knee flexion position, the gastrocnemius muscle is thought to be at a disadvantage and cannot contribute hugely to ankle plantar flexion torque production (Kendall *et al.*, 1993).

No research study fitting the **author's criteria** for a **normative database** was found in the literature for ankle plantar and dorsiflexion at 30°/s with the knee straight **(0° knee flexion)** however, Fugl-Meyer (1981) conducted some research on inactive subjects (n=15) and competitive athletes (n=15). He reported the following values **(not corrected for gravity)** for inactive subjects and athletes, respectively: ankle dorsiflexion (33 Nm & 47% BM vs. 35 Nm & 47%), plantar flexion (126 Nm & 180% BM vs. 184 Nm & 245% BM), and dorsi/plantar flexion ratio (26% vs. 19%). The author's results compare well with that of the inactive population of Fugl-Meyer (1981): dorsiflexion (36 Nm & 52% BM), plantar flexion (131 Nm & 186% BM), and a dorsi/plantar flexion ratio of 29%.

Fugl-Meyer *et al.* (1980) also conducted some research on ankle plantar flexion in **"healthy" Swedish men**, using the **straight knee position** at angular velocities of **90°/s** and **180°/s**. Their sample consisted of 30 subjects, with an average height and BM of 179 cm and 72 kg, respectively. The subjects were between the ages of 20 years and 39 years, and both the left and right ankles were tested. The authors used a **Cybex II** dynamometer and **no correction** was made **for the effects of gravity**. They reported the following results: average concentric plantar flexion at 90°/s was 76 Nm (106% BM), and at 180°/s it was 40 Nm (56% BM).

Krüger *et al.* (1995) evaluated dominant ankle plantar and dorsiflexion at **30°/s** with the **knee flexed to 90°**. They used a **Cybex II** dynamometer and their subjects totalled 306 inactive Caucasian males. The average age, height, and weight of the subjects were 26 years, 176 cm and 78 kg, respectively. **No correction** was made **for the effects of gravity**. The average for concentric dorsiflexion was 30 Nm (34% BM), and 70 Nm (102% BM) for plantar flexion.

3.6.8 Normative isokinetic values for ankle inversion and eversion

Wong *et al.* (1984) conducted research on concentric ankle inversion and eversion at three angular velocities (**30°/s, 60°**/s **& 120°**/s), using a **Cybex II** dynamometer. Although they only utilized 21 subjects (which disqualifies their data for inclusion into a normative database), their results are included in the text, due to the scarcity of data in this mode of testing. Their subjects consisted of **"healthy" males** with an average age, height, and body mass of 29 years, 178 cm and 76 kg, respectively. Their results were as follows: concentric ankle eversion torque at 30°/s, 60°/s, and 120°/s (28 Nm, 24 Nm, & 19 Nm), inversion torque (32 Nm, 26 Nm, & 22 Nm), and eversion/inversion ratios of 87%, 90%, and 86%, respectively. When expressing their torque values relative to body mass, they reported values 37% BM, 32% BM and 26% BM for ankle eversion, and 43% BM, 35% BM and 30% BM for ankle inversion.

Gross & Brugnolotti (1992) conducted similar research on **"healthy" males** at velocities of **60°**/s and **120°**/s. Forty-three subjects were used (age = 40 years, height = 177 cm, body mass = 78 kg), **no correction** was made **for gravity**, and a **Biodex** dynamometer was used. They reported the following concentric values: ankle eversion at 60°/s and 120°/s (26 Nm & 33% BM (60°/s), and 20 Nm & 25% BM (120°/s)), ankle inversion (31 Nm & 40% BM (60°/s), and 26 Nm & 34% BM (120°/s)), and an eversion/inversion ratio of 82% and 76%, respectively.

The abovementioned authors' results (Gross & Brugnolotti, 1992; Wong *et al*., 1984) are very similar and could possibly be adopted as **"normative"**, in the absence of other available data.

3.6.9 Normative isokinetic values for elbow flexion and extension

When evaluating the elbow's flexors and extensors, there are two main set-up procedures. The first involves an anatomical zero (AZ) position grip (that is, forearm in full supination). The second method has the forearm pronated 90° from full supination or AZ (90°-pronated). No normative data was found for the second positional set-up (90°-pronated) however, Knapik & Ramos (1980) used the first set-up method (AZ) and conducted research on 352 **infantry soldiers** at **0°/s, 30°/s, 90°/s, and 180°/s**. They used a Cybex II dynamometer and **did not correct for the effects of gravity**. Their subjects (age=24 years, height=176 cm, body mass=74 kg) were all **males**. They reported the following values. At **30°/s** elbow flexion was 50 Nm (67% BM), extension was 44 (59% BM), and the flexion/extension ratio was 114%. At **90°/s and 180°/s** elbow flexion values were 36 Nm (48% BM) and 29 Nm (39% BM), extension values were 33 Nm (44 % BM) and 27 Nm (36% BM), and the elbow flexion/extension ratios were 109% and 107%, respectively.

3.6.10 Normative isokinetic values for forearm pronation and supination

Very few researchers have studied isokinetics of the forearm movements, and no normative database could be found (Perrin, 1993).

3.6.11 Summary

In order to conduct and interpret an isokinetic test, a sound knowledge of isokinetic terminology is crucial. Testers should also be aware of any factors that may influence the outcome of isokinetic testing. When interpreting the results from an isokinetic test, it is sometimes helpful to refer to normative values for a specific joint. However, norms should preferably be specific for each population tested. Additionally, sport-specific norms should not be used when evaluating sedentary individuals. Thus the absence of non-gravity corrected normative values for young South African men is seen as problematic when trying to interpret isokinetic test results in this population. This is especially true for patients that suffered bilateral joint injuries or in cases where there was a certain amount of muscle atrophy in the non-involved extremity.

CHAPTER 4: ISOKINETIC TRAINING

4.1 INTRODUCTION

The ultimate goal of most training programmes is improvement in functional performance. If strength/endurance improvements are not transferred into functional improvements, like improved posture, more efficient gait, pain free activities of daily living (ADL), or jumping higher and running faster, the improvements are useless in themselves.

The question now arises: does isokinetic training lead to functional improvements? The following sections discuss the improvements that have been observed following isokinetic training.

4.2 ISOKINETIC TRAINING AND FUNCTIONAL PERFORMANCE

Although open-kinetic-chain (OKC) exercises are usually not very sport-specific, numerous studies have demonstrated **positive correlations** between OKC isokinetic testing and **CKC functional performance** (Tegner *et al.*, 1986; Wiklander & Lysholm, 1987; Sachs *et al.*, 1989; Barber *et al.*, 1990; Noyes *et al.*, 1991; Wilk *et al.*, 1994).

Unfortunately, isokinetics do not approach functional, sport-specific angular velocities (Rothstein *et al.*, 1987). Professional pitchers have reported angular velocities of between **6200°/s and 9200°/s** for shoulder internal rotation during the acceleration phase of pitching (Pappas *et al.*, 1985). The highest test velocity of an isokinetic dynamometer is **600°/s** for the Cybex Norm 7000 (User's Guide: Norm testing and rehabilitation system, 1996). This is obviously far slower than the velocities observed during functional movements.

In conflict with previous research, gains in functional performance like sprinting or throwing resulting from isokinetic training, have not been proven beyond doubt. The only resistance exercises that truly approach powerful athletic speeds, and that have been shown to enhance performance the most, are **"Olympic lifts"** (for example, "power cleans" and "clean and snatch"), and **plyometric exercises** like "bounding" and "depth jumps". This is probably because isokinetic training normally makes use of open-kinetic-chain and single-joint movements. By modifying subject positioning, isokinetics may approach more functional and sport-specific positions, thereby increasing its correlation with functional and sports performance (Davies *et al.*, 2000).

Isokinetics is also not the best choice, if **muscle hypertrophy** is the goal of training. Cote *et al.* (1988) reported no change in muscle fibre cross-sectional area even when the strength of the quadriceps increased 54% following an isokinetic training program. One possible explanation is that by **eliminating the eccentric part** of the contraction during concentric isokinetic training, the stimulus for muscle hypertrophy is diminished (Brown, 2000).

Researchers are thus **divided** regarding the effectiveness of isokinetic training and testing where sports performance is involved (Wilk *et al.*, 1994; Davies *et al.*, 2000). Does the same however hold true for rehabilitation situations?

4.3 THE USE OF ISOKINETICS IN MUSCULO-SKELETAL REHABILITATION

According to Snyder-Mackler *et al.* (1995), closed-kinetic-chain (CKC) exercise alone does not provide an adequate stimulus to the quadriceps muscle group to permit normal function of the knee in the stance phase: ***"... this is especially true for the early period after reconstruction of the anterior cruciate ligament."***

Most daily activities produce tension levels between 20% and 35% of maximum. This level is adequate for the maintenance of a person's strength level, however, if a muscle is **immobilized** there may be a loss of strength of between 8% per week to 5% per day. These strength losses should be seen against the rate of increases in muscle strength of between 5% and 12% per week (Muller, 1970; MacDougall *et al.*, 1980).

The clinical application of isokinetics mainly centres around two aspects: (1) the **clinical assessment** and (2) the **rehabilitation** of orthopaedic patients. Clinical evaluation or assessment may be performed on athletes at the pre-season evaluation to establish base-line data. Another method is to use an injured athlete's non-involved extremity to assess the strength and/or endurance deficit of the injured or involved side. During rehabilitation, isokinetics is used as a safe and effective mode for muscle strengthening and for improving local muscle endurance (Davies *et al.*, 2000).

A further aspect to take into account is the **muscle balance** between two antagonistic muscle groups like the quadriceps and hamstrings muscle groups (Burkett, 1970; Gleim et al, 1978; Yamamoto, 1993). Burkett (1970) reported that four athletes from a group of six, who had bilateral strength deficits of more than 10% in their hamstrings, sustained a **hamstrings injury** within three weeks of testing. Yamamoto (1993) found that hamstrings strength, knee flexion/extension ratio, and bilateral muscle imbalances were contributory factors to the development of hamstrings strains. Berg *et al.* (1985) reported an increased risk for **stress fractures** in the lower leg if there was a strength deficit of more than 20 ft-lb between the dorsi flexor and plantar flexor muscle groups.

Isokinetic rehabilitation was very popular during the 1970's and 1980's (Burkett, 1970; Gleim et al, 1978; Tegner *et al.*, 1986; Wiklander & Lysholm, 1987; Sachs *et* *al.*, 1989). However, in the 1990's, closed kinetic chain (CKC) exercises became the trend (Houglum, 2001). When comparing the limbs of an athlete who participates in a mono-lateral sport like javelin throwing, the biokineticist cannot use the one limb as a reference for the other (Dvir, 1995). Thus using an applicable **normative database** should be considered: compare the values of the dominant limb to the values of other javelin throwers and that of the non-dominant limb to values from the general population.

Rehabilitation of the surgically repaired anterior cruciate ligament (ACL) has been extensively researched (LoPresti *et al.*, 1988; Wilk *et al.*, 1994; Brukner & Khan, 2001; Houglum, 2001). The role of isokinetics in ACL rehabilitation has been controversial. However, most clinicians and researchers now do acknowledge that isokinetics can play a role during some part of the ACL rehabilitation programme (Perrin, 1993; Snyder-Mackler, 1995; Botha, 1997; Brown, 2000; Davies *et al.*, 2000).

It is clear that isokinetics have proven to be useful and safe in orthopaedic rehabilitation programmes, but **"prevention is better than cure"**. Could isokinetics help prevent musculo-skeletal injuries?

4.4 PREVENTION OF INJURIES BY MEANS OF ISOKINETICS

Previously, isokinetic testing was a popular way of trying to prevent sports injuries. The now notorious **"60:40-ratio"** of quadriceps to hamstrings peak torque is a classic example (Burkett, 1970). Today, researchers are not convinced that possible **hamstrings injuries** may be predicted by simply looking at a ratio of agonists to antagonists. In fact, it has been postulated that hamstrings injuries may stem from a **variety of factors**. For example, lack of flexibility, muscle imbalance and power deficits between the quadriceps and hamstrings, or inequality of strength of the left versus the right hamstrings group, may all cause injuries (Knapik *et al.*, 1991; Worrel *et al.*, 1991; Yamamoto, 1993; Aagaard, 1998). Deficits in local muscle endurance of the hamstrings, pelvic instability, weakness in the calf and/or gluteus muscles, and increased neural tension, have also received some attention (Brukner & Khan, 2001). Furthermore, **weakness** and lack of endurance in the **rotator cuff** or scapulo-thoracic musculature may lead to shoulder problems like **supraspinatus impingement** (Davies & Dickoff-Hoffman, 1993).

The true value of isokinetic testing may lie in the bilateral comparison of limbs and muscle groups, and in comparing subjects to **population-specific normative data** (Dvir, 1995). A large difference in quadriceps muscle torque between the left and right leg of a marathon runner, may predispose this athlete to an overuse injury.

Additionally, a rugby player whose knee musculature is not able to withstand high forces may injure the knee's ligaments or menisci during the course of training or competition. Furthermore, when rehabilitating someone with bilateral muscle atrophy for instance, the availability of applicable normative values, may become very useful in order to set realistic short- and long-term goals for muscle improvements.

4.5 THE RESEARCH PROBLEM

This brings one to the purpose of the present study. Why develop norms for SA men between 17 and 24 years of age?

This group falls into a "high risk" category. In South Africa, a learner's licence to drive a car is obtainable at the age of 17 and a driver's licence at 18. With the high incidence of motor vehicle accidents, one can expect that a large number of orthopaedic injuries may occur in the above population. This viewpoint is supported by the insurance industry that actually charges higher premiums on car insurance for male individuals under the age of 25. Males between 17 and 24 are also usually physically active and involved in competitive or recreational sporting activities. A large number of patients seen by sports physicians, general practitioners, and orthopaedic surgeons actually stem from this population.

Another question that might arise is why did the author then not establish sport-specific norms? This would have been a very time consuming process, because of the wide variety of sports being played in South Africa. The author decided to rather focus on a heterogeneous group of young South African men to make the results of the study more widely applicable and useful.

Thus the aim of the present study is: **to establish normative isokinetic torque values for rehabilitation in South Africa.**

CHAPTER 5: RESEARCH METHOD

5.1 INTRODUCTION

Although a wide variety of possible and viable isokinetic test protocols exist, the author attempted to utilize well-recognized protocols that are accepted by various other researchers. The protocol included essential components like warm-up, rest periods, test velocity, number of repetitions, encouragement, visual feedback and precise positioning of the subject, as described by Perrin (1993) in his authoritive work ***"Isokinetic Exercise and Assessment"***. All the testing took place from 08h00 to 13h00 and the same sequence was followed in order to keep the tests reliable and to allow the present researcher to compare the results from day to day.

5.2 APPARATUS

The following apparatus was used:

- skinfold calliper (Harpenden John Bull, British Indicators Ltd., England);
- non-stretch anthropometrical measuring tape;
- spreading calliper;
- medical scale (Richter Scale KA-10, Kubota Company, Japan);
- stadiometer; and

- Cybex 340 isokinetic dynamometer (Cybex, Division of Lumex, Inc., 2100 Smithtown Avenue, Ronkonkoma, New York).

5.3 SUBJECTS

Four hundred and forty three (n=444) South African males, between the ages of 16 and 29 years, were used as subjects. These subjects volunteered for the project as they were in a selection process of applying to become pilots in the South African Air Force (SAAF). These individuals were mostly civilians and thus not under any obligation to conduct tests against their will.

The following pre-selection criteria was used:

- passed higher grade Mathematics in standard 9 (grade 11);
- between 165 cm and 195 cm;
- between 55 kg and 100 kg;
- excellent physical health; and
- uncorrected vision.

5.4 MEDICAL SCREENING AND INFORMED CONSENT

Before the isokinetic testing took place, a medical doctor examined all the subjects to exclude any subjects with orthopaedic injuries and/or other serious medical conditions (for example, diabetes mellitus or hypertension). Before the body composition analysis and isokinetic testing, each subject was again briefed on the testing procedure and made aware of the physical exertion required for the testing. Only subjects without any medical conditions and those who completed an informed consent participated in the study.

5.5 COLLECTION OF ANTHROPOMETRICAL DATA

Personal and anthropometrical data, including age, dominance, body mass, height, skinfolds, bone widths, and limb circumferences were obtained before the isokinetic testing commenced.

Body mass was determined to the nearest 100 grams. Subjects were all dressed in running shorts without shoes. Height/stature was determined to the nearest 5 millimetres.

The skinfold thickness of the triceps, subscapula, supraspinale, abdominale, thigh, and medial calf were determined according to the method of Carter (1982). All anthropometrical measurements were performed prior to any exercise. The "MOGAP" skinfold method was used to calculate percentage body fat of each subject (Carter, 1982).

Bone widths were determined to the nearest millimetre and circumferences of the tensed upper arm and relaxed calf muscle, were determined to the nearest millimetre. The "Heath-Carter" method was used to calculate the somatotype of each subject (Carter, 1982).

All anthropometrical measurements were taken on the subject's right side apart from the abdominal skinfold, which was taken 5 centimetres left of the umbilicus. However, the limb circumferences and bone widths were taken on the subject's dominant side (Carter, 1982).

5.6 WARM-UP PROCEDURE

Some researchers (Johnson & Siegel, 1978) found that three sub-maximal and three maximal isokinetic warm-up repetitions were necessary to obtain reliable and stable knee extension torque values. Kues *et al.* (1992) even advocated one or two days of familiarization training to enhance the reliability of isokinetic testing. However, the author's clinical experience over 10 years indicated that four to five progressive repetitions were adequate to familiarize young adult male subjects with isokinetic testing. The imposed time restraints and limited access to the test subjects precluded any familiarization days.

The isokinetic testing procedure was further preceded by a general warm-up that consisted of light jogging for five minutes and static stretching. Before each movement pattern, four (4) familiarization contractions were performed as part of the specific warm-up. The first two warm-up repetitions were performed at a perceived 50% of maximum, the next repetition at 75% and the last repetition at 100% of perceived maximum. Krüger (1992) utilized five sub-maximal repetitions and one maximal repetition for familiarization purposes.

5.7 ISOKINETIC TESTING PROTOCOL

Each subject was positioned and stabilized according to the Cybex User Manual (Cybex, A division of Lumex, Inc., 2100 Smithtown Avenue, Ronkonkoma, New York). A damping value of two (2) was used during all the tests and the Cybex was calibrated after every fourth session of testing. After the warm-up/familiarization, five maximum efforts were performed on each subject's non-dominant side, using the Cybex 340 isokinetic dynamometer. Perrin (1993) recommended using three to four test repetitions when evaluating maximum torque. The author selected to evaluate the non-dominant side of each subject for the following reasons:

Time constraints prevented bilateral testing of the seven different movement patterns on one single day (an average of 12 to 15 subjects had to be evaluated per day according to the predetermined schedule of the SAAF). Also, although

Cahalan *et al.* (1991) found a significant difference during shoulder flexion (at 180°/s and 300°/s) and shoulder internal rotation (at 0°/s, 180°/s and 300°/s) between the torque values of the dominant and non-dominant side for men, Ivey *et al.* (1985) found no significant difference for shoulder torque values at 60°/s and 180°/s. Simoneau (1990) also reported no significant differences between the dominant and non-dominant limb for the ankle's evertors and invertors. Hall & Roofner (1991) reported a high correlation between the left and the right leg when considering knee flexion and extension values between 60°/s and 500°/s. Since the author utilized **slow testing velocities** (30°/s or 60°/s), it was decided to test the non-dominant limb only. Although the expected difference between the dominant and non-dominant side is approximately 5% for the lower limbs when conducting "slow" isokinetic testing, larger differences could be expected in the upper limbs, or when testing at higher velocities (User's Guide: Norm testing and rehabilitation system, 1996).

In developing possible norms for subjects in this specific age group, the author thought it wise to evaluate the "weaker" of the two sides in order for the norms to be realistic for both sides of the body, especially in individuals recovering from injury. It may however be an option to add 5% to 10% to the eventual norms of the author when considering a possible norm for a subject's dominant side (Perrin, 1993). However, according to Constain & Williams (1984) and Lucca & Kline (1989), there was no significant difference between knee peak torque values of the dominant and non-dominant limb in their subjects. Lucca & Kline (1989) reported an average difference between the left and right knee torque of approximately 3% in their study of 54 student subjects (19 males & 35 females); they also reported no significant relationship between hand preference and foot preference.

Some researchers advise against **verbal encouragement** during the isokinetic test (Perrin, 1993), while others allowed for a standardized encouragement routine (Figoni & Morris, 1984; Krüger *et al.*, 1992). Due to the fact that the present study utilized a group-testing format, and because of spontaneous peer encouragement, the author had to use verbal cues to ensure that each repetition was performed correctly. However, it was impractical to utilize a set verbal routine during encouragement and coaching cues, since some subjects were not able to grasp what was expected of them following the first explanation given.

Subjects in the present study were permitted to receive **visual feedback** of their efforts. It is thought to improve maximum voluntary contraction, especially at slow isokinetic velocities (Baltzopoulos *et al.*, 1991). Increases as great as 12% at 15°/s have been reported by Figoni and Morris (1984) as a result of visual feedback during isokinetic testing. The effect of feedback on high speed isokinetics is still unclear. Figoni and Morris (1984) and Baltzopoulos *et al.* (1991) reported no beneficial effect at 180°/s and 300°/s, respectively, while greater peak torque values were reported at 180°/s by Hald & Bottjen (1987).

Each subject was allowed to **rest** for at least five minutes between the testing of the different movement patterns, which is five times longer than the 60-second guideline set by Perrin (1993). Thus it was postulated that more than adequate recovery time was given to each subject between consecutive testing efforts. Since the ATP-PC stores are thought to be replenished within two to four minutes following intense muscle contractions (Houglum, 2001), this rest period should have been adequate to enable subjects to achieve their maximum torque values for each movement pattern tested. According to Sinacore *et al.* (1994), it takes approximately four minutes for a muscle to recover to 90% to 95% of its initial torque levels following an **exercise bout to fatigue**. However, the biggest recovery takes place in the first 30 seconds to 90 seconds. After 90 seconds the rate of recovery declines slightly. After four minutes another rate change takes place and recovery is very gradual; full recovery may take more than 40 minutes (Houglum, 2001).

If any subject expressed the view that he was not able to achieve his maximum effort, due to unfamiliarity with the testing protocol for instance, the subject was allowed to rest for five minutes, before resuming the test. If subjects experienced discomfort during any of the tests, or if they decided not to complete the testing session, they were excused and excluded from the experiment.

An angular velocity of 60°/s was used for all the movement patterns of the shoulder, elbow, and knee joint, but a velocity of 30°/s was used for testing the ankle and forearm joint.

5.7.1 Shoulder flexion and extension

Subjects were positioned supine on the upper body exercise bench (UBX), perpendicular to the dynamometer head. The grip was positioned in 90° of forearm pronation and the elbow had to be straight. The subject's feet were positioned on the footrest in such a way that the knees formed an angle of approximately 90°. The hips were in approximately 45° of hip flexion. Each subject was stabilized by a Velcro strap, which was positioned over the pelvis (just above the anterior superior iliac spines), and over the chest (just below the nipple line). The subject was allowed to grip the contra-lateral handgrip, provided with the UBX, but were not allowed to lift the head, back, pelvis or feet from the UBX (Perrin, 1993).

The dynamometer's axis of rotation corresponded with the axis of rotation of the gleno-humeral joint of the subject. The ROM was preset to range from 0° of shoulder flexion to 180° of shoulder flexion. Any further movement was eliminated, by using mechanical ROM stops. Thus the total ROM was 180°.

Each subject completed five reciprocal maximum repetitions at an angular velocity of 60°/s, after the five warm-up repetitions (see 5.5).

5.7.2 Shoulder horizontal abduction and adduction

The supine position was utilized on the UBX, with the subject positioned parallel to the dynamometer's axis of rotation. The grip position utilized was 90° of forearm pronation, and the elbow was in 0° of elbow flexion. The subject's feet were positioned on the footrest in such a way that the knees formed an angle of approximately 90°. The hips were in approximately 45° of hip flexion. Each subject was stabilized by a Velcro strap, which was positioned over the pelvis (just above the anterior superior iliac spines), and over the chest (just below the nipple line). The subject was allowed to grip the contra-lateral handgrip, provided with the UBX, but were not allowed to lift the head, back, pelvis or feet from the UBX (Perrin, 1993).

The dynamometer's axis of rotation corresponded with the subject's glenohumeral axis of rotation. ROM ranged from full horizontal adduction (45° on average), through anatomical zero, to 90° of shoulder horizontal abduction. Thus the average total ROM was approximately 135°. No mechanical ROM stop was used for horizontal adduction, but a mechanical ROM stop was positioned at the 90°-position of horizontal abduction.

A testing velocity of 60°/s was used, and each subject completed five maximum repetitions, after five warm-up repetitions.

5.7.3 Shoulder internal- and external rotation

The subject assumed a supine position on the UBX, perpendicular to the axis of rotation of the dynamometer head. The tested limb was positioned in 90° of elbow flexion and 90° of shoulder abduction. The handgrip position was in anatomical zero (0° of forearm pronation/full supination). The subject's feet were positioned on the footrest in such a way that the knees formed a 90° angle and the hips were in approximately 45° of hip flexion. Each subject was stabilized by a Velcro strap, which was positioned over the pelvis (just above the anterior superior iliac spines), and over the chest (just below the nipple line). The subject was allowed to grip the contra-lateral handgrip, provided with the UBX, but were not allowed to lift the head, back, pelvis or feet from the UBX (Perrin, 1993).

The dynamometer's axis of rotation corresponded with the subject's longitudinal axis through the humerus. ROM was from 90° of shoulder external rotation, through anatomical zero, to approximately 70° of shoulder internal rotation. Thus the total ROM was approximately 160°.

After a 5-repetition warm-up, five reciprocal maximum repetitions were performed in immediate succession, at an angular velocity of 60°/s.

5.7.4 Elbow flexion and extension

The subject was positioned supine on the UBX at an angle of approximately 45° with the dynamometer head, so that the subject's head was closer to the dynamometer than his feet. The tested limb was positioned in approximately 45° of shoulder abduction. The subject's feet were positioned on the footrest in such a way that the knees formed an angle of approximately 90° and the hips were in approximately 45° of hip flexion. Each subject was stabilized by a Velcro strap, which was positioned over the pelvis region (just above the anterior superior iliac spines), and over the chest (just below the nipple line). The subject was allowed to grip the contra-lateral handgrip, provided with the UBX, but was not allowed to lift the head, back, pelvis or feet from the UBX (Perrin, 1993).

The dynamometer's axis of rotation corresponded with the longitudinal axis through the humerus of the subject. The ROM utilized, ranged from full extension to the position of maximal flexion, with total ROM of approximately 165° on average.

Following five repetitions of warming up, five maximum repetitions were performed in immediate succession, at an angular velocity of 60°/s.

Two handgrip positions were utilized, and therefore **two sets of data** were collected:

- with the first handgrip position, the forearm was in the **anatomical zero position (AZ)**; and
- with the second handgrip position, the forearm was in **90° of pronation**.

5.7.5 Forearm pronation and supination

The subject was seated on the UBX, facing the dynamometer. The forearm rested in the stabilization device and was fastened with a Velcro strap, to limit unwanted movements of the upper extremity. The elbow was held in 90° of elbow flexion. The subject was not allowed to use his upper body or to lift his buttocks off the UBX during the test (Perrin, 1993).

The dynamometer's axis of rotation corresponded with the subject's longitudinal axis through the forearm. The ROM utilized, ranged from full supination to full pronation (thus the average ROM was approximately 135°). No mechanical ROM stops were utilized.

Isokinetic testing (five consecutive repetitions) took place at an angular velocity of 30°/s, following five repetitions of warming up.

5.7.6 Knee flexion and extension

Although Krüger *et al.* (1992) utilized a hip flexion angle of 90° the results of other researchers (Selkowitz, 1985; Ferguson *et al.*, 1989; Snyder-Mackler, 1989) prompted the author to use a hip flexion angle of 70°. The subject was seated with the hip joint in 70° of flexion and the torso of each subject was stabilized with the seatbelt provided. The upper thigh of the test limb was stabilized with a Velcro strap, which was fastened just proximal to the superior border of the patella. Since Patteson *et al.* (1984) found no significant difference in knee torque values between stabilized or non-stabilized contra-lateral limbs at 60°/s and 180°/s, the contra-lateral limb of each subject was stabilized at approximately 90° of knee flexion with the standard stop provided. The dynamometer's axis of rotation corresponded with the subject's lateral epicondyle (Perrin, 1993). Subjects were not allowed to hold onto the grips provided by the manufacturers of the Cybex 340, but were instructed to grasp the shoulder strap during testing. This was done to ensure isolation of the thigh musculature and to avoid accessory movements. Kramer (1990) reported no significant difference between grasping the test table and grasping the pelvic strap when testing the knee's flexion and extension torques.

No mechanical ROM stops were used and the ROM ranged from full possible flexion (approximately 100° to 110° of knee flexion) to full knee extension (0° of knee flexion). The ROM was thus approximately 100°.

Krüger (1992) utilized a 60-second rest period between familiarization and testing. In the present study, the five maximal repetitions were performed at an angular velocity of 60°/s, directly following the 5-repetition warm-up. The author's warm-up routine did not lead to muscular fatigue, and therefore no rest period was used following the warm-up.

5.7.7 Ankle plantar- and dorsiflexion

The subject was positioned prone on the Cybex, which was positioned flat (with the backrest in 0° of hip flexion). The subject was prone with the hip and knee joints in 0° of flexion. The dynamometer's axis of rotation was aligned with the medial maleoli of the subject. In each case, the lower leg of the subject was stabilized using a Velcro strap. The strap was positioned approximately 10 cm to 15 cm proximal to the malleoli (Perrin, 1993).

No ROM stops were used and ROM ranged from full dorsiflexion to full plantar flexion (with an average ROM of approximately 50° to 70°).

After a five repetition warm-up, isokinetic testing took place with five maximal repetitions at an angular velocity of 30°/s.

5.8 INTERPRETATION OF ISOKINETIC DATA

The peak torque of each subject was determined and expressed in Newton metres (Nm), and relative to body mass (% BM). Each agonist/antagonist ratio was also calculated and expressed as a percentage (%). Bandy & Timm (1992) found significant correlation coefficients between peak torque and both work and power of the knee flexors and extensors, in their study of 77 subjects, and thus the present study only focussed on peak torque values.

None of the results were corrected for the effect of **gravity**. This was done for the following reasons: Firstly, the author had to test large groups of subjects within a specified **timeframe**, and correcting for gravity for five joints per subject, would have taken too much time (between 10 and 20 subjects had to be tested within five hours). Secondly, the author hypothesized that **errors** made during the process of correcting for gravity, could pollute the data and subsequent calculations/interpretations. The author thus viewed the testing of raw, gravitation-uncorrected torque values as a more accurate test, when faced with a large group of subjects, and when utilizing different test personnel (more than one biokineticist).

5.9 STATISTICAL ANALYSIS

The group average, minimum, maximum, standard deviation, and normal distribution tests were calculated for each movement pattern. Percentile tables were also constructed to serve as normative values for biokinetic rehabilitation and sport science testing. It was decided to focus on the relative torque values rather than the absolute ones, to improve comparisons between individuals with differing body mass values. Every fifth percentile, the mean, median, and mode was presented in the respective normative tables.

CHAPTER 6: RESULTS AND DISCUSSION

6.1 INTRODUCTION

While some authors present their results first and then discuss these in a separate chapter, the author decided to combine the results and discussion into one comprehensive chapter.

6.2 SUBJECTS

Four hundred and forty four (n=444) South African males from a cross section of the different population groups in South Africa (Black, White, Coloured, Asian, etc.) were used as subjects. No mention was made regarding the different numbers of subjects in each of the race groups. They were all volunteers for becoming pilots in the South African National Defence Force (SANDF). All subjects that reported as volunteers were tested, provided that they were first examined and cleared for testing by the medical doctor. The physical testing took place over a three-year period, according to the regulations laid down by the South African Medical Services (SAMS), in conjunction with the Institute for Aviation Medicine of the SANDF, and the Biokinetics Centre of 1 Military Hospital.

The body composition of the sample group is summarized in Table 6.1. Their ages varied between 16 and 29 years, with the average age being 19.07 years (± 1.91). The average body mass of the subjects was 71.58 kg (± 9.06) and their average height/stature was 178.58 cm (± 5.54). Subjects displayed an average body fat percentage of 9.97% (± 3.21). This value places them in the *"ideal"* range for fat percentage of young adult men according to Carter (1982).

Roughly half the group (n=245) also underwent somatotype testing. These subjects displayed the following somatotype: an endomorphic component of 3.1, a mesomorphic component of 4.3, and an ectomorphic component of 3.2. Thus the average subject was a balanced mesomorph. This research study is the only one to the author's knowledge that reports on somatotype as well as on normative isokinetic strength values.

It may therefore be feasible to suggest that subjects that do not fit the average somatotype of this group (**3.1-4.3-3.2**) may not display similar isokinetic strength values. A possible solution to this problem may lie in comparing a subject's torque produced in Nm, divided by the subject's lean body mass (LBM) in kilograms. However, very few studies have determined their subject's LBM, thus it is suggested that the torque divided by the body mass value (Nm/kg or % BM) be used when comparing a subject's value to that of a normative data base.

Table 6.1: Body composition of subjects.

	Average	Maximum	Minimum	STD	N
Age (years)	19.06	24	17	1.86	439
Body mass (kg)	71.5	95	46	8.7	439
Stature (cm)	178.6	192	160	5.6	439
Percentage body fat (%)	9.9	22.3	5.6	3.04	436
Endomorphy	3.02	9.8	1.1	1.45	240
Mesomorphy	4.3	7.4	0.58	1.22	240
Ectomorphy	3.22	5.9	0.1	1.16	240
X-Component	0.2	4.36	-8.8	2.37	240
Y-Component	2.36	9.0	-6.18	3.04	240

6.3 INTERPRETATION OF TORQUE VALUES

When presenting the results of the present study, it will be compared to those of other researchers in the field. If values differ, the author may offer possible explanations to the phenomenon.

Although both absolute (Nm) and relative (Nm/kg BM) torque values will be presented in the results, the focus will fall on the relative values, especially when proposing normative scales for the given population of this study.

As far as **"normative scales"** are concerned, one should be very cautious. If, for example the object was to establish whether the knee extension torque value of a sedentary person was acceptable, the method would differ from that relating to establishing this same person's ability to partake in elite sport. The author suggests using one of the following methods: When evaluating a non-athlete, one could use the following values to determine whether the score is acceptable or not: **"sample mean plus/minus (±) one standard deviation (STD)** or values that fall between the **15th and 85th percentile.** However, if elite athletes are considered, one could use a variety of other methods, including the following: selecting only those individuals with **scores above** the **"sample mean plus one STD"** or those scores above the **85th percentile.**

To accommodate the above, the STD will be included with the mean torque values and a percentile table will be supplied for each movement pattern that was tested.

6.4 KNEE FLEXION AND EXTENSION

When one compares the knee joint torque results from the present study in Table 6.2 to that of other researchers one observes the following. Gross *et al.* (1989) used a Cybex II dynamometer in testing male subjects of approximately 30 years of age and reported an average knee extension (KE) torque of 240 Nm and 153 Nm for knee flexion (KF). Although they corrected for the effects of gravity, their values were very similar to that of the present study. When one compares the torque values expressed per kilograms body mass reported by Gross *et al.* (1989) to that of the present study, one also finds similar values (KE: 307% vs. 331%, and KF: 196% vs. 222%). A possible reason for the slightly lower relative values reported by Gross *et al.* (1989) could be that their subjects were 6.5 kg heavier on average than the subjects of the present study. They reported a knee flexion/extension ratio of 64% compared to 67.6% for the present study. Krüger *et al.* (1992) reported a knee extension torque value of 238 Nm (338% BM), 127 Nm (183% BM) for knee flexion, and a knee flexion/extension ratio of 54% (all values were corrected for gravity). The slightly lower values for knee flexion and flexion/extension ratio compared to the present study could possibly be attributed to two factors. Firstly, the torque values of Krüger *et al.* (1992) were corrected for gravity, which effectively decreases knee flexion scores. Secondly, Krüger *et al.* (1992) conducted their research on *"inactive"* male subjects (n=536); their subjects might have displayed lower values for knee flexion (due to inactivity) compared to the mixed group of the present study.

Wyatt & Edwards (1981) studied 50 healthy male subjects with an average age of 29 years and they did not correct for the effects of gravity. They reported a knee extension torque value of 183 Nm (236% BM), a knee flexion value of 130 Nm (168% BM), and a knee flexion/extension ratio of 72%. The lower values reported by this study, compared to that of the present study, could also be attributed to the 6 kg difference in BM (77.6 kg versus 71.6 kg). It is also interesting to note the similarity between the knee flexion/extension ratio of Wyatt & Edwards (72%) and that of the present study (67.6%), since both studies did not correct for gravitational effects.

Ghena *et al.* (1991) used a **Biodex B-2000** to investigate concentric and eccentric knee flexion and extension at **60°/s** in **male, university athletes** (n=100). The dominant side was selected and values were **corrected for gravity**. The average age, height and weight were 20 years, 182 cm, and 76 kg, respectively. Their values were as follows: **concentric** knee flexion (142 Nm and 186% BM), knee extension (260 Nm and 340% BM), and knee flexion/extension (55%).

Schlinkman (1984) reported very similar values at **60°/s** compared to that of Krüger *et al.* (1992) and Ghena *et al.* (1991). Their values were 127 Nm and 179% BM for knee flexion, 235 Nm and 338% BM for knee extension, and a flexion/extension ratio of 54%. They used a **Cybex II** dynamometer and **corrected for the effects of gravity**. Their subjects consisted of male, **high school football players** (n=342) with an average age of 16 years. Thus, it may seem that the subjects from the study of Krüger *et al.* (1992), although reported as inactive, compared favourably to these football players tested by Schlinkman (1984).

It is clear that the ratio of 72%, reported by Wyatt & Edwards (1981) and the 67.6% reported by the present study is much higher than that of the abovementioned researchers, who took the effects of gravity into consideration (Krüger *et al.*, 1992; Ghena *et al.*, 1991; Schlinkman, 1984). It was only the knee flexion/extension value (64%), reported by Gross *et al.* (1989), that did not agree with these low ratios (54% to 55%). When comparing the data of Krüger *et al.* (1992) and that of Gross *et al.* (1989), a possible explanation lies in the fact that the subjects of Krüger *et al.* (1992) displayed much higher knee extension torque values compared to Gross *et al.* (1989) (238 Nm vs. 198 Nm). Even when the torque values are expressed relative to percentage BM, the trend still holds (338% BM vs. 272% BM). Seen together with the fact that the knee flexion values are fairly similar (127 Nm vs. 134 Nm, and 183% BM vs. 184% BM), one might think that the subjects of Krüger *et al.* (1992) were more athletically inclined than those of Gross *et al.* (1989).

In conclusion, the present study's torque values and flexion/extension ratio are higher than most of the previously reported normative studies. A possible explanation for this may be the extremely high levels of motivation displayed by subjects in the present study (they were all competing for selection as Air Force pilots), and the fact that no corrections were made for gravity (which led to elevated knee flexion torque values and the high knee flexion/extension ratio).

Table 6.2: Knee flexion and extension torque at 60°/s (NGC).

Movement pattern	Average	Maximum	Minimum	STD	N
Knee flexion					
Peak torque (Nm)	158.5	256	91	26.1	438
Peak torque/BM (%)	222.5	321	145	29.4	438
Peak torque/LBM (%)	246.9	349	164	30.6	435
Knee extension					
Peak torque (Nm)	235.90	358.00	137.00	34.4	438
Peak torque/BM (%)	330.9	428	227	36.3	438
Peak torque/LBM (%)	367.4	493	255	37.4	435
Knee flexion/extension ratio (%)	67.6	103.68	44.56	8.8	438

Table 6.3: Percentile scores for knee flexion and extension at 60°/s

		Knee extension (Nm/kg BM)	Knee flexion (Nm/kg BM)
N	Valid	438	438
	Missing	1	1
Mean		330.9064	222.4909
Median		330	222
Mode		347	214
Percentiles	5	273	173.95
	10	288	185
	15	296.85	192
	20	301	196.8
	25	306.75	201.75
	30	310.7	207
	35	316	211
	40	320.6	214
	45	325	217
	50	330	222
	55	334.45	226
	60	339	230
	65	343	234
	70	347.3	238
	75	356	242.25
	80	361	247
	85	369.15	253
	90	380	259.1
	95	393.05	272.05
	100	428	321

Table 6.4: Percentile scores for knee flexion/extension ratio at 60°/s.

Statistics

		Knee flexion/extension (%)
N	**Valid**	438
	Missing	1
Mean		67.603
Median		67.175
Mode		66.67(a)
Percentiles	**5**	54.977
	10	57.474
	15	58.9355
	20	60.238
	25	61.2175
	30	62.294
	35	63.3595
	40	65.142
	45	66.1055
	50	67.175
	55	68.5935
	60	69.37
	65	70.35
	70	71.819
	75	72.6475
	80	73.686
	85	74.733
	90	77.335
	95	83.2855
	100	103.68

a Multiple modes exist. The smallest value is shown

6.5 ANKLE PLANTAR AND DORSIFLEXION

No research study fitting the **criteria** for a **normative database** was found in the literature for ankle plantar and dorsiflexion at 30°/s with the knee straight **(0° knee flexion).** However, Fugl-Meyer (1981) conducted some research on inactive subjects and competitive athletes. He reported the following values for **inactive**

subjects and **athletes**, respectively: ankle dorsiflexion (33 Nm & 47% BM vs. 35 Nm & 47%), plantar flexion (126 Nm & 180% BM vs. 184 Nm & 245% BM), and dorsi/plantar flexion (26% vs. 19%). The author's results (Table 6.3) compares well with that of the inactive population of Fugl-Meyer (1981): dorsiflexion (36 Nm & 52% BM), plantar flexion (131 Nm & 186% BM), and a dorsi/plantar flexion ratio of 29%.

Table 6.5: Ankle plantar and dorsiflexion torque at 30°/s (knee and hip straight) (NGC).

Movement pattern	Average	Maximum	Minimum	STD	N
Ankle dorsiflexion:					
Peak torque (Nm)	36.3	55	17	6.4	219
Peak torque/BM (%)	51.6	75	22	8.4	219
Peak torque/LBM (%)	57.3	82	31	8.9	219
Ankle plantar flexion:					
Peak torque (Nm)	131.2	229	57	27.5	219
Peak torque/BM (%)	186.3	280	61	34.4	219
Peak torque/LBM (%)	206.5	302	78	36.7	219
Ankle dorsi/plantar flexion ratio (%)	28.8	80.7	14.8	8.2	215

Table 6.6: Percentile scores for ankle dorsi and plantar flexion at 30°/s.

		Ankle plantar flexion (Nm/kg BM) 0° knee flexion	Ankle dorsi flexion (Nm/kg BM) 0° knee flexion
N	Valid	201	201
	Missing	238	238
Mean		186.6119	70.8607
Median		187	70
Mode		175.00(a)	48.00(a)
Percentiles	5	135.2	41.1
	10	144	44.4
	15	148.3	48
	20	159	49.4
	25	163	53
	30	168	57.6
	35	174	60
	40	177	62
	45	184	67
	50	187	70
	55	191.1	74.1
	60	194	77
	65	197	82
	70	200	84.4
	75	207.5	87.5
	80	214.6	91
	85	225.7	94
	90	237	98.8
	95	245.8	114
	100	280	129

Table 6.7: Percentile scores for ankle dorsi/plantar flexion ratio at 30°/s (knee and hip straight).

		Ankle dorsi/plantar flexion (%) 0° knee flexion
N	Valid	215
	Missing	224
Mean		28.8763
Median		28.14
Mode		23.03(a)
Percentiles	5	19.102
	10	20.352
	15	21.494
	20	22.736
	25	23.28
	30	24.124
	35	25.336
	40	26.094
	45	27.054
	50	28.14
	55	28.818
	60	29.44
	65	30.18
	70	30.862
	75	32.43
	80	33.848
	85	34.996
	90	38.406
	95	43.406
	100	80.7

Following the author's proposed method for determining the **"normality"** of a person's ankle dorsi- and plantar flexion torque values at 0° of knee and hip flexion, the following recommendations are made: ankle dorsiflexion torque relative to BM should be between 47% BM and 95% BM. Ankle plantar flexion should be between 152% BM and 221% BM, and the ankle dorsi/plantar flexion ratio should be between 21% and 37%.

6.6 ELBOW FLEXION AND EXTENSION

6.6.1 Ninety degree pronated handgrip-position (90°)

The present study utilized two different grip positions for elbow flexion and extension testing. The first grip position was with the forearm in 90° of pronation. No normative data was found for this grip position. Thus, the normative data from the present study (Table 6.5) may be a first step in establishing population-specific normative scales for elbow flexion and extension, using a 90°-pronated grip position.

Table 6.8: Elbow flexion and extension torque (NGC) at 60°/s (forearm pronated to 90°).

Movement pattern	Average	Maximum	Minimum	STD	N
Elbow flexion:					
Peak torque (Nm)	48.5	76	27	9.6	234
Peak torque/BM (%)	69.1	102	43	10.9	234
Peak torque/LBM (%)	76.7	110	48	11.8	234
Elbow extension:					
Peak torque (Nm)	60.6	110	33	14.2	234
Peak torque/BM (%)	86.0	133	46	15.9	234
Peak torque/LBM (%)	95.5	150	51	17.5	234
Elbow flexion/extension ratio (%)	81.8	134.3	50.8	14.0	234

Table 6.9: Percentile scores for elbow flexion and extension at 60°/s (90°-pronated handgrip).

		Elbow extension (Nm/kg) 90° pronated grip	Elbow flexion (Nm/kg) 90° pronated grip
N	Valid	234	234
	Missing	205	205
Mean		86.04	69.08
Median		85.135	68.966
Mode		86	70
Percentiles	5	61	51
	10	67	55
	15	70	58
	20	72	60
	25	75	62
	30	77	63
	35	79	65
	40	82	66
	45	83	67
	50	85	69
	55	87	70
	60	89	71
	65	91	73
	70	93	75
	75	96	77
	80	99	78
	85	101	80
	90	104	83
	95	117	87
	100	133	102

Table 6.10: Percentile scores for elbow flexion/extension ratio at 60°/s (90°-pronated handgrip).

		Elbow flexion/extension (%) 90° pronated grip
N	**Valid**	234
	Missing	205
Mean		81.8106
Median		80.7
Mode		100
Percentiles	**5**	60.68
	10	65.8
	15	67.305
	20	69.7
	25	71.335
	30	73.97
	35	76.185
	40	77.5
	45	79.17
	50	80.7
	55	82.155
	60	83.64
	65	86.0825
	70	87.8
	75	89.83
	80	92.73
	85	96
	90	100
	95	108.04
	100	134.29

Following the author's proposed method for determining the **"normality"** of a person's elbow flexion and extension torque values using a 90° pronated grip, the following recommendations are made: elbow flexion torque relative to BM should be between 58% BM and 80% BM. Elbow extension should be between 70% BM and 102% BM, and the elbow flexion/extension ratio should be between 68% and 96%.

6.6.2 Anatomical zero handgrip-position (AZ)

The second grip position for elbow testing was in the anatomical zero (AZ) position. Knapik & Ramos (1980) used a similar grip position and conducted research on 352 **infantry soldiers** at 0, **30, 90, and 180°**/s. They used a Cybex II dynamometer and **did not correct for the effects of gravity**. Their subjects (24 years, 176 cm, 74 kg) were all **males**. They reported that elbow flexion peak torque was 50 Nm (67% BM), extension peak torque was 44 Nm (59% BM), and the flexion/extension ratio was 114% (at 30°/s). The results of the present study (Table 6.6) for elbow flexion (56.5 Nm & 77.7% BM), elbow extension (48.4 Nm & 66.5% BM), and the flexion/extension ratio (119%) compare favourably to that of Knapik & Ramos (1980), and could thus be used as a normative scale for young adult men.

Table 6.11: Elbow flexion and extension torque (NGC) at 60°/s (forearm in anatomical zero position).

Movement pattern	Average	Maximum	Minimum	STD	N
Elbow flexion:					
Peak torque (Nm)	56.52	91.00	28.00	11.14	199
Peak torque/BM (%)	77.71	121.43	47.95	12.42	199
Peak torque/LBM (%)	86.4	131	55	13.2	196
Elbow extension:					
Peak torque (Nm)	48.38	84.00	24.00	10.85	199
Peak torque/BM (%)	66.47	110.00	39.13	12.48	199
Peak torque/LBM (%)	73.9	121	46	13.5	196
Elbow flexion/extension ratio (%)	119.02	178.57	77.03	19.82	199

Following the author's proposed method for determining the **"normality"** of a person's elbow flexion and extension torque values using an AZ-grip, the following recommendations are made: elbow flexion torque relative to BM should be between 65% BM and 90% BM. Elbow extension should be between 54% BM and 79% BM, and the elbow flexion/extension ratio should be between 99% and 139%.

Table 6.12: Percentile scores for elbow flexion and extension at 60°/s (AZ handgrip position).

		Elbow extension (Nm/kg BM) AZ grip	Elbow flexion (Nm/kg BM) AZ grip
N	**Valid**	199	199
	Missing	240	240
Mean		66.47	77.6935
Median		64.384	77.307
Mode		63	77.00(a)
Percentiles	**5**	49	58
	10	52	62
	15	55	66
	20	58	67
	25	59	69
	30	60.5	71
	35	61	73
	40	62	74
	45	63	76
	50	64	77
	55	66	79
	60	68	80
	65	70	82
	70	71	83
	75	73	85
	80	75	87
	85	76	90
	90	82	93
	95	92	99
	100	110	121

Table 6.13: Percentile scores for elbow flexion/extension ratio at 60°/s (AZ handgrip position).

		Elbow flexion/extension (%) AZ grip
N	Valid	199
	Missing	240
Mean		119.02%
Median		118.60%
Mode		100.00%
Percentiles	5	86.00%
	10	93.10%
	15	98.18%
	20	101.89%
	25	105.00%
	30	108.06%
	35	109.43%
	40	112.50%
	45	116.67%
	50	118.60%
	55	121.43%
	60	123.68%
	65	126.42%
	70	128.21%
	75	131.03%
	80	135.90%
	85	140.91%
	90	146.15%
	95	151.43%
	100	178.57%

6.7 FOREARM SUPINATION AND PRONATION

Very few researchers have studied isokinetics of the forearm movements, and no normative database could be found. However, Ellenbecker (1991) tested the forearms of 22 highly skilled adult tennis players at 90°/s, 210°/s, and 300°/s. He reported a forearm pronation torque of 11.9 Nm (19.4% BM), a forearm supination value of 11.7 Nm (19% BM), and a supination/pronation ratio of 98% for the non-dominant side at 90°/s. The average forearm pronation value of the present study of 18 Nm (25% BM), 13 Nm (18% BM) for supination, and 74% for the supination/pronation ratio at a velocity of 30°/s (Table 6.7) does not differ substantially from that of Ellenbecker (1991).

In the absence of other normative data on the forearm's supination and pronation torque (Perrin, 1993), the results of the present study may be used as a normative scale for young adult men.

Table 6.14: Forearm supination and pronation torque (NGC) at 30°/s.

Movement pattern	Average	Maximum	Minimum	STD	N
Forearm supination:					
Peak torque (Nm)	12.97	23.00	8.00	2.56	199
Peak torque/BM (%)	17.94	26.35	10.59	3.18	196
Peak torque/LBM (%)	19.9	29	12	3.5	196
Forearm pronation:					
Peak torque (Nm)	17.97	31.00	9.00	3.73	199
Peak torque/BM (%)	24.88	46.97	10.59	4.81	196
Peak torque/LBM (%)	27.6	51	13	5.1	196
Forearm supination/pronation ratio (%)	73.83	121.42	47.62	2.24	199

Table 6.15: Percentile scores for forearm supination and pronation at 30°/s.

		Forearm pronation (Nm/kg BM)	Forearm supination (Nm/kg BM)
N	Valid	199	199
	Missing	240	240
Mean		24.8392	17.9196
Median		25	18
Mode		21	18
Percentiles	5	18	13
	10	19	14
	15	20	15
	20	21	15
	25	21	16
	30	22	16
	35	23	16
	40	23	17
	45	24	17
	50	25	18
	55	25	18
	60	26	19
	65	26	19
	70	27	19
	75	28	20
	80	29	21
	85	30	21
	90	31	22
	95	33	24
	100	47	26

Table 6.16: Percentile scores for forearm supination/pronation ratio at 30°/s.

Statistics

		Forearm supination/pronation (%)
N	**Valid**	199
	Missing	240
Mean		73.82%
Median		71.43%
Mode		100.00%
Percentiles	**5**	52.63%
	10	56.52%
	15	58.82%
	20	60.87%
	25	62.50%
	30	63.16%
	35	66.67%
	40	68.42%
	45	70.00%
	50	71.43%
	55	75.00%
	60	75.00%
	65	76.47%
	70	80.00%
	75	83.33%
	80	85.71%
	85	92.86%
	90	100.00%
	95	100.00%
	100	121.43%

Following the author's proposed method for determining the **"normality"** of a person's forearm pronation and supination torque values, the following recommendations are made: forearm pronation torque relative to BM should be between 20% BM and 30% BM. Forearm supination should be between 15% BM and 21% BM, and the forearm supination/pronation ratio should be between 59% and 89%.

6.8 SHOULDER HORIZONTAL ABDUCTION AND ADDUCTION

Weir *et al.* (1992) conducted research on 104 **male high school wrestlers** between the ages of 16 and 18, using a **Cybex II** dynamometer. The dominant side was evaluated and the damp setting was two (gravity was not corrected for). Test speeds of 30, 180, and 300°/s were included. The resultant values for **30°/s** were as follows: concentric shoulder horizontal abduction: 68 Nm (100% BM), horizontal adduction: 74 Nm (106% BM), and a horizontal shoulder abduction/adduction ratio of 93%. The values of the present study (Table 6.8) were slightly higher in all respects: horizontal shoulder abduction was 93 Nm (131% BM), horizontal shoulder adduction was 92 Nm (129% BM), and the horizontal abduction/adduction ratio was 101%.

Taking into account that the test velocity was 60°/s for the present study, the values reported by Weir *et al.* (1992) at a test velocity of 30°/s, are very similar to those of the present study.

Table 6.17: Shoulder horizontal abduction and adduction torque at 60°/s (NGC).

Movement pattern	Average	Maximum	Minimum	STD	N
Shoulder horizontal abduction:					
Peak torque (Nm)	93.4	210	50	27.06	103
Peak torque/BM (%)	132	266	72	34.73	103
Peak torque/LBM (%)	145.5	286	80	236.9	103
Shoulder horizontal adduction:					
Peak torque (Nm)	91.8	184	40	23.46	103
Peak torque/BM (%)	129.5	261	73	27.87	103
Peak torque/LBM (%)	142.9	279	78	29.7	103
Shoulder abduction/adduction ratio (%)	101.3	186	53.4	21.9	103

Table 6.18: Percentile scores for shoulder abduction and adduction at 60°/s.

Statistics

		Shoulder horizontal adduction (Nm/kg BM)	Shoulder horizontal abduction (Nm/kg BM)
N	Valid	103	103
	Missing	336	336
Mean		129.466	131.9612
Median		126	126
Mode		95.00(a)	102
Percentiles	5	93.4	83.2
	10	95.4	97.4
	15	102.2	102
	20	104	104.8
	25	111	109
	30	114.4	113.2
	35	116.4	116.4
	40	120.6	118.6
	45	122.8	122
	50	126	126
	55	131	128
	60	133.4	131
	65	137	138.8
	70	140	144
	75	146	148
	80	153.2	150
	85	156	162
	90	162.8	178.6
	95	175.8	205.2
	100	261	266

a Multiple modes exist. The smallest value is shown

Table 6.19: Percentile scores for shoulder horizontal abduction/adduction ratio at 60°/s.

		Shoulder horizontal adduction/abduction (%)
N	Valid	103
	Missing	336
Mean		101.2836
Median		100
Mode		100
Percentiles	5	67.04
	10	76.672
	15	80.276
	20	85.632
	25	88.51
	30	91.022
	35	93.264
	40	95.75
	45	97.652
	50	100
	55	101.306
	60	102.522
	65	106.932
	70	109.322
	75	110.99
	80	114.364
	85	117.958
	90	129.94
	95	145
	100	185.96

Following the author's proposed method for determining the **"normality"** of a person's shoulder horizontal abduction and adduction torque values, the following recommendations are made: shoulder horizontal abduction torque relative to BM should be between 98% BM and 167% BM. Shoulder horizontal adduction should be between 102% BM and 157% BM, and the shoulder horizontal adduction/abduction ratio should be between 79% and 123%.

6.9 SHOULDER FLEXION AND EXTENSION

At **60°/s concentric** shoulder flexion and torques varied from 65 Nm (Cahalan *et al.*, 1991), to 62 Nm (Ivey *et al.*, 1985), and extension values from 80 Nm (Ivey *et al.*, 1985), to 122 Nm (Cahalan *et al.*, 1991). Torque relative to bodyweight (BM) varied between 80% (Cahalan *et al.*, 1991) and 76% (Ivey *et al.*, 1985) for shoulder flexion, and between 97% (Ivey *et al.*, 1985) and 150% (Cahalan *et al.*, 1991) for shoulder extension. These two authors reported flexion/extension ratios of between 53% (Cahalan *et al.*, 1991) and 77% (Ivey *et al.*, 1985). Both these researchers used a **Cybex II** dynamometer, **did not correct for gravity**, used **healthy males** between the ages of 21 and 50 years, and their sample consisted of 36 (Ivey *et al.*, 1985) and 26 (Cahalan *et al.*, 1991) subjects. When the author pooled (n=62) the data, the following values were obtained: shoulder flexion 64 Nm (78% BM), shoulder extension 101 Nm (123% BM), and a flexion/extension ratio of 65%. These values correspond closely to those reported by Freedson *et al.* (1993) on males between the ages of 21 and 30 years: shoulder flexion: 62 Nm, shoulder extension: 98 Nm, and flexion/extension ratio: 63%. Shklar & Dvir (1995) reported the following values at 60°/s: a shoulder flexion value of 61 Nm, a shoulder extension value of 85 Nm, and a flexion/extension ratio of 72%.

The author's shoulder flexion peak torque of 81 Nm (113.5% BM) is higher (Table 6.9) than that reported previously in the literature, while the 87.5 Nm (123% BM) for shoulder extension compares favourably. The flexion/extension ratio (94%) of the present study is also higher than that of previous studies (Ivey *et al.*, 1985; Calahan *et al.*, 1991; Freedson *et al.*, 1993; Shklar & Dvir, 1995). The reason for this finding is unclear and warrants further investigation.

Table 6.20: Shoulder flexion and extension torque (NGC) at 60°/s (90° pronated grip).

Movement pattern	Average	Maximum	Minimum	STD	N
Shoulder flexion:					
Peak torque (Nm)	80.5	137	44	19.0	116
Peak torque/BM (%)	113.9	191	79	21.8	116
Peak torque/LBM (%)	125.9	204	85	123.5	116
Shoulder extension:					
Peak torque (Nm)	87.2	138	40	19.8	116
Peak torque/BM (%)	123.3	182	53	21.1	116
Peak torque/LBM (%)	136.3	205	61	22.6	116
Shoulder flexion/extension ratio (%)	93.9	230	59	20.0	116

Table 6.21: Percentile scores for shoulder flexion and extension at 60°/s.

Statistics

		Shoulder flexion (Nm/kg BM) 90° pronated grip	Shoulder extension (Nm/kg BM) 90° pronated grip
N	Valid	116	116
	Missing	323	323
Mean		113.8534	123.2845
Median		112.5	120
Mode		94.00(a)	109
Percentiles	5	84.85	89.55
	10	88	99.4
	15	93.55	104.55
	20	94.4	109
	25	97	109
	30	100.1	111.2
	35	103.95	114
	40	105	116.8
	45	109	119
	50	112.5	120
	55	113.35	123
	60	118	126
	65	120	128
	70	122	130.9
	75	126	135.75
	80	130	139
	85	133.45	145.35
	90	143.3	155
	95	157.15	163.3
	100	191	182

a Multiple modes exist. The smallest value is shown

Table 6.22: Percentile scores for shoulder flexion/extension ratio at 60°/s.

		Shoulder flexion/extension (%)
N	Valid	116
	Missing	323
Mean		93.8557
Median		93.1
Mode		100
Percentiles	5	69.747
	10	75.305
	15	77.1845
	20	78.242
	25	80.625
	30	83.205
	35	85.652
	40	89.222
	45	90.7525
	50	93.1
	55	93.977
	60	95.152
	65	96.6385
	70	100
	75	101.385
	80	104.49
	85	107.5
	90	111.217
	95	123.7715
	100	230

Following the author's proposed method for determining the **"normality"** of a person's shoulder flexion and extension torque values using a 90° pronated grip, the following recommendations are made: shoulder flexion torque relative to BM should be between 92% BM and 136% BM. Shoulder extension should be between 102% BM and 144% BM, and the shoulder flexion/extension ratio should be between 74% and 114%.

6.10 SHOULDER INTERNAL AND EXTERNAL ROTATION

Ivey *et al.* (1985), Connelly Maddux *et al.* (1989), and Cahalan *et al.* (1991) conducted research at **60°/s** using the **Cybex II** dynamometer. They **did not correct for the effects of gravity** and their subjects were **males** between the ages of 21 and 50 years. The subjects were positioned with their shoulders in 90° of abduction. They reported the values for concentric shoulder internal rotation between 46 Nm and 53 Nm (57-66% BM), between 26 Nm and 33 Nm (32-39% BM) for shoulder external rotation, with external/internal rotation values between 57% and 65%.

The author's shoulder external rotation torque values are higher than those reported previously (Ivey *et al.* (1985); Connelly Maddux *et al.* (1989); Cahalan *et al.* (1991), but the internal rotation values are very similar. Due to the higher external rotation values, the shoulder external/internal rotation ratio of the present study is also higher: 80% (see Table 6.10).

Table 6.23: Shoulder internal and external rotation torque at 60°/s (90°-abducted shoulder position) (NGC).

Movement pattern	Average	Maximum	Minimum	STD	N
Shoulder external rotation:					
Peak torque (Nm)	39.3	80	20	9.3	239
Peak torque/BM (%)	55.7	85	34	10.6	239
Peak torque/LBM (%)	61.7	97	37	11.4	237
Shoulder internal rotation:					
Peak torque (Nm)	50.6	88	27	12.7	239
Peak torque/BM (%)	71.6	114	40	14.9	239
Peak torque/LBM (%)	79.4	124	43	16.3	237
Shoulder external/internal rotation ratio (%)	79.6	187.9	48.9	18.1	239

Table 6.24: Percentile scores for shoulder external and internal rotation at 60°/s.

		Shoulder external rotation (Nm/kg BM) 90° abducted pos.	Shoulder internal rotation (Nm/kg BM) 90° abducted pos.
N	Valid	239	239
	Missing	200	200
Mean		55.7029	71.7573
Median		55	72
Mode		57	72.00(a)
Percentiles	5	39	48
	10	42	52
	15	44	56
	20	47	59
	25	49	61
	30	50	63
	35	51	65
	40	53	68
	45	54	70
	50	55	72
	55	57	73
	60	58	75
	65	59	76
	70	61	79
	75	62	82
	80	64	85
	85	67	88
	90	70	91
	95	75	96
	100	85	114

Table 6.25: Percentile scores for shoulder external/internal rotation at 60°/s.

Statistics

		Shoulder external/internal rotation (%) 90° abducted pos.
N	Valid	239
	Missing	200
Mean		79.629
Median		77.14
Mode		66.67(a)
Percentiles	5	58.46
	10	61.36
	15	64.18
	20	66.67
	25	68.42
	30	69.74
	35	71.74
	40	73.08
	45	75
	50	77.14
	55	78.57
	60	81.13
	65	82.61
	70	84.38
	75	87.01
	80	89.47
	85	92.11
	90	98.04
	95	107.55
	100	187.88

a Multiple modes exist. The smallest value is shown

Following the author's proposed method for determining the **"normality"** of a person's shoulder external and internal rotation torque values using an AZ-grip position, the following recommendations are made: shoulder external rotation torque relative to BM should be between 45% BM and 66% BM. Shoulder internal rotation should be between 57% BM and 87% BM, and the shoulder external/internal rotation ratio should be between 62% and 98%.

6.11 SUMMARY OF NORMATIVE VALUES

To present the results in a normative fashion, the following tables have been constructed for the different movement patterns that were tested.

Table 6.26: Normative values for knee flexion and extension torque at 60°/s (NGC).

Knee flexion & extension	AVG (%BM)	AVG ±1STD	15th %tile	85th %tile
Knee flexion (Nm/kg)	223	193-251	192	253
Knee extension (Nm/kg)	331	294-366	297	369
Knee flexion/extension ratio (%)	68	59-76	59	75

As is very clear from the above table, the average plus/minus one STD values correspond very closely to that of the 15th and 85th percentiles. The author thus decided to omit the percentile values from the summary tables. The percentile tables of each joint are available in the discussion above.

Thus, the subsequent tables present normative values in two ways:

- as the sample mean or average value **(AVG)**; and
- as the mean ± one standard deviation **(± 1STD)**.

The inclusion of the **AVG ± 1STD notation** was the result of each movement pattern having a **"normal distribution"**. This was tested statistically before reporting on each movement pattern; since all results of the movement patterns were normally distributed, the author decided to use this notation for the establishment of the relevant isokinetic norms or normal values in this population.

Table 6.27: Normative values for ankle dorsi and plantar flexion torque at 30°/s.

Ankle dorsi & plantar flexion	AVG (%BM)	AVG ±1STD
Ankle dorsiflexion (Nm/kg)	36	47–95
Ankle plantar flexion (Nm/kg)	131	152–221
Ankle dorsi/plantar flexion (%)	29	21–37

Table 6.28: Normative values for elbow flexion and extension torque at 60°/s using the (1) 90°-pronated and (2) AZ-handgrip.

Elbow flexion & extension	AVG (%BM)	AVG ±1STD
(1) 90°-pronated handgrip		
Elbow flexion (Nm/kg)	69	58-80
Elbow extension (Nm/kg)	86	70-102
Elbow flexion/extension ratio (%)	82	68-96
(2) AZ-handgrip		
Elbow flexion (Nm/kg)	78	65-90
Elbow extension (Nm/kg)	67	54-79
Elbow flexion/extension ratio (%)	119	99-139

Table 6.29: Normative values for forearm supination and pronation torque at 30°/s.

Forearm supination & pronation	AVG (%BM)	AVG ±1STD
Forearm supination (Nm/kg)	13	20-30
Forearm pronation (Nm/kg)	18	15-21
Forearm supination/pronation ratio (%)	74	59-89

Table 6.30: Normative values for shoulder horizontal abduction and adduction torque at 60°/s (NGC).

Shoulder horizontal abduction & adduction	AVG (%BM)	AVG ±1STD
Shoulder horizontal abduction (Nm/kg)	132	98-167
Shoulder horizontal adduction (Nm/kg)	130	102-157
Shoulder horizontal abduction/adduction ratio (%)	101	79-123

Table 6.31: Normative values for shoulder flexion and extension torque at 60°/s (NGC).

Shoulder flexion & extension	AVG (%BM)	AVG ±1STD
Shoulder flexion (Nm/kg)	114	92-136
Shoulder extension (Nm/kg)	123	102-144
Shoulder flexion/extension ratio (%)	94	74-114

Table 6.32: Normative values for shoulder external and internal rotation torque at 60°/s (90°-abducted shoulder position).

Shoulder external & internal rotation	AVG (%BM)	AVG ±1STD
Shoulder external rotation (Nm/kg)	56	45-66
Shoulder internal rotation (Nm/kg)	72	57-87
Shoulder external/internal rotation ratio (%)	80	62-98

6.12 Summary

The purpose of the present study was to establish normative isokinetic torque values for young South African men. The shoulder, elbow, forearm, knee, and ankle joints were investigated. This was done by testing 444 young South African men from a cross-section of the different race groups in the country. Although some of the normative values were different to those proposed by other researchers, one should bear in mind that norms are population- and method-specific. To offer conclusive reasons for the differences observed between the torque values of the present study and that of previous studies, would be inappropriate, but clinicians are cautioned that norms are always established for a certain sector of the population and should not be extrapolated to include subjects that fall outside this sub-group or population. In addition, methodological differences like gravity correction, subject positioning, visual feedback, etc., may have a large influence on the eventual results of isokinetic testing.

The author proposes that the established isokinetic norms, will serve to guide biokineticists, physiotherapists, orthopaedic surgeons and other exercise scientists in setting objective and realistic goals for orthopaedic rehabilitation programmes. Furthermore, these normative values may be useful when conducting sport-specific strength screening of young South African men. These norms may then be used as a guideline when evaluating elite or high performance athletes. These norms may even be used to identify athletes with superior peak torque producing capabilities (i.e. above the 85th percentile). Other applications may include screening workers for job-specific strength demands (for example, operators of heavy tools or machinery).

CHAPTER 7: CONCLUSIONS

Although the author established normative data for young, healthy South African (SA) men between the ages of 17 years and 24 years, the opportunities for future research in the South African population are huge. For instance, very little normative data is available regarding the torque values of SA women. The absence of normative data for SA women is very pertinent in joints like the elbow, forearm, ankle, and shoulder. Furthermore, the hip joint's movements have not been extensively researched, in both SA and elsewhere. The absence of normative studies on the hip joint provides an ideal opportunity for future research to be done.

Other areas that may be investigated in the future includes sport-specific normative values, as well as normative values for older population groups, for instance, middle-aged subjects or the elderly. Very little information also exists regarding normative isokinetic values for SA children.

Other opportunities for future research include the analysis of muscle function by means of three-dimensional mapping **(Isomap)**. This method was developed by Biodex and could prove a valuable new tool for studying isokinetic muscle function. In short, it involves plotting muscle length (ROM), torque, and velocity on three different axes in order to construct **"topographic surfaces"** (Brown, 2000; Davies *et al.*, 2000).

The author is of the opinion that the present study may provide much needed normative isokinetic values for young SA males. It is hoped that other SA researchers may help to take the process of establishing normative isokinetic values, for the SA population, further.

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