LABORATORY AND OCCUPATION-SIMULATING ISOKINETIC AND PSYCHOPHYSICAL RESPONSES OF MILITARY PERSONNEL

BY

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THESIS

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ABSTRACT

The present study assessed the isokinetic responses of male military personnel (N=42). The study aimed to evaluate the strength capabilities of South African infantrymen and establish benchmark data on a population not previously tested. “Work-simulation” packages have not been widely exploited and this study further aimed to approximate how effectively occupation-simulating tasks could identify the capabilities of soldiers.

Testing was carried out using a CYBEX 6000 isokinetic dynamometer and involved six laboratory tests (LTs) and four occupation-simulating tests (OSTs). Subjects were required to complete two testing sessions with the order of tests randomized. The LTs consisted of ankle, elbow, hip, knee, shoulder and trunk. In the OSTs, gripping, valve-tightening, wrench-turning and pulling/pushing responses were collected. Slow, medium and fast test speeds were used for each bout. Cardiac responses were measured using heart rate monitoring and perceptual measures assessed using Borg’s (1971) RPE scale.

The results of the testing showed significant differences in agonist and antagonist responses at all three testing speeds, the only exception being slow speed trunk values (peak torque). Upper- to lower-extremity ratios highlighted a possible weakness in the elbow flexors group, while correlations between LTs and OSTs highlighted the specificity of strength principle, as poor relationships were observed.

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CHAPTER ONE

INTRODUCTION

BACKGROUND TO THE STUDY

The South African National Defence Force (SANDF) is faced with a number of challenges relating to the morphological diversity of its personnel. The Defence Force's "African Warrior" programme has promoted ongoing research into the capabilities of South Africans and has provided funding for numerous studies throughout the country. The present study forms part of this research initiative and aims to contribute in an area which has long been neglected, that of strength assessment of the indigenous peoples of South Africa.

The practice of load-carriage by military personnel has received much attention as a result of a high incidence of injury (Haisman, 1988, Frykman **et al.**, 1994, Johnson **et al.**, 1995 and Knapik **et al.**, 1996). Despite the importance of strength requirements in military contexts, musculo-skeletal assessments using isokinetic dynamometry have been relatively neglected, with little work done to assess the capabilities of armed forces personnel.

Essentially, international study has thus far focussed on the effects of load carriage on factors such as energy-cost and gait patterns (Martin and Nelson, 1986 and Frykman **et al.**, 1994), little emphasis having been placed on strength evaluations in the context of post-march combat readiness or even everyday tasks such as the driving of heavy military vehicles.

Task requirements often exceed the capabilities of military personnel, with serious implications for personal safety and well-being. The mis-match between foot-soldiers and the requirements of their tasks is often manifested as an increase in the incidence of injury. It is much less readily appreciated as a factor in mission success.

Isokinetic strength assessments have been shown to have a number of applications in medical, occupational and sports-conditioning settings. Isokinetic contraction is the muscular contraction that accompanies constant-velocity limb movements around a joint or joints (Baltzopoulos and Brodie, 1989). The present study aimed to assess the relationship between the traditional joint-aligned clinical or "laboratory tests" and the new non-joint aligned occupation-simulating isokinetic strength responses.

The recently developed CYBEX 6000 "Work-Simulation" package (CYBEX, Lumex Inc., 1993) has not yet been widely exploited by researchers. The present study provides benchmark data on musculo-skeletal performance assumed representative of South African National Defence Force (SANDF) personnel. Ergonomics implications of strength expression are further assessed relative to testing methods used *in situ,* for example, hand-held dynamometry. *In situ* task analyses would entail assessment of physical tasks like shovelling or building, using strain gauges or hand-held dynamometers. The occupation-simulating test values obtained in this study, although not *in situ* measures, do still provide a basis for comparison in future studies associated with the assessment of muscle strength of military personnel.

Basic strength data have been collected on European and American soldiers (Johnson **et al.**, 1995, Knapik **et al.**, 1996 and Rayson **et al.**, 2000). However these data lack relevance in South African military contexts, as the morphological profile of this country's people is very different. In contrast to the situation in South Africa where little research is being published, in the U.S.A. the monthly journal Military Medicine is devoted almost entirely to studies of the capabilities of military personnel.

STATEMENT OF THE PROBLEM

Military training is inherently strenuous. In some military operations soldiers are required to march long distances and perform critical military tasks at the completion of the trip (Knapik **et al.**, 1996). Likelihood of injury is therefore increased and strength and endurance become essential considerations in planning an efficient upper- and lower-body training programme.

Virtually no isokinetic strength data have hitherto been collected on male military personnel in South Africa. It is not yet known what the capabilities of many recruits are and in fact many may not possess sufficient strength for safe completion of everyday training and working activities over prolonged periods of time. For example, Knapik **et al.** (1996) conclude that very strenuous foot-slogging in the U.S. military can lead to diminished combat readiness with post-march decrements in marksmanship and grenade-throw distance. Accidents and increased injury incidence may therefore result and, in a worst-case scenario, mission success may be compromised.

Upper- and lower-extremity isokinetic values and ratios have been investigated on a number of different samples, but not on South African infantrymen. It is thus difficult to assess what impact, if any, morphological differences associated with South Africa's population have on isokinetic responses. A particular upper-extremity muscular weakness has been identified by military trainers in the SANDF (personal communication with officers in the South African National Defence Force, 1999). For example, following a route march, many soldiers are not able to perform adequately the movements required for efficient handling of a rifle: in short, combat-readiness is significantly impaired. Whether this was due to differential fatigue of the shoulder muscles caused by overloaded or poorly designed backpacks was not known. The identified upper-extremity weakness, however, merits investigation.

RESEARCH HYPOTHESES

The present study aims to provide good benchmark data in a comprehensive profile of the strength expression capabilities of the new SANDF soldier. Beyond this, comparability of the "African Warrior" with foreign infantry personnel merits evaluation. When agonist-antagonist responses are considered it is expected, for example, that quadriceps strength will exceed that of hamstrings, but that biceps strength will not exceed that of the triceps. What is not known is the extent of agonist-antagonist differences, or of opposite-direction ratio differences in this hitherto unstudied population. Higher overall strength ratings (both upper- and lower-extremity) will obviously enable stronger soldiers to cope more efficiently with the demands of daily tasks and training, while also enhancing overall combat-readiness.

Lower-extremity responses in the laboratory tests are expected to exceed those of the more gracile upper-extremity. Upper- and lower-extremity torque, work and power isokinetic values are expected to highlight specific weakness in the upper-extremity responses of SANDF infantrymen. Strength ratios should therefore differ significantly from those observed in other studies if the SANDF's claimed relative weakness of the musculature of the upper-extremity is confirmed.

It is expected that specificity of strength expression will pertain, so that predictions focussed on isokinetic tests measuring different movements about comparable joints will be kinesiologically meaningless. Isokinetic strength in a joint-specific laboratory test (LT) of, for example, the shoulder or the hip is expected to be very poorly related to effectiveness and strength in an occupation-simulating test (OST) like valve-tightening or pulling-pushing, because of the specificity of strength principle. The alignment of the dynamometer with the centre of the joint being tested in LTs is expected to allow for more effective isolation of specific muscle groups involved in the movement, for example, knee extensors/flexors. In contrast, OSTs make it impossible to isolate muscle groups because of non-alignment of a specific axis of rotation with the dynamometer. In the "whole body" OSTs, for example the pulling-pushing test, mean responses are expected to be greater than those of the movements which isolated specific muscle groups.

STATISTICAL HYPOTHESES

The mathematical hypotheses are stated as the Null (H_o; or Test; H_t) and Alternative (H_a; or Expected; H_e) hypotheses. These hypotheses were framed as follows:

1.) (a) Reciprocal muscle groups produce equal isokinetic responses through the velocity spectrum (in non-gravity corrected LTs).

H_o 1(a): μ T W P $_{\text{(Agonists)}}$ = μ T W P $_{\text{(Antagonists)}}$ at all speeds tested
H_a 1(a): μ T W P $_{\text{(Agonists)}}$ $\neq$ μ T W P $_{\text{(Antagonists)}}$ at all speeds tested

where: T = Peak Torque; W = Total Work; P = Average Power, all assessed in the "best work repetition"

(b) Opposite-direction responses are equal across the velocity spectrum (in non-gravity corrected OSTs).

H_o 1(b): μ T W P $_{\text{(Right or Pushing)}}$ = μ T W P $_{\text{(Left or Pulling)}}$ at all speeds tested
H_a 1(b): μ T W P $_{\text{(Right or Pushing)}}$ $\neq$ μ T W P $_{\text{(Left or Pulling)}}$ at all speeds tested

2.) Comparable upper- vs lower-extremity motions produce equal isokinetic responses through the velocity spectrum.

H_o2: μ T W P $_{\text{(Upper-extremity)}}$ = μ T W P $_{\text{(Lower-extremity)}}$
H_a2: μ T W P $_{\text{(Upper-extremity)}}$ $\neq$ μ T W P $_{\text{(Lower-extremity)}}$

3.) (a) No relationship exists between "Laboratory" and "Occupation-Simulating" isokinetic test responses.

H_o3(a): Rho $_{\text{(LTs; OSTs)}}$ = 0
H_a3(a): Rho $_{\text{(LTs; OSTs)}}$ $\neq$ 0

(b) No relationship exists between heart rate (HR) and Ratings of Perceived Exertion (RPE).

H_o3(b): Rho $_{\text{(HR; RPE)}}$ = 0
H_a3(b): Rho $_{\text{(HR; RPE)}}$ $\neq$ 0

DELIMITATIONS

- The subjects in the present study were volunteer adult male military personnel stationed at the Sixth South African Infantry Battalion Base (6 S.A.I.) in Grahamstown. The study was delimited to the responses of 42 subjects; a sample assumed to be broadly representative of infantrymen in South Africa.

- The testing procedures were confined to a laboratory environment. The influence of environmental factors like temperature extremes (which could play a significant role when considering South African conditions) were thus minimized by a light- and heat-controlled environment.

- Isokinetic strength assessment was used as opposed to testing of the subjects *in situ*, where strain-gauge type dynamometers could have been employed to assess strength during actual military tasks. Habituation of subjects was carried out as extensively as possible with a number of familiarization tests being conducted.

LIMITATIONS

- Psychological factors are known to influence the performance of test subjects. The motivation of test subjects was a factor which could have affected the results of the present study. No extrinsic rewards were offered, although comprehensive feed-back was given to the subjects and uniform verbal encouragement to perform maximally was given during each effort. Subjects were only working to the limit to which they were prepared to go voluntarily in the testing session. While acknowledging this possibility the author was convinced by the effort-level consistency observed that effectively maximal efforts were being made (see Chapter III).

- Present level of training could also have influenced the responses. Some subjects may have been at a higher level of training at the time of testing.

- Clinical history is a further significant factor in terms of the data, although every attempt was made to ensure that the subjects were free from injury. There is a possibility that subjects could have been experiencing, but not reporting, slight muscle strain before the testing commenced. This factor was beyond control in the study, but was considered when the results were assessed.

- Despite the period of habituation and the trials given to each subject it is possible that some of the subjects were still not comfortable with the equipment and procedures when recorded test bouts were completed.

CHAPTER TWO

REVIEW OF LITERATURE

INTRODUCTION

The heavy loads soldiers frequently carry on marches can lead to symptoms of body soreness, aches, pains, and tiredness which in turn could interfere with the accomplishment of the mission (Johnson **et al.**, 1995 and Knapik **et al.**, 1996). Upper- and lower-extremity strength reserves are consequently critical factors in post-march combat readiness (Knapik **et al.**, 1996). Assessment of strength capabilities and efficiency of military personnel has hitherto been neglected in South Africa, despite availability of testing resources.

Strength assessment can be carried out in a number of ways with isokinetics being one of the most commonly used testing modalities. Isokinetic devices permit individuals to exert as much force as they can generate through a range of movement - be that large or small - up to a predetermined velocity (Perrin, 1993). The research application of isokinetic data is linked with comparisons of peak and average values of torque, work and power. From these data it is possible to gauge the efficiency of the test subject in many different contexts, whether in sport, rehabilitation or occupational environments.

Typically, peak force and power are assessed for a number of reasons: to quantify their contributions in various athletic events and occupations; to identify specific deficiencies in muscle function in order to improve individual deficiencies (that is, strength diagnosis); to identify an individual who may be suited to a particular work task or athletic pursuit and to monitor the effects of various training and rehabilitation interventions (Abernethy **et al.**, 1995). Linking wide-ranging musculo-skeletal isokinetic test results to *in situ* military performance efficiency, however, has yet to be done in South Africa, and appears not to have been extensively studied elsewhere either. Before this can be done, however isokinetic strength profiles need to be determined.

1. LOAD CARRIAGE: GENERAL OVERVIEW

Individuals employed in specific recreational, occupational and military pursuits often carry heavy loads using a variety of pack systems (Knapik **et al.**, 1996). The loads carried by military personnel thus require high levels of upper-body strength, something often neglected in a training environment. Although much emphasis is placed on general conditioning, the specific training of the upper-extremity is given less attention.

Dubik and Fullerton (1987) argue that although technology has advanced and lighter materials have become available the loads carried in the infantry have in fact increased. More equipment is now required and military personnel need to carry significantly heavier loads during training, for example, on a 20-km route march (Johnson **et al**, 1995).

Haisman (1988) provides a good example of how the load of a foot soldier can increase when different battle gear is required. The break-down of the load carried by a British infantryman is set out in Table I. This table shows equipment and clothing masses. To meet different conditions and requirements in a battle setting, it is often necessary for a soldier to carry extremely heavy loads. Should all the equipment be required for one route march the approximate load is 56.2 kg (or heavier in some cases), which could demand that many subjects carry a load equal to or only slightly less than personal body mass. Pack weights have been known to exceed 80 kg in training and combat, thus placing the infantryman at high risk of injury.

Table I: Mass of clothing and personal equipment carried by a British infantryman (Adapted from Haisman, 1988).

Category		**Specific Breakdown**	**Mass (kg)**	**Cumulative Load (kg)**
A	Dress	Clothing, boots and helmet	7.0	7.0
B	Assault Dress	Clothing etc as in A, plus weapon, ammunition, digging tool and equipment	19.4	26.4
C	Combat Order	Dress and equipment as in A and B, plus food and warm clothing	3.7	30.0
D	Marching Order	Clothing and equipment as in A, B and C, plus spare clothing, rations, rucksack and sleeping bag	10.2	40.2
E	Additional equipment	There are a number of additional items which could have to be carried ranging in weight up to 16 kg	up to 16.0	at least 56.2

Johnson **et al.** (1995) tested infantrymen with a load-carry of 61 kg and demonstrated that significant performance decrements were associated with excessive demands. Discomfort and pain also increased when the load became excessive. Haisman (1988) argued that the extent of the military load carriage problem may not be fully appreciated, either because it is erroneously believed that mechanised transport will always be available, or because the diversity of the equipment involved obscures the cumulative loads involved.

Determinants of Load Carrying Ability

There are a number of factors which could influence load carrying ability. Haisman (1988) noted the following: age, physique, aerobic and anaerobic power, muscle strength, body composition and sex. All these factors need to be considered when assessing the efficiency of performance of, for example, a foot-soldier who has completed a long march. However, it is not only the physical make-up of the soldier which influences load carrying ability. Significant consideration should be given to the dimensions and placement of the load, biomechanical factors, nature of the terrain and the gradient, the effect of climate and protective clothing (Haisman, 1988). In a military training or combat environment, many of these factors, such as environmental temperature extremes and protective clothing like battle jackets, can influence the level of fatigue and consequently bring about strength decrements. Following a prolonged march there could be a significant decrease in efficiency of, for example, the throwing of a grenade (Knapik **et al.**, 1996). Likelihood of injury as a result of fatigue could therefore increase.

Aoyagi **et al.** (1998) offer a possible training solution to overcoming some of the effects of environmental extremes. Physical training and artificial heat acclimation was shown to improve a lightly clothed person’s homeostatic mechanisms in a period of 1 to 2 weeks.

However, the effects of physical training and acclimation on more heavily clothed individuals were not as marked.

The Influence of Load Carriage on Task Performance

Fatigue of combatants is an important consideration in regard to battle-readiness. Voight **et al.** (1996) found that high levels of muscular fatigue significantly alter shoulder proprioception. The efficiency of task execution involving the upper-extremity would thus decrease. The lower-extremity is also influenced by fatigue. As a consequence of marching for long periods of time the muscles of the lower-extremity would show strength decrements, with the infantryman less able to execute tasks with a high degree of accuracy. Frykman **et al.** (1994) found that fatigue during a 20-km march caused significant changes in the gait patterns of troops. Factors identified included: increased forward trunk inclination, reduction in hip and knee angle at mid-stance and reduced stride length.

Knapik **et al.** (1993) documented performance decrements following heavy load carriage. Marksmanship was less efficient and grenade throw distance was decreased. Decrements in marksmanship were attributed to fatigue of the upper-body muscles (Knapik **et al.**, 1993). However, the influence of fatigue was shown to be short- term as the subjects were only affected for the first target. In an assessment of task performance the level of training is an essential consideration: special forces soldiers (the soldiers involved in the Knapik **et al.** (1993) study) would be expected to score better in terms of general strength and task efficiency than a new recruit (basic trainer).

Muscle Activity and Perception of Effort During Load Carriage

The level of muscular activity in different parts of the body is dependent on the load being carried. Under heavier backpack loading the spinal extensors are clearly more active than during unloaded walking; an increase which appears particularly pronounced when the load mass exceeds 30 or 40kg (Knapik **et al.**, 1996). The gastrocnemius muscles show similar increases in myo-electrical activity with an increased load (Harman **et al.**, 1992).

A further factor which would influence muscle activity is walking speed. Han **et al.** (1992) found that EMG amplitudes of the quadriceps, gastrocnemius and, most markedly, the hamstrings and tibialis anterior muscles increased significantly with faster walking speed.

Johnson **et al.** (1995) assessed the effects of heavy load carriage on the perceptions of military personnel. Three different mass categories were used to quantify the effects of load carriage, these being 34, 48 and 61 kg packs respectively. The study showed that of all the symptoms reported the highest incidence was of muscular discomfort and heat illness reported during the carriage of the 61 kg load. Thus mass to be carried critically influenced perceived exertion of the soldier and could have impaired performance following a heavily loaded march. Pack design and the point of load carriage are also important. Knapik **et al.** (1993) found that the highest report of pain and discomfort following a loaded march was in the upper-body, a factor which can be directly attributed to pack design.

Influences of Training on Load Carriage

Regular walking has been shown to improve aerobic capacity and decrease the relative energy cost to the individual (Taylor **et al.**, 1980 ; Shoenfeld **et al.**, 1980). With an effective training programme and more regular load carriage, improved task completion and also more efficient end performance have been shown (Knapik **et al.**, 1990). By training specifically for load carriage it thus becomes possible to maximize the performance of the soldiers and minimize the decrements to performance. However, Aoyagi **et al.** (1998) warn that neither endurance training nor heat acclimation reduce psychological strain when protective clothing is worn during vigorous activity, because sweat accumulation adds to discomfort. In a country like South Africa where heat can reach extreme levels the efficiency of task performance can be compromised. The degree of training should therefore not be viewed in isolation when considering task efficiency; psychological well-being of the soldier should also be focussed upon.

Strength Training and Work-Hardening Programmes

Military personnel are often required to perform tasks which entail manual materials handling and load carrying; for example, the carrying of ammunition boxes or poles used in the construction of structures. Asfour **et al.** (1984) observed that back injuries resulting from manual materials handling activities in industry are a major source of lost time and compensation claims. Not surprisingly, Asfour **et al.** (1984) and Genaidy **et al.** (1989); have proposed work-hardening programmes for strength improvement in industry. Work-hardening programmes could significantly improve performance of troops. Likelihood of injury has been shown to decrease when effective strength training has been implemented (Asfour **et al.**, 1984, Genaidy **et al.**, 1989 and Genaidy **et al.**, 1992). Effective training and recruit-hardening programmes, targeting weak areas, could bring about the desired increase in, especially, upper-body strength.

Knapik (1997) assessed the influence of a training programme on the manual material handling capabilities of women. His study aimed to examine whether a general strengthening programme could influence efficiency in manual tasks. Following a 14-week programme significant improvements were seen in weight lifting strength and in manual materials handling tasks. Sharp **et al.** (1993) had earlier carried out a similar study on male subjects. The programme was aimed at assessing the performance of manual materials handling tasks following a general strength training programme lasting for 12 weeks. Table II compares these two studies.

Subjects in the study conducted by Sharp **et al.** (1993) showed a greater percentage improvement. However both studies demonstrated that a general strength training programme could influence manual materials handling efficiency by bringing about improvements of between 7 and 16 %. Similar improvements could thus be applicable to the SANDF and lifting ability of personnel enhanced.

Table II: Strength improvements following training programmes. (Adapted from Knapik, 1997).

Study	Pre-programme Maximum Lift (N)	Post-programme Maximum Lift (N)	% Improvement
Sharp **et al.** (1993) (Males)	730	890	16.0
Knapik (1997) (Females)	488	566	7.8

2. ISOKINETIC DYNAMOMETRY AND STRENGTH: GENERAL OVERVIEW

Isokinetic assessments involve the measurement of torque, work and power through a range of motion in which the limb is moving at a constant angular velocity. A number of isokinetic devices are commercially available, including the Cybex, Kin-com, Biodex and Merac systems (Abernethy **et al.**, 1995). Isokinetic testing devices have gained increasing acceptance both as modalities for clinical strength assessment and as means of rehabilitation (Charteris and Goslin, 1986; Perrin, 1993 and Frisiello **et al.**, 1994).

The accuracy and reliability of calibrated equipment makes isokinetic dynamometry a very effective means of strength assessment. Perrin (1993) has assessed the advantages and disadvantages of isokinetic testing devices. Under the advantages of isokinetics he includes: the ability to isolate weak muscle groups; to quantify torque work and power;

the inherent safety mechanism provided by accommodating resistance and the ability to monitor performance over the complete range of motion through which maximal resistance is given by the dynamometer. Among the disadvantages he lists: cost of equipment; the limitation of reliable measures to isolated muscle groups in the cardinal plane and the fact that in most protocols the activity occurs primarily in non-weight-bearing (seated, supine or prone) open-kinetic-chain positions. To this he could have added the fact that isokinetic dynamometers test to speeds of 500°.s^{-1} whereas humans typically move the appendicular skeleton at much faster speeds. Moreover accelerative, not constant-velocity movements are natural. However, with advances in technology and changes to testing protocol, isokinetic dynamometery has shown increasing reliability as a means of assessing strength (Frisello **et al.**, 1994 and Li **et al.**, 1996).

The concept of isokinetic exercise and testing works according to the following principles: at the extremes of the range of motion the muscle group has its lowest mechanical advantage and resistance from the dynamometer is at its lowest level. Toward the midrange, where the mechanical advantage is greatest, the accommodating resistance increases proportionately. Figure 1 shows the force output of the skeletal lever during isokinetic exercise.

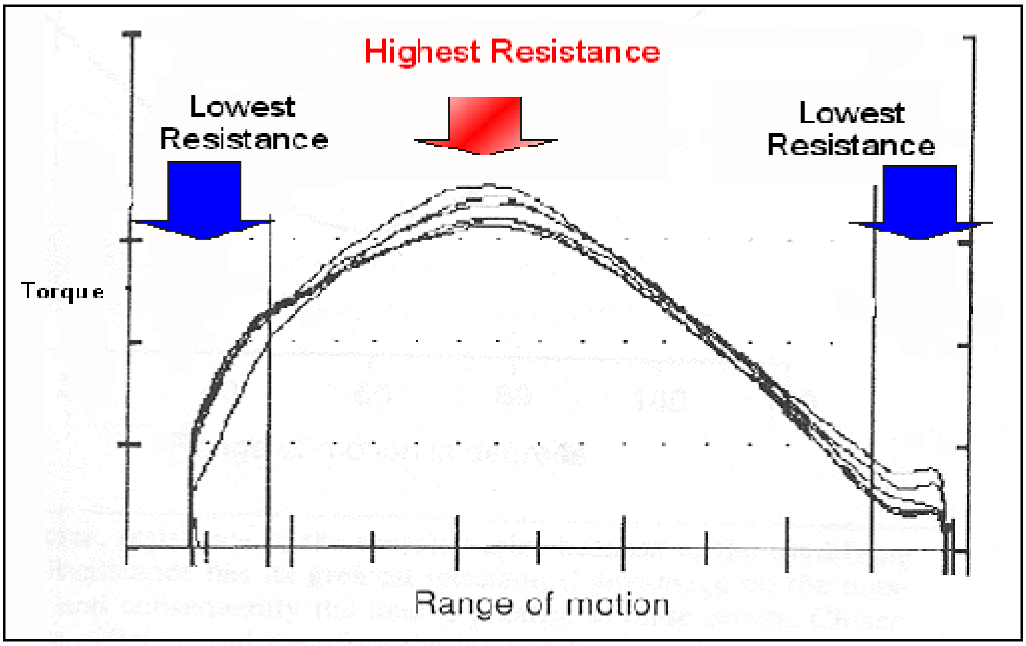

Figure 1: Torque output at the skeletal level during isokinetic exercise. (Adapted from Perrin, 1993).

Measurements Used in Isokinetic Dynamometry

(a) Torque

Torque is caused by force applied about an axis of rotation. It is an "instantaneous" measurement, averaged by the CYBEX 6000 over every half-degree in the range of motion (CYBEX 6000 User's Guide, 1994). The formula for torque is:

Torque (Nm) = Force (N) x Distance (m)

where distance indicates the perpendicular distance from the input of force to the centre of rotation. Because the CYBEX 6000 measures torque directly at this centre of rotation, the force and distance components are not measured (CYBEX 6000 User's Guide, 1994).

(b) Peak Torque (Nm)

The term peak torque is often used interchangeably with T_{max}. Peak torque is a measure of maximum muscular capability and has long been regarded as one of the key isokinetic values, but Charteris (1999a; b) warns against using T_{max} as the defining criterion for determining muscular strength. A higher peak torque in one subject is no guarantee of greater total work output or of greater average power generation in another (Perrin, 1993 and Charteris, 1999a; b). Essentially, peak torque represents performance or output at a point in the range of motion which is often not specified. The unit of measure for peak torque is newton metres (Nm).

(c) Total Work (J)

Total work is the sum of all the work performed by the subject in each direction of the movement, for example, flexion or extension of the knee. Range of motion is critical to the assessment of total work values as it is essential that the subject completes the same range of motion. The present study used a consistency value (higher than 90% for all tests) to ensure that the subjects were working at a sufficient level for movements in both directions. The unit of measure for total work is joules (J).

(d) Average Power (W)

Average power (best work repetition) is an expression of work per unit of time and is an accurate indicator of the subject's actual work rate. An isokinetic system divides the amount of work performed in the best work repetition (BWR) by the actual contraction time separately for each direction, for example, shoulder internal and external rotation. The unit of measure for average power is watts (W).

Isokinetic Evaluations: Normal and Deficient Curves

Values of peak torque (Nm), total work (J) and average power (W) are derived from an isokinetic torque curve. A normal isokinetic curve is shown in Figure 2.

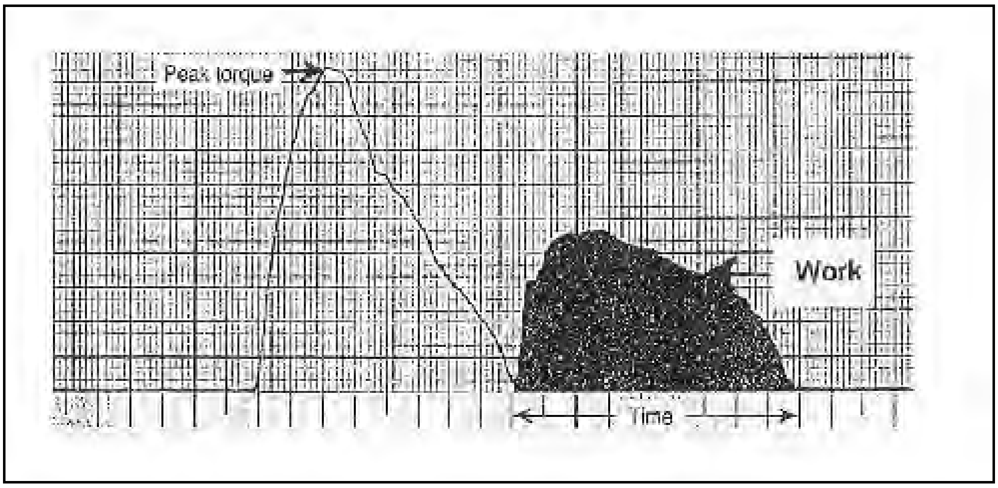

Figure 2: Normal isokinetic torque curves representing peak torque, total work and average power. Peak torque is the single highest point of the torque curve; total work is the total area under the torque curve, and average power is the time required to perform work (Adapted from Perrin, 1993).

The efficiency of subjects can be assessed by analysis of the form of the curve and injured or malingering subjects can be identified. Figure 3 identifies a work deficit in a subject involved in isokinetic testing.

Peak torque should not be used as the only criterion for the assessment of the efficiency of subjects in isokinetic testing. Figure 3 shows how two tests having the same peak torque may represent very different values for work done through the same range of motion.

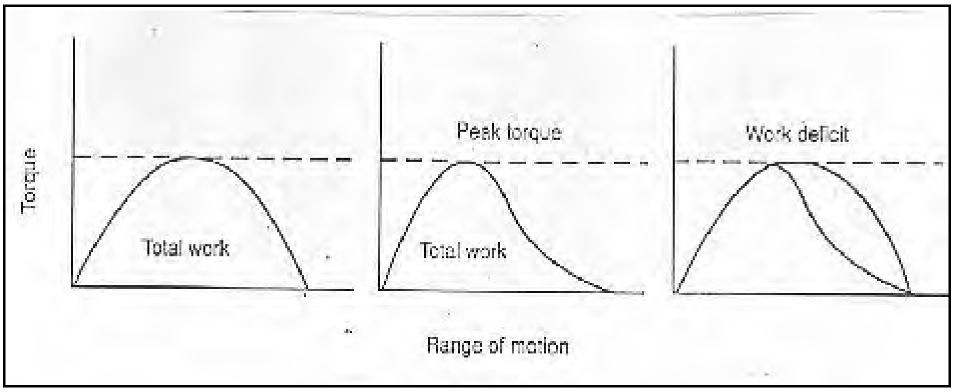

Figure 3: Two curves having equal values of peak torque, but an inability to produce a maximal amount of force throughout the full range of motion in the second curve results in a deficit in work. (Adapted from Perrin, 1993).

Although subjects may appear to be equally strong in terms of peak torque output (Nm), there may well be a work (J) deficiency when the entire range of motion is considered. Perrin (1993) stresses that the return of peak torque in a rehabilitating muscle may not be closely related to that muscle's work and power capabilities. The ability of subjects to complete a task which requires a high power output (W) or a great deal of work (J) would be significantly impaired.

Charteris (1999b) states that peak torque usually represents performance at some (usually unspecified) point in the range of motion. Like Perrin (1993) he argues that higher peak torques are not a guarantee of greater total work outputs. He regards “summated torques” or the area under the torque curve as being the superior measure of full-range tension development and therefore work capacity.

In analysis of results it is also important to take into account the effects of body mass by assessing torque relative to the mass of the subject. High peak torque values do not always indicate that the subject is efficient. Charteris and Dirkse van Schalkwyk (1999) contend that a very small subject may in fact have the highest torque relative to body mass ($Nm.kg^{-1}$). Females, for instance, largely because of higher percentage fat values, still exhibit lower relative torque values, but this disparity is considerably lessened when relatavised for lean body mass (LBM).

Isokinetic Evaluations: Laboratory Tests (LTs)

(a) Trunk

Low back injuries can pose a significant problem during load carriage (Knapik **et al.,** 1996). Adequate trunk strength is critical in the completion of various military tasks, particularly those involving load carriage. In an evaluation of infantrymen, it is critical to assess the strength of these muscle groups and to closely analyse the reciprocal (agonist-antagonist) ratios derived from the results. Trunk evaluations have been made possible, and indeed more reliable, via the CYBEX 6000 TEF modular component, but trunk research is still not prevalent in the literature. Extensors of the normal trunk are stronger than flexors (Charteris, 1999a). However, when testing takes place in the standing position the effect of gravity is to add to the peak and average values for flexors but to lower the values for the extensor group. The mass of head, arms and trunk (HAT) is also an important factor, as in some cases this may well account for as much as 75% of body mass of subjects (Perrin, 1993).

(b) Lower-Extremity

Knee pain has been associated with the practice of load carriage (Knapik **et al.,** 1996). Due to injury incidence the focus of lower-extremity testing has been on the knee musculature (Ghena **et al.**, 1991; Bishop **et al.**,1991; Cress **et al.**, 1992; Lin **et al.**, 1996; Li **et al.**, 1996 and Wu **et al.**, 1997). The early design of isokinetic dynamometers in the late 1960s has led to knee tests being more commonly carried out as a result of the ease with which subjects are tested. However, redesign of isokinetic equipment has been given more attention; machines like the Cybex® NORM system now allow greater scope for testing with a more user-friendly set-up. Testing of the upper-extremity is now as easily administered as the testing of the lower-extremity.

The anatomical configuration of the knee joint renders it highly vulnerable to injury (Perrin, 1993) . In activities like rugby union or American football, the incidence of knee injury is high, the result being an increased focus on knee isokinetics in the literature. In a military setting, the likelihood of knee injury is also increased in activities like timed obstacle course running. Weak lower-extremity musculature and fatigue are contributory factors to increased injury incidence.

Bennell **et al.** (1998) provide a warning about the ability of isokinetic testing to predict injury. In a study on Australian Rules Footballers, pre-existing functional deficiencies were identified in the hamstring muscle group, yet the study was not able to directly discriminate players at risk for hamstring injury. Taylor and Casey (1986) highlight another problem associated with isokinetic assessments of the knee. Following this study they concluded that the exact alignment of the joint axis of rotation was impossible to maintain as a result of the movement of the extremity of the subject.

Although the present study aimed to identify possible weaknesses or disparities in the ratios between reciprocal muscle groups (for example the quadriceps and hamstrings groups in the form of the Q/H ratio) comparisons and generalizations based on previously conducted research were approached with caution due to the diversity of subjects assessed.

In contrast to the knee, the ankle and the hip have not received much attention in isokinetic research. The setup procedures for these tests have resulted in significant debate as to the correct positioning for subjects (Karnofel **et al.,** 1989). The rather expansive cross-sectional area of the muscles that produce hip flexion/extension, results in the hip having the highest values for peak torque in either of the upper- or lower-extremity. In testing of the hip joint it is particularly important to ensure that the subject is stabilised when completing the maximal responses. A lack of standardization can significantly influence hip responses, as the hip extensors and flexors are not effectively isolated, the subject being able to recruit other muscle groups during the repetitions.

Perrin (1993) states that the biomechanics of the ankle region complicate its assessment. Changing the position of the subject has been shown to influence the results obtained with the plantarflexors being strongest when testing in the prone position and dorsiflexors stronger when tested with the knee flexed at 90°.

(c) Upper-Extremity

Clinicians and researchers are becoming increasingly interested in the upper extremity (Perrin, 1993). Shoulder injuries are shown to be frequent in athletics or occupations in which the arms move at high velocity, under load, or are stressed at the end of the range of motion (Soderberg and Blaschak, 1987). Historically the predominant test focus for upper-extremity isokinetic dynamometry has been the shoulder. Given the high incidence of rotator-cuff injury the use of upper-extremity isokinetics has gained relative popularity as a means of rehabilitation (Ellenbecker **et al.**, 1988; Hageman **et al.** 1989; Frisello **et al.**, 1994 and Voight **et al.** 1996).

Opinion on the optimal position for isokinetic assessment of shoulder rotation remains somewhat controversial (Perrin, 1993). The 90° abducted position has been avoided by some clinicians for fear of inducing symptoms associated with shoulder impingement syndrome. In healthy subjects this problem should not be as significant an influence as it is in the case of subjects in a rehabilitation setting. The fear of inducing symptoms associated with muscle injury is also an important consideration for upper-extremity assessments.

Work on the elbow joint has been limited, however various researchers have shown the elbow flexor and extensor groups to produce similar peak torque responses at slow isokinetic speeds (Charteris and Goslin, 1986; Pawlowski and Perrin, 1989; Charteris, 1999b). The design of isokinetic dynamometers has essentially rendered testing of the upper-extremity more difficult than testing of the lower-extremity. Set-up procedures and positioning are not always as efficient or easily administered as those for the lower-extremity. Changes in equipment and the focus of research should help to address the imbalance to a large degree.

Specificity of Strength

A great deal of research has been carried out to assess the specificity of strength for individuals of different body size, sex and age (Hettinger, 1961; Asmussen **et al.**, 1965; Lambert, 1965). The variability in muscle testing and the large range of movements possible in a testing setting have made it difficult to quantify the relationship between symmetrical (right and left) and reciprocal (agonist and antagonist) muscle groups.

Traditional research (Asmussen **et al.**, 1965 and Lambert, 1965) has shown a correlation r = 0.8 between symmetrical muscle groups and a much lower correlation between muscles from different parts of the body (r = 0.4) .

High levels of muscle strength are often related to general strength training and the present occupation of subjects. For example, infantrymen who are involved in regular training would be expected to exhibit higher strength values than subjects who are sedentary. However, the efficient performance of a subject in a single test of strength does not imply that that subject can be expected to express general body strength, that is to excel in other such tests. Upper- or lower-body strength in isokinetic or isometric tests does not allow for generalizations with regard to total body strength values or the relationship between upper- and lower-body strength ratios. Hettinger (1961) demonstrated that assumptions regarding general muscle strength should not be extrapolated from measurements in one single muscle group (for example, the finger flexors in the hand grip) but from application of a battery of selected, well-standardized muscle tests. These findings are particularly relevant to the present study, as individuals who performed efficiently in tests of, for example, the shoulder, should not be expected to have similar strength in the elbow or the lower-extremities or even in the elbow for that matter. Testing of subjects in a field setting using only a simple device like a hand-grip dynamometer should therefore also be approached with circumspection. Selection of stronger individuals on the basis of isolated simple testing measures is problematic as will be discussed in the concluding chapter.

Reciprocal (Agonist/Antagonist) Ratios

Isokinetic strength testing can be used to identify muscle strength imbalance or weakness (Davimes and Levinrad, 1985). Reciprocal muscle groups provide for interesting comparisons between torque, work and power responses. By assessing the agonist/antagonist ratios established during isokinetic evaluations it becomes possible to highlight areas of relative weakness and compare the results to benchmark data already available. Strength training specialists have long recognized the importance of training both the muscle groups producing opposite actions about a joint (Perrin, 1993). By assessing quadriceps to hamstrings (Q/H) and biceps to triceps (B/T) torque, work and power ratios it becomes possible to make estimations of agonist/antagonist imbalances and to advise subjects on possible training programmes.

In a rehabilitation setting it is feasible to test the injured and uninjured sides of a subject and then to implement a programme which best suits that individual. Similarly in a sporting situation: for example rugby union players who over-emphasize quadriceps training may exhibit higher Q/H ratios as a result of relatively de-emphasised hamstring training, possibly predisposing them to injury. In the present study subjects were military personnel who place high stress on the lower-extremity through marching and running, but who may neglect the upper-extremity in training sessions. Zakas **et al.** (1995) argued that because the musculature around the knee is important in the prevention of injuries as well as in the enhancement of knee function, deficiencies in any of the quadriceps or hamstring muscles (with the subsequent changes in the Q/H ratio) could thus lead to increased likelihood of injury.

Normative databases relating to work and power output ratios could be useful in establishing rehabilitation goals after bilateral upper or lower limb musculoskeletal injury (Charteris, 1999b). Goslin and Charteris (1979) set up a table of normative data for $30^{o}.s^{-1}$ knee extensions in male subjects (See Appendix A). This table allows for comparisons between individuals and the normative data presented, but the table is velocity-specific. Appen and Duncan (1986) caution that there is no fixed ratio of hamstrings to quadriceps across test velocities that would be appropriate for most individuals in the same occupation or sporting activity.

Isokinetic Evaluations: Normative Data for Laboratory Tests (LTs)

A number of studies have been carried out in order to determine peak torque, work and power outputs of different subjects from different populations (Alderink and Kuck, 1986; Appen and Duncan, 1986; Read and Bellamy, 1990 and Zakas **et al.**, 1995). In assessment of performance over a velocity spectrum, it becomes possible to gauge how the subjects involved in isokinetic evaluations compare to fellow infantrymen, workers or athletes and even individuals of a higher or lower level of training.

(a) Trunk

Assessment of trunk strength is important among athletes, but may be more valuable for industrial workers given the extremely high incidence of occupational back pain (Perrin, 1993). The TEF modular component has added to the testing functionality of the CYBEX 6000 isokinetic dynamometer, but despite improvements in technologies, trunk isokinetics is still not as prevalent in the literature as, for example, knee or shoulder research. Charteris (1999a) provides benchmark data for male subjects at slow and medium testing velocities. These data provide a useful base of comparison for the trunk in respect of peak torque, total work and average power outputs. Figure 4 shows values recorded in Charteris' (1999a) study (N=27 and mean age=27 yr).

Trunk extension, although involving a large cross-sectional area of muscle has to overcome the effects of gravitational force on the masses of the head, the arms and the trunk or HAT. This HAT mass can account for as much as 75% of the mass of an adult male (Thorstensson and Nilsson, 1982; Perrin, 1993). It is obvious that data collected in respect of the trunk in the standing position will therefore be impacted upon, to differing levels, by the effects of gravitational force on the mass of HAT.

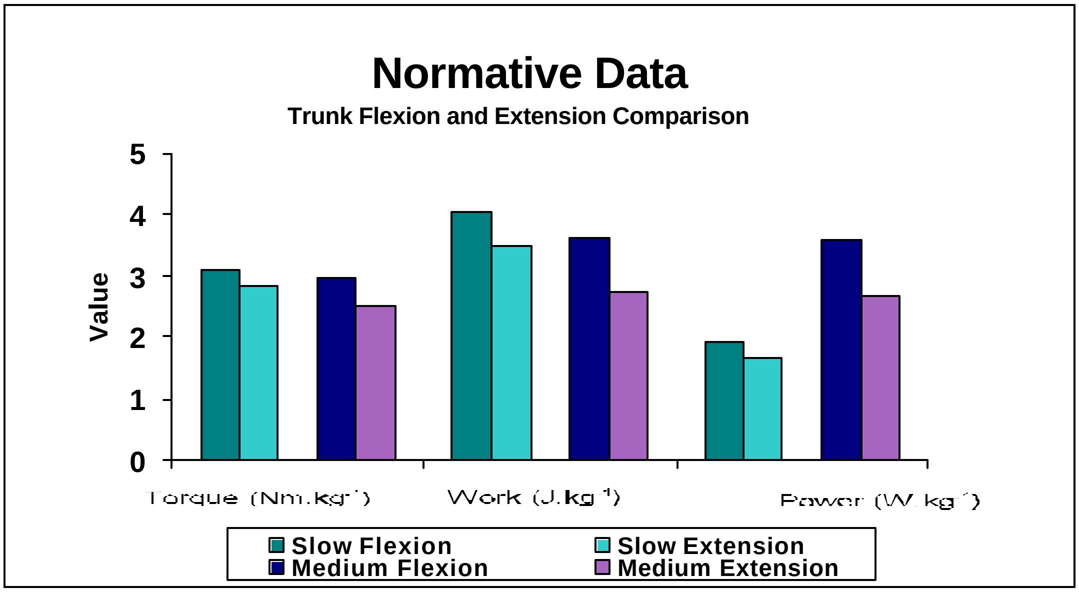

Figure 4: Normative data for trunk flexion and extension (Adapted from Charteris, 1999a).

The dominance ratio (flexors/extensors) for Charteris' (1999a) study changes from 1.08 at the slow speed to 1.18 at the medium speed for peak torque. A possible reason for the observed data is offered by the author, who states that the manufacturer's rationale for not including a gravity correction for the TEF unit may well be based on the notion that we naturally work with or against gravity as upright bipeds and do so without the awareness of its effects in our daily lives, so that it would be artificial to build "awareness" of it into our technology. These factors will be given due consideration in Chapter IV where trunk data from the present study will be compared to the values presented in Figure 4.

(b) Lower-Extremity

The lower-extremity has a long tradition as a focus for isokinetic testing. The knee joint (flexion and extension) has been the most widely tested with more limited data available for the ankle and the hip. The following figure provides a comparison of normative values collected on the hip and knee, and highlights the effect of velocity on peak torque production. The force-velocity relationship (Hill, 1938) is shown to have a significant influence when lower-extremity hip and knee values are considered. Data display a decrease in peak torque (Nm) which the subject is able to produce when testing velocity is increased.

Knee normative values are widely available for the both concentric and eccentric tests. Non-gravity corrected data is often used in the literature with diverse populations given due consideration. The data in Figure 5 relates specifically to the studies of Hageman **et al.**, (1988) where non-disabled males where tested and Stafford and Grana (1984) where college football players were assessed. These values, although not specifically collected on military personnel, are still useful in the construct of normative graphs of peak torque (Nm). In the analysis of results from the present study, the collected isokinetic data may easily be compared to data previously collected to highlight any possible deficiencies or experimental error (This will be carried out in Chapter IV).

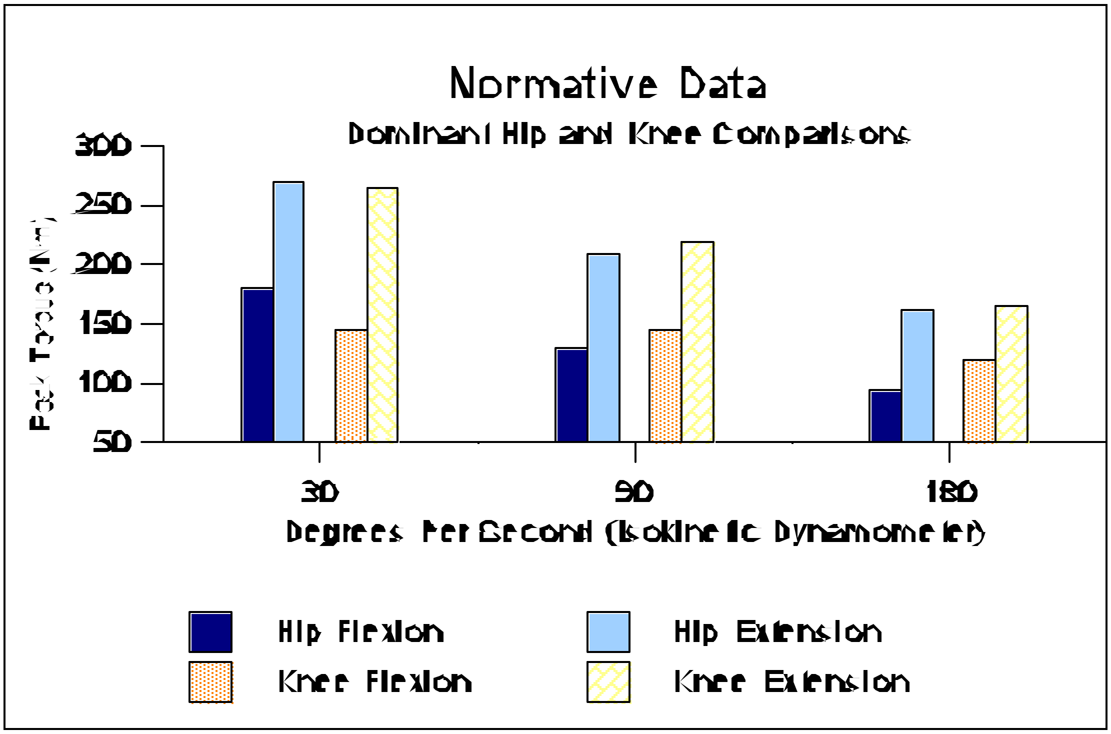

Figure 5: Normative data of dominant hip and knee extensor and flexor peak torque. Knee: Adapted from Hageman **et al.**, (1988) and Stafford and Grana (1984). Hip: Adapted from Poulmedis (1985).

Flexion and extension of the hip occur in the sagittal plane. Perrin (1993) states that the flexors tend to produce between 60 and 75 % of the peak torque observed in the extensors. Poulmedis (1985) provides some benchmark hip data over a velocity spectrum on elite male soccer players. These data (Figure 5) show that hip extension values are greater than flexion values, a similar trend is seen in knee extension and flexion. Both hip flexion and extension drop-off with an increased testing velocity. At the slow speed of testing the flexors are 66% of the extensors, while a speed increase of 150°.s^{-1} sees a change to 59%. The values for knee flexion/extension are 63% at the slow speed and 82% at the fast speed. Drop-off is therefore shown to be highest in the knee extensors with an increase in testing velocity.

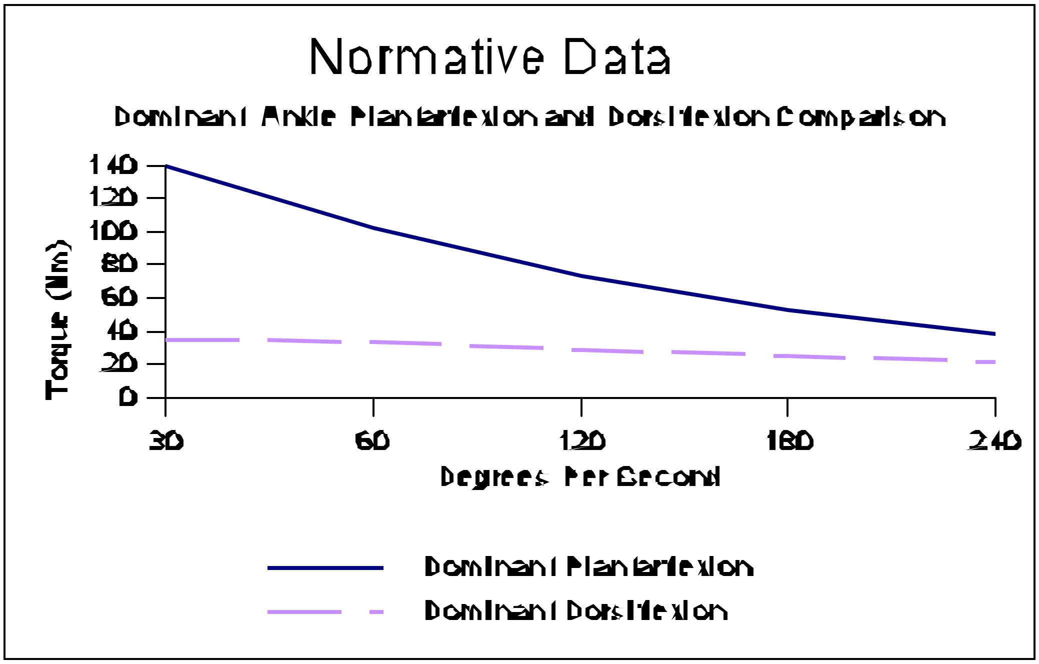

Figure 6: Normative Data: Ankle plantarflexion and dorsiflexion (Adapted from Öberg **et al.**, 1987)

Movements at the ankle occur at several articulations, which renders the biomechanics of this region quite complicated (Perrin, 1993). Ankle plantarflexion and dorsiflexion occur principally at the talocrural joint. Isokinetic testing of the ankle can be carried out prone with the knee extended at 0° or supine with the knee flexed at 90°. Research carried out by Öberg **et al.**, (1987) provides useful benchmark data for the ankle with the knee extended at 0° (the selected method for the present study). The findings of this study for dominant plantar and dorsiflexorion are provided over a velocity spectrum of 30 to 240°.s^{-1} in Figure 6. Peak torque values are shown to be significantly higher for plantarflexion at the slow isokinetic speeds, for both dominant and non-dominant sides. The force-velocity relationship (Hill, 1938) appears to affect the plantarflexors more than is the case for dorsiflexors. This will in turn influence the dominance ratios (agonist/antagonist) which should show dorsiflexors dropping-off at a slower rate than is the case for plantarflexors.

Research has shown that in the prone testing position the dominance of plantarflexors over dorsiflexors is significantly greater than when the knee is flexed at 90°.

(c) Upper-Extremity

Establishment of a normative data base for elbow flexion and extension values across a range of speeds has been relatively neglected and more research is still required. As argued earlier, the design of isokinetic dynamometers could be one factor which influences the type of testing which is carried out. Testing of the knee is more easily administered and this could be one of the main contributing factors to the limited collection of data on elbow flexion and extension. The relatively high incidence of hamstring and quadriceps injuries in athletes participating in a variety of sports could also be a contributing factor to the research emphasis on lower-extremity testing. Data collected in respect of the shoulder are more comprehensive than those collected on the elbow. However, some aspects of shoulder strength assessment, most significantly eccentric versus concentric contraction, still need to be assessed. Figure 7 shows normative values established by different researchers for elbow extensor/flexor peak torques and shoulder internal/external rotation.

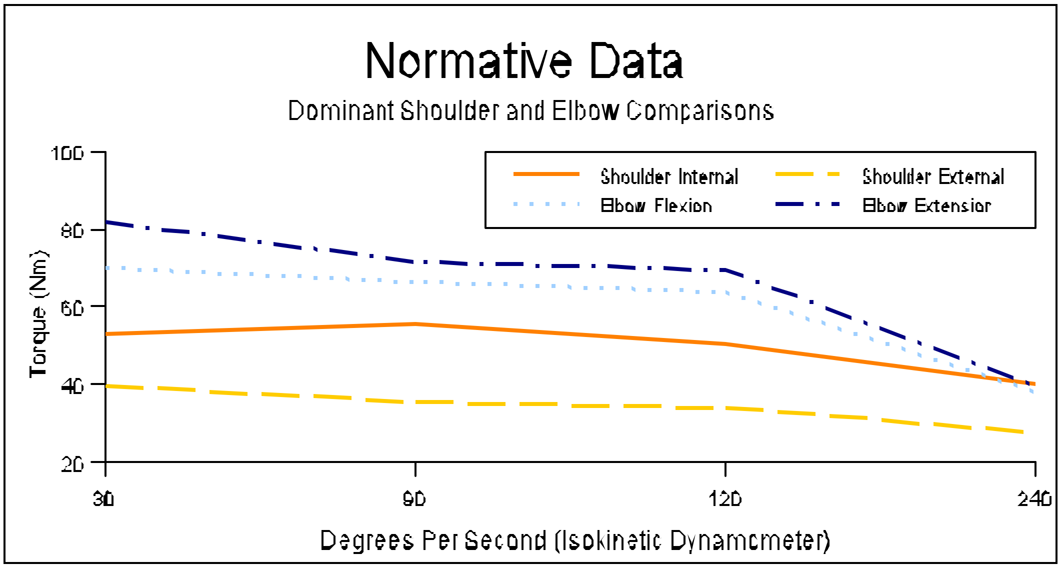

Figure 7: Normative data: elbow flexion and extension and shoulder internal and external rotation. (Shoulder: Adapted from Alderick and Kuck (1986), Pawlowski and Perrin (1989), Mc Master **et al.** (1991) and McMaster **et al.** (1992)). (Elbow: Adapted from Hortobagyi and Katch (1990) and Pawlowski and Perrin (1989)).

The assessment of upper-extremity agonist/antagonist strength ratios has not received as much attention in isokinetic testing. However, Charteris' (1999b) recently completed study assessing the effects of velocity on upper- to lower-extremity muscular work and power output ratios of intercollegiate athletes provides some new insights into setting up rehabilitation goals and normative standards for both extremities. Table III shows the ratios calculated following data collection.

Table III: Reciprocal (agonist to antagonist) ratios for work and power. Means, with SD in brackets. (Adapted from Charteris, 1999b).

Measure	***Elbow F to E Ratio***		***Knee F to E Ratio***	
	30°.s^{-1}	***180°.s^{-1}***	***30°.s^{-1}***	***180°.s^{-1}***
Peak Torque (Nm.kg^{-1})	1.01 (0.16)	1.06 (0.14)	0.57 (0.09)	0.66 (0.10)
Total Work (J.kg^{-1})	1.06 (0.15)	1.04 (0.21)	0.65 (0.13)	0.67 (0.11)
Average Power (W.kg^{-1})	1.08 (0.17)	1.08 (0.23)	0.66 (0.14)	0.65 (0.12)

F = Flexors; E = Extensors

Charteris (1999b) states that in cases of bilateral upper extremity injury, a useful guide to rehabilitation could be to target combined flexor plus extensor upper extremity work capacity goals at 55%, and power output goals at 39% of the measured capability of the unaffected lower extremity. Through testing of the lower-extremity it is thus possible to set-up more efficient criteria for upper-extremity work and power restoration. A normative data table for elbow extension and flexion was set-up by Charteris and Goslin (See Appendix A). This table allows comparisons to be made between the scores achieved by the subjects involved in the present study and the normative values developed for isokinetic testing of the elbow. In a rehabilitation setting this is useful to determine how the subject is progressing on injured and uninjured sides. Similarly, military recruits can be compared to the normative data and any inherent weaknesses targeted.

Isokinetic Evaluations: Normative Data for Occupation-simulating Tests (OSTs)

The hands' major functions entail gripping, manipulation, and strength expression (Balogun **et al.**, 1991). In a rehabilitation setting, grip strength is often recorded on a portable, hand-held dynamometer. Grip strength measurement has been shown to provide an objective index of the functional integrity of the upper-extremities (Balogun **et al.**, 1991). With more sophisticated equipment available as a result of work-simulation packages for isokinetic dynamometers, it is now possible to make more accurate assessments of grip strength.

Previous studies have shown that while hand-held dynamometers are useful means of assessing clients in rehabilitation or clinical settings, their accuracy after long periods of use needs to be quantified. Bohannon and Andrews (1989) found that spring gauge dynamometers (hand-held dynamometers) can be inaccurate after long periods of use.
Using a "work-simulation" package on the CYBEX 6000 dynamometer has an advantage, as the calibration of equipment can be done at the commencement of each testing session with data being less affected by the equipment used.

Benchmark data on the pushing/pulling, valve-tightening, wrench-turning and gripping capabilities of individuals from diverse sectors of industry and sport are still not available to researchers and the present study will thus further the field of work-simulation isokinetics.

Isokinetic Evaluations: Other Considerations

The Selection of a Testing Velocity

Arnold **et al.** (1997) argue that one of the difficulties of isokinetic evaluations centres on the selection of appropriate test velocities for the sample being tested. The present study used test velocities of 30, 120 and 210° .s^{-1} for the shoulder, elbow , ankle, hip, trunk , knee, valve-turning and wrench-turning bouts. The gripping tests were not deemed to be possible at these machine speeds, with the result that speeds of 30, 60 and 90° .s^{-1} were selected. In choosing test speeds across a velocity spectrum, consideration had to be given to the ability of the subjects, who were all involved in military training and were capable of performing isokinetic work at a slow speed.

In another study, for example one involving rehabilitees, it may well have been impossible to expect the subjects to complete maximal repetitions at fast speeds. Charteris (1999b) states that as a generalisation while peak torque decreases as speed increases, power, in contrast will increase whenever the decrease in time taken to complete the given task outstrips the torque-velocity decrement rate.

The Identification of Sub-maximal Efforts during Isokinetic Testing

The study of submaximal effort in isokinetic testing has not received much attention. Lin **et al.** (1996) suggest a possible method of submaximal effort evaluation. The coefficient of variation of average torque, coefficient of variation of peak torque, and slope to peak torque were obtained from maximal and submaximal torque curves during isometric and two isokinetic tests. Results showed that the best method of evaluation for submaximal efforts was the combining of the coefficient of variation of average torque with slope to peak torque (produced by the computer). Submaximal detection rate increased from 63% (using only the coefficient of variation of average torque) to 84% when this method was used. Subjects who are performing below their potential could therefore be identified, and this would be particularly useful in determining whether a subject is feigning injury or has a serious problem.

Charteris and James (2000) provide a more simple means of analysis of replication of work output levels in able-bodied workers and candidates for disability assessments. This method was used in the present study and will be outlined in the following chapter.

Visual Feedback (VF) and Knowledge of Results (KR)

Hald and Bottjen (1987) argue that one area receiving limited attention is the use of visual feedback (VF) as an adjunct to isokinetics. Without the use of feedback, subjects are often more focussed on the effects of the activity and are not certain how much of the work still has to be completed. Motivation to complete the testing could therefore decrease and the result will be more rapid fatigue. These authors found VF to be of limited success in maintaining an increased effort level. Motivating subjects to continue producing a maximal effort therefore provides a number of obstacles to accurate data collection in isokinetic testing. Knowledge of results (KR) is a factor which is closely aligned to feedback. In the present study KR was provided whenever possible. Figoni and Morris (1984) studied the effects of KR on muscular strength and fatigue. They conclude that KR can be a motivator in eliciting maximal strength outputs and also a factor which contributes to increasing levels of fatigue in testing of maximal strength.

Baltzopoulos **et al.** (1991) contend that VF can have a significant effect on torque production. The magnitude of the effect depends on the angular velocity of the movement. Their study found that when VF was used at higher testing velocities, subjects were motivated to produce higher torque outputs. The effects of VF and KR still require further study to allow for more detailed assessment of their effectivity.

The Uses of Isokinetics in Training

Isokinetic dynamometers have a number of different uses in training settings. Perrin **et al.** (1989) found that isokinetic power training is effective for the development not only of average power, but also of peak torque and instantaneous power. For military personnel, who need lower- and upper-extremity strength for combat-related activities, this would be of particular use. Isokinetic training could be utilised by individuals for their specific activity, be it marching or driving, and to address imbalances in reciprocal muscle groups. By targeting a weak muscle group identified in maximal testing, steps could be taken to decrease likelihood of injury through on-going isokinetic assessment. The data collected here on infantrymen provides a useful database for the variety of professionals who are involved in the rehabilitation of SANDF personnel.

3. PSYCHOPHYSICAL RESPONSES: GENERAL OVERVIEW

During recent decades we have become more interested in how people experience their aches and pains, and how difficult they perceive their work to be (Borg, 1982). Psychological factors have been shown to exert significant influences on the efficiency of performance of military personnel. The thermal environment, protective clothing, battle conditions and intensity of effort all influence psychological perceptions (White **et al.**, 1991 and Aoyagi **et al.**, 1998). The importance of entraining military personnel to cope adequately with the demands of the battle environment has therefore become central to successful task completion.

A number of methods have been developed to aid the assessment of the psychological impact of training and combat. For example, Borg's (1971) Rating of Perceived Exertion (RPE) scale (See Appendix B), Kobrick and Sampson's (1979) Environmental Symptoms Questionnaire and the profile of mood states (POMS), McNair **et al.** (1981). Various researchers (Knapik **et al.**, 1993; Johnson **et al.**, 1995) have utilized these testing means to assess the perception of effort and the efficiency of task completion in a military combat environment.

The Influence of Environment on Psychophysical Ratings

Carton and Rhodes (1985) state that environmental manipulation may create alterations in ratings of perceived exertion. In modern industry, human tolerance of a combined exertional and heat stress challenge is usually determined more by psychological than by physiological responses (Aoyagi **et al.**, 1998). The is same is true for a military setting. Military gear and equipment has been shown to weigh in excess of 50 kg (Haisman, 1988). Heavy load carriage requirements and the need for protective clothing have thus resulted in increased demands being placed on the soldier. Environmental temperature influences have also been assessed. Horstman (1977) found that RPE was significantly lower when subjects performed a task at 5^{o} C compared to the same test performed at
25^{o} C.

Psychological analysis is now performed more regularly than was the case in the past, with for example, Knapik **et al.** (1993) placing increased emphasis on the psychological profile of the infantrymen through use of the POMS profile. In the present study, environmental extremes were not considered as the testing took place in a controlled environment.

Perceived Exertion and Physical Strain

It has been argued by Borg (1982) that the individuals' perception of exertion during physical work is interesting when studying man during work and leisure-time activities. The ability to cope with a measure of physical strain, especially when military combat is considered, is essential to successful task completion. Where workers are required to lift or carry heavy loads or to work under trying conditions, the psychological make-up of the individual needs to be adequately matched with the demands of the task. Perceived exertion has an important application in an occupational setting (Noble, 1982). A mis-match between a particular machine and human operator can have significant consequences. If the individual perceives the strain involved in a particular task to be excessive, the final task completion will be impaired.

Nature of the Test and RPE

Carton and Rhodes (1985) state that the nature of the test itself may influence ratings of perceived exertion. In isokinetic tests of strength, the environment was controlled, but the work which was required from the subjects was maximal. Horstman **et al.** (1979) state that a lack of previous experience in strength testing and the use of the RPE scale could significantly influence the results obtained. In the present study the subjects involved were unlikely to have had previous experience in isokinetic testing and the results could therefore have been influenced. RPE ratings are also subjective and the infantrymen could have under rated the task being performed as a result of inexperience.

4. STRAIN-GAUGE DYNAMOMETRY

Strain-gauge type leg strength dynamometers have a number of uses in industrial and sports settings. These pieces of equipment, which measure isometric force, offer a low-cost alternative to isokinetic dynamometers and allow for the assessment of leg strength values in a short period of time with limited expertise required by the tester.

A number of factors have been shown to influence leg strength in post-march situations. Knapik **et al.** (1993) found that leg strength was lower following a loaded route march. The decrease in leg strength was seen to be related to repeated eccentric work to decelerate the shank while walking. Their study collected leg, upper-torso, back and hand grip strength of subjects and provided a further base for comparison with the present study.

Table IV shows the values recorded in the Knapik **et al.** (1993) study and similar work on military personnel.

Table IV: Comparison of isometric strength values of armed forces personnel. Means, with SD in brackets. (Adapted from Knapik **et al.**, 1993).

Study	**Subjects**	**Leg strength (N)**	**Upper-torso strength (N)**	**Back strength (N)**	**Hand grip strength (N)**
Knapik **et al.** (1993)	Special Forces	1690 (510)	1340 (160)	950 (150)	610 (80)
Sharp **et al.** (1980)	Male Infantrymen (n=181)	1670	1080	800	550
Knapik **et al.** (1980)	Male Basic Trainers (n=769)	1580 (410)	1020 (160)	790 (170)	-

Hand-Grip Strength

Knapik **et al.** (1993) highlights the diurnal variation in grip strength. Isometric hand grip strength testing has been shown to deliver higher test results in the afternoon than in the morning (Wright, 1959 and Hislop, 1963). Time of day must thus be considered when an assessment is made of strength. In a similar manner to the comparisons of peak torque, grip strength data can be analysed and compared to the normative values established by Knapik **et al.** (1993). The efficiency of South African military personnel can thereby be established and deductions made specific to the SANDF.

CHAPTER THREE

METHOD

INTRODUCTION

Isokinetic strength assessment has a long tradition, with knee and shoulder testing being most frequently carried out (Ellenbecker **et al.**, 1988; Perrin, 1993). Methods used in the testing of the knee, elbow, trunk, ankle, hip and shoulder have been well documented and tested for reliability (Voight **et al.**, 1996; Li **et al.**,1996). In contrast, the assessment of occupation-simulating tests, made possible through the CYBEX 6000 "work-simulation" package (1993), appears not to have been given fractionally as much attention in the recent literature. The set-up and placement of, for example, the gripping-tool, provides a number of variations and opportunities for new testing procedures or protocols. Capadaglio **et al.** (1997) measured grip endurance on an isokinetic dynamometer and then used the data to assess the ergonomics implications of the findings. This study demonstrated that isokinetic measures can be used as effectively in ergonomics assessments as they are in their more traditional role in rehabilitative settings in the study of human strength capabilities.

In the present study isokinetic performance measures were obtained using a CYBEX 6000 Isokinetic Dynamometer. Standard protocols were used according to the manufacturer's instructions (CYBEX, Division of Lumex, Inc., Ronkoncoma, NY 11779). Determination of the dominant lower-extremity was based on kicking preference and of the dominant upper-extremity on writing handedness. Before testing commenced the subjects were familiarised with the test procedures on the isokinetic dynamometer and completed a number of trials at each of the testing speeds as part of the warm-up (dynamometer on manual mode).

1. SUBJECT CHARACTERISTICS

Selection

Forty two subjects (volunteer male military personnel) were selected on the basis of their experience of military training. All were infantrymen, members of the South African National Defence Force, who were involved in training or physical work on a regular basis. All were healthy and free of clinical histories relative to any of the joints tested. No specific criteria were set for the selection of morphology or age.

Demographic Data

The following measured or derived data were obtained before the commencement of testing: stature (mm); body mass (kg); body fat (%); lean body mass (kg); body mass index (BMI) and reciprocal ponderal index (RPI). The morphological data for the subjects are shown in Table V.

Table V: Basic demographic data relative to the sample (N=42).

Measure	Mean	SD	C.V.
Age (yr)	29.6	3.97	13.41
Stature (mm)	1701	57	3.36
Body Mass (kg)	68.00	8.00	11.76
Body fat (%)	16.78	3.52	20.95
Lean body Mass	83.22	3.52	4.22
BMI (kg/m^2)	23.49	2.16	9.21
RPI ($Stature/Mass^{0.333}$)	417.44	13.08	4.22

2. RESEARCH PROTOCOL

Pre-Experiment Procedures

Informed Consent

Prior to testing, subjects were asked to sign informed consent forms (See Appendix C). The contents of the informed consent instrument were explained verbally and in a written information document supplied to each subject. The subject, the researcher and a witness signed each form. Ethical approval of this project via an institutional review process was a pre-requisite of the study and the informed consent document and procedures formed part of this approval.

Pilot Study

A pilot study was carried out to assess the viability of the test protocol. Three male subjects completed the testing. This pilot work was conducted under simulated conditions which attempted to mirror the actual test environment as closely as possible.

A number of adjustments were made to the original test protocol. These included the following: The test of valve-tightening was changed from a seated to a standing test of maximal strength. Standardization of the starting position was seen as an essential requirement. This was achieved by the placement of a demarcated plinth which ensured that subjects were not able to move beyond the blocked area. In the pulling/pushing test a demarcated leading foot area was used to ensure that all the subjects started from the same point. Gripping strength pilot work also showed that subjects were unlikely to “catch” the machine speeds of 120 and 210°.s^{-1} . This test was thus the only exception in terms of dynamometer speeds, with 30, 60 and 90°.s^{-1} being selected.

Isokinetic testing was originally to have been carried out both eccentrically and concentrically. However, familiarity with eccentric testing would have added to the general period of habituation. Furthermore, general time constraints discouraged this and the fact that measurement of concentric contraction was possible through a range of speeds was deemed more useful.

Test Focus: Laboratory Tests (LTs)

The laboratory tests (LTs) were as follows: shoulder internal/external rotation, knee flexion/extension, trunk flexion/extension, hip flexion/extension, ankle plantar/dorsiflexion and elbow flexion/extension. All tests, therefore, involved sagittal plane exertions of the segments moved.

Trunk strength was tested in a flexed knee standing posture with the limbs stabilised in the TEF unit. The range of motion was approximately 100 degrees, which included 10 degrees of hyper-extension. Musculature of the back and abdominal regions were assessed.

Shoulder internal rotation is produced by the subscapularis, teres major, petoralis major, latissimus dorsi, and anterior deltoid muscles, with the relative contribution from these muscles related to variations in their respective length-tension relationships as the glenohumeral joint moves for the neutral to 90° abducted position (Perrin, 1993). External rotation is produced by the infraspinatus, teres minor and posterior deltoid muscles. The range of motion which was assessed was approximately 160 degrees.

Knee extension is produced by contraction of the quadriceps femoris muscles, which consist of the rectus femoris and vasti (medialis, intermedius and lateralis). Flexion is the result of contraction of the hamstring muscle group, consisting of biceps femoris, semitendinosus and semimembranosus. In general, the hamstring muscle group has been shown to produce about 60% of the torque values generated by the quadriceps muscles at slow isokinetic test velocities (Morris **et al.**, 1983; Perrin, 1993 and Li **et al.**, 1996). The range of motion assessed in the test of knee flexion/extension was 95 degrees. In the case of knee flexion and extension testing, gravity correction is an important consideration. The weight of the leg being tested has an influence on the quadriceps to hamstring (Q/H) ratio, as the subject is assisted by the effects of gravity when flexion of the knee is considered. The CYBEX 6000 isokinetic dynamometer therefore has a gravity correction default for knee extension/flexion. In contrast, the elbow does not have a gravity correction option as the assistance to the elbow extensors and shoulder rotators is regarded as being minimal.

Flexion and extension of the elbow involved the full range of motion (150 degrees) of subjects. Principle muscles involved in flexion are biceps brachii, brachialis and brachioradialis. Extension is produced by contraction of the triceps brachii. The size of the musculature of the arm is far smaller than that of the thigh and in terms of absolute values, the torque, power and work outputs are much lower.

Muscular strength in the ankle region relates to running and marching ability especially when loaded. The present study assessed the full range of plantar and dorsiflexion (70 degrees). Load-carrying capacity also depends on hip strength. The 125 degree range of flexion and extension was assessed. Both these parameters combined with the strength of the knee give a good indication of the overall strength of the lower-extremity of the subjects involved in the present study. When running and load-carrying tasks are considered these strength values become central to determining the efficiency of subjects.

Test Focus: Occupation-Simulating Tests (OSTs)

The occupation-simulating isokinetic tests (OSTs) used in the present study involved the following: gripping, pulling/pushing, wrench-turning and valve-tightening. Military personnel are required to complete a number of tasks in training and daily living (Johnson **et al.**, 1995 and Knapik **et al.**, 1996). The tests were selected as they were deemed to represent a broad spectrum of military-type activities, for example, the valve-turn is commonly used by those soldiers involved in the driving corps and the pulling/pushing action is used by those involved in the construction of structures or digging of trenches. The occupation-simulating package for isokinetic dynamometers has not been widely tested with little literature available in the field. One study which has assessed the efficiency of an occupation-simulation package was carried out by Capadaglio **et al.** (1997). They assessed the reliability of a hand-gripping endurance test using the Lido WorkSET (Loredan, Davis, CA) dynamometer attached to a hand-grip tool. The aim of the study was to assess the reliability of an isokinetic hand grip test and review the ergonomics applications of the test results.

Matheson **et al.** (1991) contend that the advantage of using a Lido dynamometer is that many different tools may be attached to it, thus simulating specific leisure and occupational activities. Similarly, the CYBEX 6000 “work-simulation” package can be used to assess performance capabilities of different groups, for the purpose of the present study, military personnel. However, despite the effectiveness of isokinetics as a testing tool, it has remained largely unused in terms of work simulation tasks.

Strength Measures

Warm-Up

The subjects were required to complete a warm-up programme before commencing with the maximal test exertions. For this, 2 min of light activity were completed on a (Monark™) cycle ergometer at a low resistance (2 kg) and a stretching programme was followed which incorporated both the upper- and lower-extremities.

Figure 8: Warm-up procedure on the Monark™ cycle ergometer.

The warm-up was aimed at minimizing the risk of injury in the study, and served also to encourage an activity mind-set in the subjects. Figure 8 shows the cycling activity, with a verbal explanation being given to the subject as to the reasons for the selected warm-up programme. Standardization of these procedures was ensured by each of the test assistants involved in the warm-up programme.

Familiarization

The subjects completed a number of familiarization trials at each of the speeds tested. Due to the nature of isokinetic testing and the inexperience of subjects, practice bouts were deemed essential for the collection of valid data. In order to ensure consistency in the familiarization bouts, testing assistants followed a set routine for familiarization: three sub-maximal efforts were completed by subjects at each speed. Adequate recovery time was allowed for each subject while the isokinetic dynamometer setup was completed.

Figure 9: Subject undergoing a familiarization trial on the pulling/pushing test.

Procedures

Testing positions for both LTs and OST's were standardized according to the instruction manual provided by CYBEX 6000 (Lumex Inc.). For the LTs the fulcrum of the input arm of the dynamometer was aligned with the mean axis of motion of the joint being tested. For example, in the test of knee flexion/extension, the palpated centre of the knee joint was aligned with the dynamometer's axis of rotation to ensure the valid measurement of isokinetic values. Machine settings relative to subject positioning were recorded on the CYBEX 6000 computer for re-test in the event of data loss or machine complications.

The laboratory tests (knee, ankle, hip, shoulder, elbow and trunk) allowed for standardization of starting position (See Appendix D). In contrast, the occupation-simulating tests (gripping, pulling/pushing, wrench-turning and valve-tightening) record input torques not referable to any specific muscle groups about any specific joint. Consequently, the dynamometer was adjusted according to morphological characteristics of subjects and in order to facilitate wide ranges of motion relative to the task under investigation.

Figure 10 shows the set-up for the gripping test. Subjects were required to complete 3 sets of 4 repetitions at the following speeds: 30, 60 and $90°.s^{-1}$. Only fist clenching values were obtained during this testing.

The range of motion tested was limited to 15° in order to allow for variability in grip sizes of subjects. The grip device was placed in the neutral position for testing. The left CYBEX 6000 seat was used to stabilize the subject standing side-on in front of it. Thus the subject was able to take a wide-spread open-palm grip and from this position close the hand through its full flexor range.

Figure 10: Set-up procedure: gripping test.

The method used in the wrench-turning test is displayed in Figure 11. Subjects were supported by an assistant and constrained to forearm-only motion by means of velcro strapping placed around the body. This ensured that the whole body was not used in exerting a maximal effort. Standardization of this factor was seen as critical in ensuring that none of the subjects gained an inertial or muscular advantage from the trunk and shoulders. The range of motion tested was 130°, 65° to either side of neutral with arms pendant and the forearm horizontal on the dominant (tested) side.

Figure 11: Set-up procedure: wrench-turning.

The method for assessment of pulling/pushing strength is displayed in Figure 12. Each subject was required to place the leading foot over a set starting position demarcated on the floor. A simple chalk foot demarcation area was used for this purpose. Each subject began the test in full pull position and was not permitted to raise the leading foot. The pulling/pushing test required the subject to make maximal exertions over a distance equivalent to an object moving 4m across the floor in either direction. The full range of motion assessed was approximately 130°.

Figure 12: Set-up procedure: pulling/pushing test.

In the valve-tightening test subjects were required to stand in a demarcated area (on a demarcated plinth) to perform the task. Figure 13 shows the subject set-up for this assessment. The subject positioning was standardized with height adjustment. The valve-tightening test was through a range of motion of approximately 140°, 70° to either sides of a neutral standing position with arms pendant and forearms horizontal. Unlike the wrench-turning test, where the movement of the subject was restricted by means of velcro-strapping, the valve-tightening test was not restricted. Subjects were thus able to make use of musculature of the shoulder and back to increase the force exerted in these test bouts. Greater freedom of movement was deemed to be more reflective of actual tasks performed in military settings, thus making data a more reliable reflection of the capabilities of subjects.

Figure 13: Set-up procedure: valve-tightening test.

Figure 14 shows the points of placement of the hands during the test of valve-tightening. In the phase of left rotation the right hand was in a better position to exert maximal force. The predominance of right-handedness in the subjects could well explain the data observed for OSTs; left scores are higher than right scores. Similarly, the test of wrench-turning shows a left- over right-rotation dominance. This is related to the explanation given for the valve-tightening test.

Figure 14: Placement of Hands in OST: Valve-tightening

Strain-Gauge Dynamometry: Back, Leg and Grip Strength

Prior to isokinetic testing on the CYBEX 6000 all subjects completed a number of tensiometric tests of leg, back and grip strength. These tests were carried out in order to assess the general capabilities of infantrymen in simply administered strength tests. These evaluations were deemed to have particular relevance to the SANDF, as *in situ* testing methods are cost effective and easily administered, and could be made available to SANDF trainers. A base of comparison could therefore be established and different samples compared to those from the present study. Subjects completed two trials in respect of each of the back, leg and grip, following the Rogers P.F.I. protocol (See Appendix D). Harpenden dynamometers were used in the assessments with setup procedures shown in Figures 15 and 16.

Figure 15: Testing procedure for handheld dynamometry of gripping

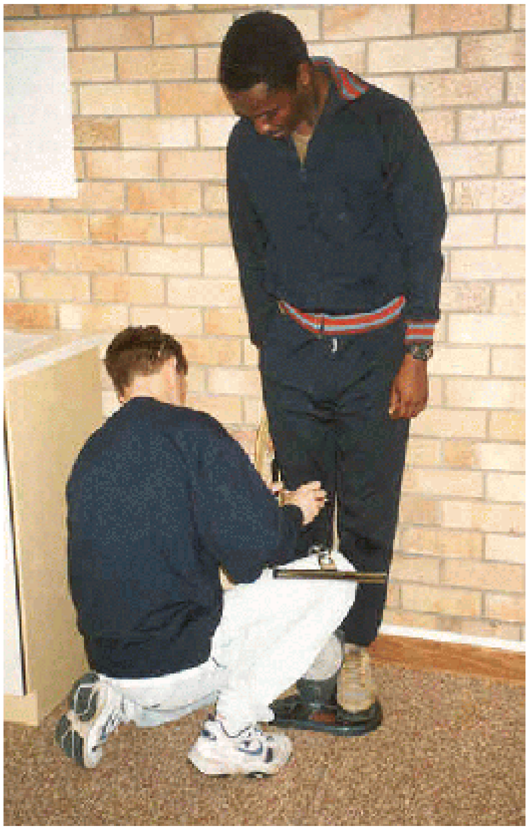

Figure 16: Setup procedure for leg and back strength dynamometry

No subjects had previous experience in isokinetic testing and the machine-type strength assessment thus demanded a period of familiarization. Three trials were conducted at each of the machine speeds for the laboratory- and occupation-simulating tests. Subjects were reminded not to over-exert in the familiarization tests, as this might adversely influence the strength expression levels of the test proper.

Data Collection

Collection of data took place over a period of four weeks. Sessions were scheduled to permit a minimum rest period of one day. Standardized instructions were given to all subjects prior to the commencement of testing. Subjects were given a 5s warning and then asked to perform the maximal repetitions. Following each set of 4 repetitions a rest period of 30s was allowed to ensure that the next speed was completed as efficiently as possible. Speed settings were randomized and rest periods between isokinetic tests were maximized to ensure recovery.

Order of Testing

The following test schedule was used:

Session 1: 1.) Knee flexion/extension
2.) Trunk flexion/extension
3.) Valve-tightening right/left rotation
4.) Wrench-turning right/left rotation
5.) Pulling/Pushing

Session 2: 6.) Gripping (Closed only)
7.) Hip flexion/extension
8.) Elbow flexion/extension
9.) Shoulder internal/external rotation
10.) Ankle plantar/dorsiflexion

The battery comprising Sessions 1 and 2 remained the same, but the order of presentation of tests within each session was randomized. The rest period thus involved the time it took to set-up the dynamometer (with the relevant attachments) and the time taken to test the other subjects. This provided each subject a break of approximately 15 min between each test.

Replication of Maximal Work Output Levels

Inter-repetition consistency of total work output has been shown to be an effective indicator that subjects are not malingering or adversely affecting mean isokinetic responses. In order to ensure that maximal efforts were being recorded a consistency criterion measure was employed. This measure followed the guidelines set up by Charteris and James (2000) who offer a simple, yet effective method for detection of work effort-level consistency. This method is founded on the assumption that it is not so much the tension developed at the strongest point in the range of motion, but the tension developed through the entire range that counts. Thus the criterion for effort-level consistency evaluates total work output, not peak torque generated, and uses the following formula:

(mean work per repetition/best work repetition) x100

For infantrymen, who are involved in regular physical activity, the criterion for maximal effort was set at a level of consistency of 90% for the mean/best work repetition. In the present study achieved consistency levels across the battery of tests ranged from 89.5% to 95.9% over the 4-repetition exertions, leading credence to the author's contention that the efforts made, across the board, were indeed maximal.

Psychophysical Responses

Perceptual Measures

Perception of exertion ratings were taken, using Borg's (1971) RPE scale. An adapted African language (Xhosa) version was explained by a fluent Xhosa speaker and then used when subjects were not fluent in English. Prior to the commencement of each session, care was taken to adequately define the procedures of the rating scale to the subjects involved in the testing. The RPE responses were recorded at the completion of each maximal testing bout (See Appendix C).

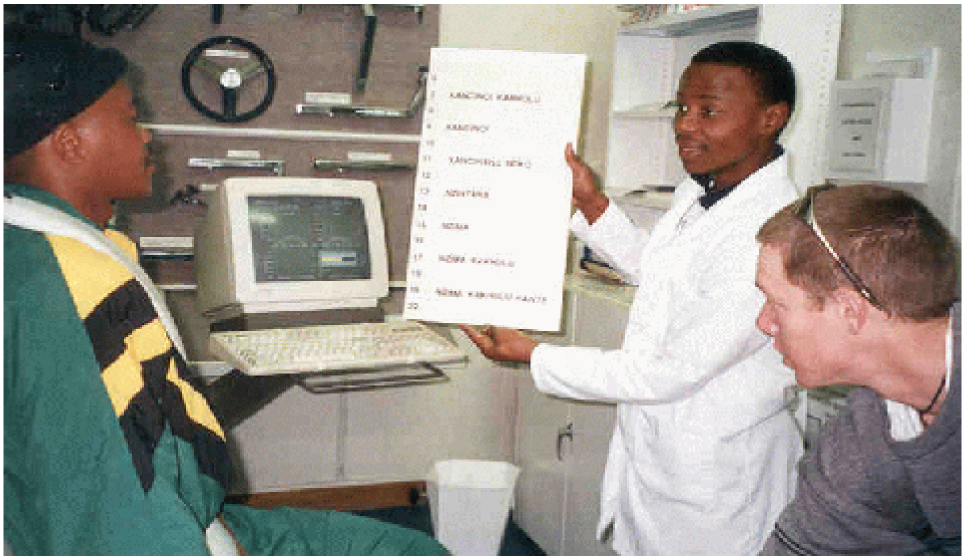

Figure 17: RPE scale used in the present study

Cardiovascular Measures

Heart rate responses were registered during the maximal testing using POLAR™ and UNIQ™ heart rate monitors. Readings were taken at the end of each set of four maximal repetitions. Reference heart rates were also taken at the commencement of Session 1 for each different sub-group of subjects. A period of habituation to the heart watch was required as the subjects involved had no previous experience with the procedures of heart- rate monitoring and anticipatory reference heart rates were thus spuriously high.

Figure 18: Polar™ heart-rate monitor being fitted to a subject prior to testing.

Post-Hoc Issues

Test Feedback

All subjects were given test feedback (See Appendix E). Anonymity of results was guaranteed to each subject. Measures included peak torque, total work and mean power in CYBEX 6000 testing and also graphical presentation of the work-bout. Strength ratios were calculated and the subjects' performance relative to the test group assessed. Suggestions were also offered as to possible strength training ideas for discovered areas of weakness.

Statistical Treatment

Analysis of data was carried out using the STATGRAPHICS (Version 6.0: Manugistics, Inc. and StatsGraphics Corporation, 1992) programme. (See Appendix F for an example of the print-out used in analysis). Data were tested for symmetry, which included the use of normal distribution analysis. The level of significance was set at $p = 0.05$, providing a level of confidence of 95%. Statistical analyses comprised the following:

In respect of H_o1: Two-way ANOVAs, comparing agonists and antagonists and opposite-direction responses through the velocity spectrum (See Appendix G).

In respect of H_o2: Two-way ANOVAs, comparing the $\sum$ F+E (upper-extremity) and the $\sum$ F+E (lower-extremity) through the velocity spectrum.

Relative to hypotheses 1 and 2 post-hoc analyses (Tukey method) were conducted.

In respect of H_o3: Pearson Product-Moment Correlation Analyses determining strength of relationships between:

S LTs and OSTs
S Heart Rates and Ratings of Perceived Exertion (RPE)

Judgements of correlation strength involved coefficients of “determination” and “non-determination”, following Silverstein (1978, 1988).

CHAPTER FOUR

RESULTS AND DISCUSSION

INTRODUCTION

Isokinetic dynamometers facilitate rapid and simply administered assessment of musculo-skeletal capacity. A number of variables need to be considered when evaluating the efficiency of performance of military subjects: level of training, recent injury history, motivation and perception of effort. Subjects of the present study were not participating for any rewards when completing the maximal testing. This factor could have influenced the level of strength expression of certain subjects. The consistency of effort-level, which ranged between 89.5% and 95.9% over the 4-repetition exertions, however, is indicative of maximal effort (Charteris and James, 2000).

Laboratory and occupation-simulating isokinetic assessments involve the measurement of torque, work and power through a range of motion in which the limb is moving at a constant angular velocity. The accuracy and reliability of calibrated equipment makes isokinetic dynamometry a very effective means of strength assessment. This study quantified the performance of subjects in torque, work and power outputs in laboratory tests (LTs) and occupation-simulating tests (OSTs) through a velocity spectrum: 30,120 and $210^{\circ}.s^{-1}$ in all tests but that of grip strength, which involved 30, 60 and $90^{\circ}.s^{-1}$. The following tables and figures summarise the responses of the group (N=42).

1. LABORATORY TEST RESPONSES

Note: The details of the statistical analyses relating to $H_0 1(a)$ can be found on page 178 (Appendix G).

Slow Isokinetic Speed

The laboratory tests assessed a variety of movements, all in the sagittal plane, and the related muscle groups of the upper- and lower-extremity, permitting assessment of absolute responses, relative responses, agonist/antagonist ratios, and upper-to-lower-extremity ratios and facilitating the development of a general strength profile of the South African infantryman.

Table VI: Laboratory Test (LT) responses at Slow Isokinetic Speed ($30^{\circ}.s^{-1}$): comparisons across joints tested. (Means, with SD in brackets). *

Joint	Motion	Peak Torque ($Nm.kg^{-1}$)	Total Work ($J.kg^{-1}$)	Average Power ($W.kg^{-1}$)
Trunk	Extension	3.82 (0.78)	4.77 (0.82)	1.22 (0.26)
	Flexion	3.26 (0.46)	4.63 (0.49)	1.19 (0.16)
Hip	Extension	3.23 (0.78)	3.94 (1.01)	1.11 (0.28)
	Flexion	1.93 (0.36)	2.00 (0.34)	0.56 (0.11)
Knee	Extension	3.34 (0.48)	3.11 (0.49)	0.90 (0.17)
	Flexion	2.09 (0.35)	2.39 (0.43)	0.72 (0.15)
Ankle	Plantarflexion	1.07 (0.20)	0.59 (0.14)	0.31 (0.07)
	Dorsiflexion	0.54 (0.10)	0.33 (0.07)	0.17 (0.04)
Shoulder	Internal Rotation	0.65 (0.11)	1.40 (0.25)	0.27 (0.05)
	External Rotation	0.49 (0.09)	1.02 (0.18)	0.19 (0.04)
Elbow	Extension	0.87 (0.14)	1.34 (0.21)	0.32 (0.05)
	Flexion	0.75 (0.12)	1.20 (0.21)	0.29 (0.05)

* None of these tests involved gravity-correction.

It has already been argued that little is known about general strength capabilities of South African military personnel. It would be true to say that even less is known with regard to how these subjects compare to other populations. Data comparisons have critical relevance to the SANDF and researchers working in training and rehabilitation settings in South Africa. The significance of these data can therefore not be underestimated, as setting up a strength profile specific to South Africans has long been overdue and documenting the responses of infantrymen adds to the field of isokinetics and strength evaluation in general.

The findings of this study allow for interesting comparisons against data from diverse isokinetic studies of the past several decades. A cross-section of isokinetic literature has been categorised by Perrin (1993) to provide a comprehensive source of upper- and lower-extremity isokinetic responses, with more limited focus on the values obtained for the trunk using the TEF module. Research has in the past largely concentrated on peak torque values, with some reciprocal ratio comparisons. This poses problems for the evaluation of total work and average power assessments, which have been shown to be more important by, among others, Perrin (1993) and Charteris (1999 a;b).

(a) Trunk

The slow speed ($30^{\circ}.s^{-1}$) data are summarized in Table VI. At this velocity the trunk produced higher mean outputs for peak torque, total work and average power, during extension. These findings are comparable with the work of Thompson **et al.** (1985) who state that trunk extensors tend to produce more torque than flexors at slower testing velocities. The size of the muscle groups involved in trunk extension (principally the erector spinae) should result in higher mean outputs during this phase of movement. However, given that the head, arms and trunk (HAT) together constitute about 75% of body mass, recorded trunk extensor values are significantly undervalued and trunk flexors (principally the rectus abdominis, external oblique and internal oblique muscles) significantly overvalued in the absence of gravity correction (Charteris, 1999a). Application of a gravity correction factor (which unfortunately is not built into CYBEX software) would thus have significantly increased the values for trunk extension, and resulted in lower flexor responses, whatever the test speeds.

Peak torque is not always the best indicator of working capacity. The following figure is thus important, as it compares the general capabilities of this sample of SANDF infantrymen in torque, work and power terms (relative to body mass) against values available in the literature. A comparison of trunk flexion and extension at slow speeds shows that the infantrymen performed efficiently in trunk isokinetic tests when compared to similar test samples. These responses could well be related to training, as military personnel are required to perform tasks entailing heavy load carriage which would develop both the trunk flexors and extensors. The comparable trunk data (from Charteris, 1999a) were collected on thirty-five male manual workers who had volunteered to participate in a work-hardening programme. All were free of clinical histories of back pain (mean age: 32.9 yr (SD 7.5) and mass 64.8 kg (SD 11.8)). The mean response comparisons are show in Figure 19.

These data suggest that very little difference exists between the mean responses of infantrymen (present study) and South African manual workers (Charteris, 1999a) when considering slow speed torque, work and power responses. The mean responses for the present study were higher for peak torque and total work, but due to movement time, lower for average power outputs. Based on these findings it could be argued that infantrymen compare favourably to manual South African workers with no identifiable weakness in trunk extension or flexion at the slow isokinetic speed.

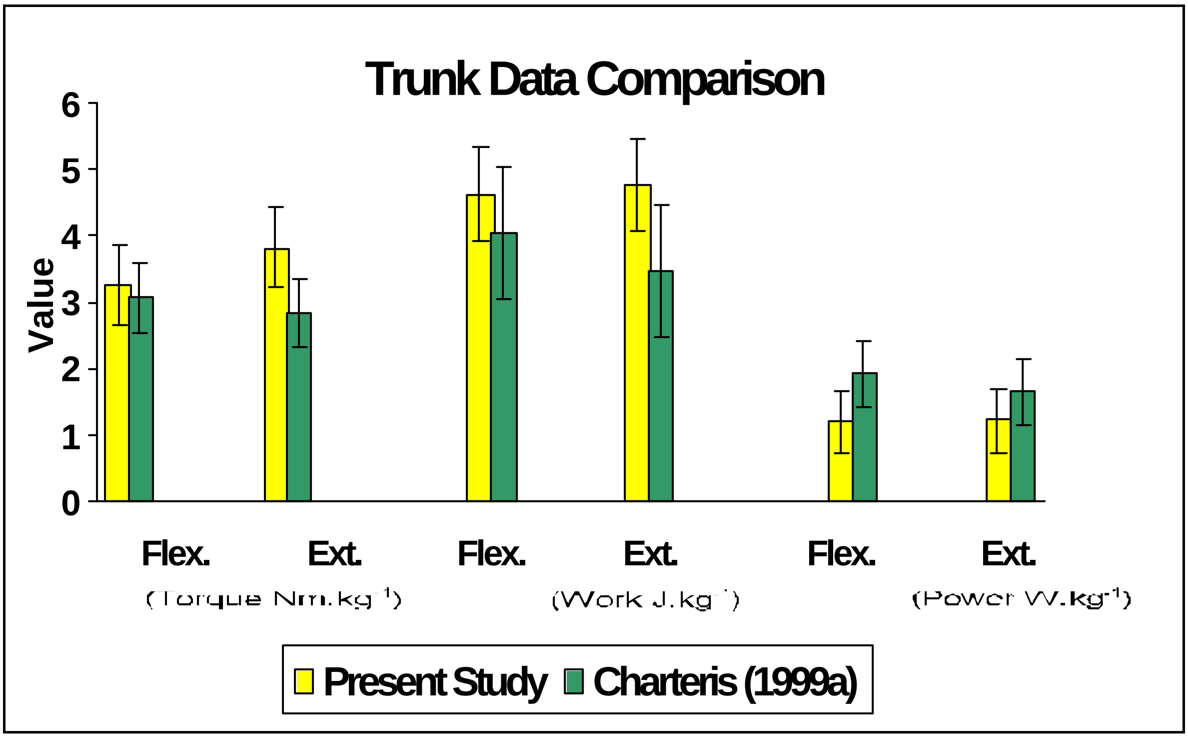

Figure 19: Present study compared to the data from Charteris (1999a) for trunk flexion and extension at slow isokinetic speed. *

* **Note:** although testing speeds were not identical, they were deemed comparable.

(b) Lower-extremity

As stated previously, the major focus of isokinetic research has clearly been on the lower-extremity. The hip test evidenced high overall mean values for torque, work and power outputs. The hip was stronger during extension than flexion, confirming the findings of Poulmedis (1985) and Tippet (1986). The mean work value for the slow speed hip extension (3.94 J.kg^{-1}) was only surpassed by the values recorded for standing trunk flexion and extension, a test which has been shown to include very large muscle groups. Hip extension is produced by gluteus maximus and by biceps femoris, semitendinosus and semimembranosus of the hamstring group. In terms of the size of muscle groups acting at the hip, it is to be expected that the hip should out-perform many of the other LTs. The data in Table VI confirm this. Hip responses at slow isokinetic speeds showed closer similarity in extension than in flexion when compared with the findings of Poulmedis (1985). Mean responses are shown in Table VII. All subjects in Poulmedis' (1985) study were elite Greek soccer players (mean age 27.8 yr (SD 3.4) and mass 75.5kg (SD 5.2)).

Table VII: Comparison of absolute hip isokinetic responses. (Means, with SD in brackets).

Source	Flexion Peak Torque (Nm.kg^{-1})	Extension Peak Torque (Nm.kg^{-1})
Present Study	1.93 (0.36)	3.23 (0.78)
Poulmedis (1985)	2.37 (0.38)	3.56 (0.52)
Congruence [1]	81%	91%

[1] (Present Study Value/Poulmedis' (1985) Value x 100)

Generalizations with regard to hip responses were complicated by the discrepancy between extension and flexion values. Hip extension congruence (91%) suggests that SANDF personnel compare favourably to well trained subjects. The training of infantrymen often involves a great deal of lower-extremity activity and could be a possible reason for the observed results. However, flexion values show a somewhat lower level of congruence which may be related in part to the specificity and level of training of Poulmedis' (1985) sample. Elite soccer players might have greater levels of overall leg strength than would be the case for infantrymen, thereby resulting in higher flexion (and extension) values.

Knee isokinetic dynamometry is probably the most commonly administered test (Perrin, 1993). The design of the dynamometer (see Chapter III) makes assessment of this movement more user-friendly than is the case for many other upper- and lower-extremity tests. Torque, work and power values were, as expected, higher in knee extension than in knee flexion, even without gravity correction. This follows the findings of previous research, for example, Charteris and Goslin, 1982; Appen and Duncan, 1986; Figoni **et al.**, 1988 and Zakas **et al.**, 1995. The relative strength of the quadriceps muscle group in comparison to the hamstrings explains this. Of equal relevance in the present study was assessment of the quadriceps/hamstrings ratio. Strength training specialists have long recognized the importance of training both the muscle groups producing opposite actions about a joint (Perrin, 1993). This is true for all the reciprocal muscle groups tested (see later in this chapter).

Figure 20 provides a comparison between the knee responses presented in Table VI and work carried out by Charteris (1999b) on intercollegiate athletes. All subjects in Charteris' study(mean age: 21 yr (SD 2) and mass 84 kg (SD 13)) were free of clinical histories. This comparison shows that little difference exists between the responses for peak torque, total work and average power outputs of the infantrymen when compared to an athletic male sample with no clinical histories. In these data, extensor peak torque values were 98% congruent and flexor average power responses, 96% congruent with the results of Charteris (1999b).

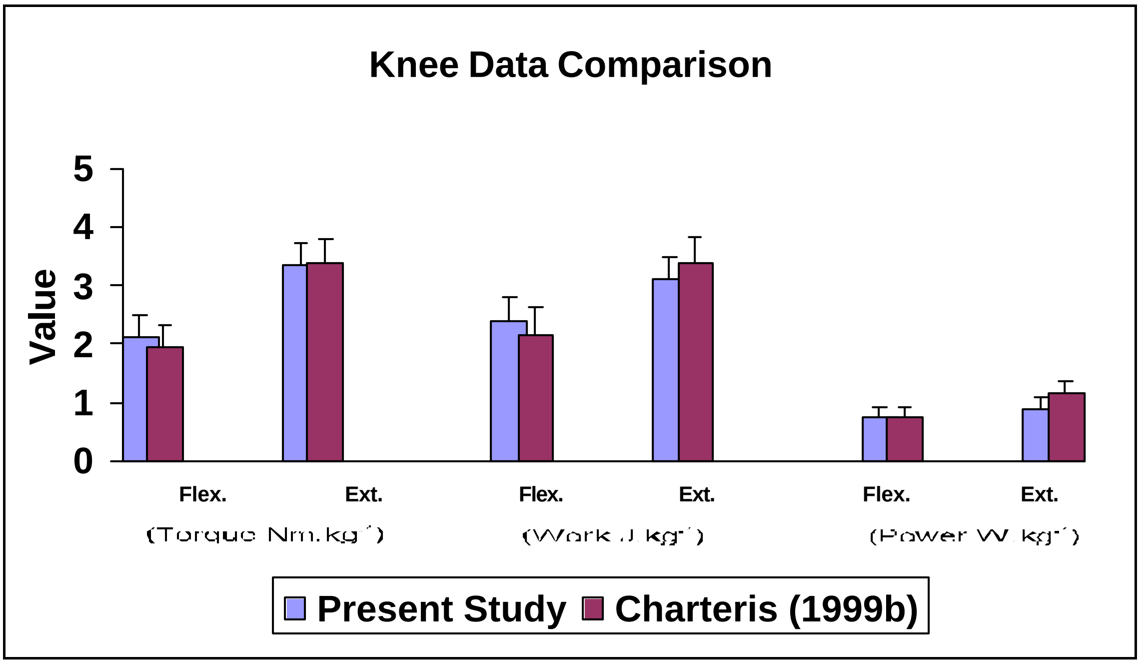

Figure 20: Present study values compared to data from Charteris (1999b) for knee extension and flexion for slow isokinetic speeds.

Ankle plantarflexion and dorsiflexion were tested with the subject lying prone, the knee on the test side fully extended. Subjects expressed less strength in dorsiflexion than in plantarflexion, an expected trend also identified by Öberg **et al.**, (1987). The plantarflexors of the ankle have a combined muscle cross-sectional area approximately four times the size of dorsiflexors and were thus expected to exhibit greater force production.

The dorsiflexion peak torque mean value was 36.72Nm (0.54Nm.kg^{-1}) at the slow speed and was consonant with a large body of isokinetic research focusing on the ankle. In contrast, plantarflexion values were significantly lower than expected in the present study. The plantarflexion peak torque mean was 72.76 Nm (1.07Nm.kg^{-1}) which was significantly lower than values reported in the literature by Fugl-Meyer, 1981; Poulmedis, 1985 and Öberg **et al.**, 1987. A part of this difference can be explained by considering the training status of subjects assessed in these studies. For example, Poulmedis' (1985) sample was drawn from a group of elite athletes who may well have had greater strength in the lower-extremities.

However, a number of other factors could have influenced the plantarflexion response, including: intrinsically weak CYBEX 6000 equipment design and the variation in the size and type of the footwear worn by the infantrymen. The selection of footwear was left by the officers in charge to the infantrymen themselves and involved the choice of either army boots or sports shoes. This selection process was beyond the control of the researchers and it was noticed during testing that the design of the heel of the army boots impaired the ability of the subjects in plantarflexion. This observed limitation was manifested in the isokinetic responses, particularly with respect to plantarflexion where values were significantly lower than expected.

Moreover, the design of the CYBEX 6000 footplate does not accommodate large variations in shoe size and this might have contributed to the hindrance of force production. Although every effort was made to ensure that subjects were in a position to exert maximal force and that they met the requirements for the consistency of effort-level, the plantarflexion data should be viewed with scepticism as they are probably not a true reflection of the capabilities of SANDF personnel.

(c) Upper-Extremity

The upper-extremity has not received as much attention in the isokinetic literature as the lower-extremity. The weakness of the upper-extremity relative to the lower-extremity, especially in terms of peak torque outputs, has been shown by numerous authors, including Charteris and Goslin (1982) and Falkel **et al.** (1987). The shoulder, because of the incidence of injury related to activities involving high rotational speeds, has been the most widely researched upper-extremity joint (Alderink and Kuck, 1986; Appen and Duncan, 1986 and McMaster **et al.** (1992 a; b).

A large body of research has focused on activities involving high rotational speeds at the gleno-humeral joint. The results from Table VI show substantially higher outputs for internal rotation (produced by the subscapularis, teres major, pectoralis major, latissimus dorsi and anterior deltoids), than for external rotation (produced by infraspinatus, teres major and posterior deltoid), a finding confirming the majority of isokinetic shoulder research (Alderink and Kuck, 1986; Hageman **et al.**, 1989; Voight **et al.**, 1996 and Ellenbecker and Mattalin, 1997). Isokinetic response comparisons for the upper-extremity are relevant as they allow for further assessment of the weakness identified anecdotally by officers of the SANDF. It is important to consider the level and type of training of the sample under consideration, as elite baseball pitchers will presumably have greater strength in muscles of the rotator-cuff muscles than would be the case for the infantrymen assessed here. Data from the present study were compared against similar work on non-disabled males carried out by Connelly Maddux **et al.** (1989), whose subjects were of a similar age to the infantrymen (mean age: 34 yr, SD: 10), and were also tested in the 90° abducted position.

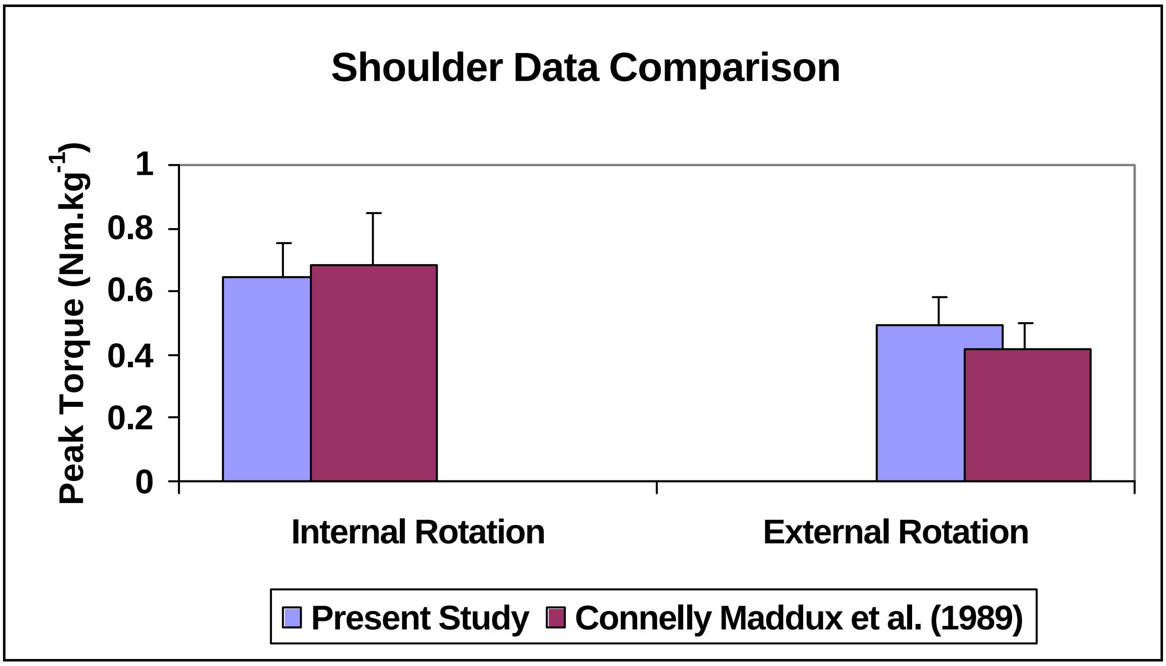

Figure 21: Present study compared to Connelly Maddux **et al.** (1989) for shoulder internal and external rotation at slow isokinetic speed. *

* **Note:** although testing speeds were not identical, they were deemed comparable.

The comparison shows that the military subjects compare favourably to non-disabled males, when shoulder internal and external rotation responses are assessed. Figure 21 shows that at slow testing speeds the internal rotators of the infantrymen are 4% weaker and the external rotators 17% stronger than subjects in the Comparison Study. Although these data do not necessarily show that infantrymen have the required level of strength for upper-extremity tasks like grenade throwing, they do in fact show that there are no significant differences in strength expression between the two groups.

Elbow extension (triceps brachii) values were higher than flexion outputs (biceps brachii, brachialis and brachioradialis). Research has shown that the extensor and flexor muscle groups about the elbow often exhibit similar strength with torque ratios reported around 1.0 (Charteris and Goslin, 1986). Table VIII provides a comparison between the present study and work carried out by Charteris (1999b).

Table VIII: A comparison between the present study and data from Charteris (1999b) for elbow flexion and extension at slow isokinetic speed (30°.s^{-1}). (Means, with SD in brackets).

	Peak Torque (Nm.kg^{-1})		**Total Work (J.kg^{-1})**		**Average Power (W.kg^{-1})**	
Source	**Flexion**	**Extension**	**Flexion**	**Extension**	**Flexion**	**Extension**
Present Study	0.75 (0.12)	0.87 (0.14)	1.20 (0.21)	1.34 (0.21)	0.29 (0.05)	0.32 (0.05)
Charteris (1999b)	0.92 (0.15)	0.92 (0.19)	1.53 (0.25)	1.46 (0.26)	0.37 (0.06)	0.35 (0.06)
Congruence [1]	82%	95%	78%	92%	78%	91%

[1] (Present Study Value/Charteris' (1999b) Value x 100)

Table VIII shows low congruence in flexion values when the elbow is evaluated at slow isokinetic speed. The level of congruence between these studies was high for extension at slow speeds. These data lend credence to the view of SANDF trainers that muscle weaknesses do exist in the upper-extremity, particularly in the flexors of the elbow. This finding may well be related to the training programmes of infantrymen who often complete physical exercise routines which particularly develop the extensors (for example push-ups), but may not cater well for development of the flexors (for example chin-ups).

Medium Isokinetic Speed

Table IX: Laboratory Test (LT) responses at Medium Isokinetic Speed (120°.s^{-1}): comparisons across joints tested. (Means, with SD in brackets).

Joint	Motion	Peak Torque ($Nm.kg^{-1}$)	Total Work ($J.kg^{-1}$)	Average Power ($W.kg^{-1}$)
Trunk	Extension	2.80 (0.57)	3.06 (0.64)	3.11 (0.70)
	Flexion	3.01 (0.62)	3.63 (0.56)	3.72 (0.68)
Hip	Extension	2.63 (0.76)	2.89 (0.92)	3.00 (0.97)
	Flexion	1.70 (0.38)	1.30 (0.29)	1.38 (0.31)
Knee	Extension	2.10 (0.34)	2.20 (0.36)	2.34 (0.56)
	Flexion	1.52 (0.30)	1.74 (0.35)	1.93 (0.39)
Ankle	Plantarflexion	0.52 (0.11)	0.31 (0.09)	0.59 (0.16)
	Dorsiflexion	0.29 (0.07)	0.16 (0.05)	0.31 (0.08)
Shoulder	Internal Rotation	0.55 (0.11)	1.13 (0.24)	0.83 (0.18)
	External Rotation	0.40 (0.07)	0.81 (0.15)	0.59 (0.11)
Elbow	Extension	0.65 (0.11)	0.98 (0.18)	0.88 (0.17)
	Flexion	0.58 (0.09)	0.85 (0.17)	0.78 (0.16)

(a) Trunk

Table IX shows the medium speed (120°.s^{-1}) isokinetic responses of the group. Relative to the slow-speed responses, all torque and work outputs decreased, as expected in terms of the “force-velocity” relationship (Hill, 1938). Power (the rate of doing work) showed an expected increase because the reduction in available time to produce work outstripped the “force-velocity” drop-off rate. The effect, on trunk isokinetic outputs, of a speed increase of 90°.s^{-1} under conditions in which the response data were not gravity-corrected, was to disproportionally disadvantage anti-gravity extension outputs and advantage with-gravity flexion scores. Thus the slow-speed peak torque dominance ratios were shifted in favour of flexion at the medium speed. Data comparisons at the medium speed were made using the work of Charteris (1999a). Table X shows the congruence between trunk values when movement velocity is increased.

Table X: A comparison between the present study and data from Charteris (1999a) for trunk flexion and extension at medium isokinetic speed (120°.s^{-1}). (Means, with SD in brackets). *

	Peak Torque (Nm.kg^{-1})		Total Work (J.kg^{-1})		Average Power (W.kg^{-1})	
	Flexion	**Extension**	**Flexion**	**Extension**	**Flexion**	**Extension**
Present Study	3.01 (0.62)	2.80 (0.57)	3.63 (0.56)	3.06 (0.64)	3.72 (0.68)	3.11 (0.70)
Charteris (1999a)	2.97 (0.56)	2.52 (0.90)	3.61 (0.80)	2.73 (1.03)	3.59 (0.91)	2.67 (1.08)
Congruence [1]	101%	111%	101%	112%	104%	116%

* None of these tests involved gravity-correction

[1] (Present Study Value/Charteris’ (1999a) Value x 100)

This comparison shows a generally high level of congruence between the studies. The infantrymen compare favourably to South African manual workers, with trunk extension strength values actually being between 11% and 16% higher than the values from the comparative study. Specific military training in heavy load carriage during forced marches is the probable reason.

(b) Lower-Extremity

Hip values remained higher during extension than flexion at the medium speed. As was the case with the other lower-extremity LTs, the drop-off in extensor strength was more dramatic than in flexor strength. The decrement in flexor peak torque outputs from the slow to the medium speed was 12% while extensor values decreased by 19%.

Velocity-related decrements are well documented for knee flexion and extension (Poulmedis, 1985; Appen and Duncan, 1986; Cress **et al.**, 1992; Perrin, 1993). The knee extensor and flexor total work values dropped-off from 3.11 $J.kg^{-1}$ (extensor) and 2.39 $J.kg^{-1}$ (flexor) at the slow speed to 2.20 $J.kg^{-1}$ and 1.74 $J.kg^{-1}$ respectively at the medium speed. These shifts were expected as the increase in velocity resulted in lower peak torque values. The hamstrings tapered-off at a much slower rate (27.3% decrease) than the quadriceps (37.1% decrease) when peak torque values are considered.

Responses for the ankle at medium isokinetic speeds were again significantly lower for plantarflexion than those found in the literature. As stated previously, the footwear chosen by infantrymen was a significant factor in the expression of maximal force and in many cases hindered force production. The dorsiflexors of the ankle showed a slower drop-off in torque output at the medium speed. Plantarflexor mean values at the medium speed were 48% of the value recorded for the slow speed, whereas dorsiflexors were 54% as strong. Work values were marginally different, as the plantarflexor drop-off was less than that of the dorsiflexor group. The footplate used in the assessment of the ankle has already been identified as a probable reason for discrepancies in work and power outputs, as effort through the entire range of motion (approximately 110°) did appear to be less effectively completed by subjects at the higher testing velocity.

(c) Upper-Extremity

Shoulder values continued to show the internal rotators stronger than the external rotators at $120^{\circ}.s^{-1}$. The medium speed actually displayed a slight increase in the dominance of the internal rotators. The internal/external rotation ratio changed from 1.33 to 1.40 at the medium speed (when peak torque values were considered).

The medium speed shoulder internal rotator peak torque mean was 85% of the slow speed value and the external rotator peak torque was 82% of the slow speed value. The elbow showed a similar trend to the shoulder and follows the findings of Berg **et al.**, (1985) who found that speed related decrements in the upper-extremity were not as pronounced as was the case for the lower-extremity. Peak values for the elbow extensors were 75% of the slow speed responses. Extensor and flexor decrement rates were fairly comparable.

Fast Isokinetic Speed

Table XI: Laboratory Test (LT) responses at Fast Isokinetic Speed (210°.s^{-1}): comparisons across joints tested. (Means, with SD in brackets).

Joint	Motion	Peak Torque (Nm.kg^{-1})	Total Work (J.kg^{-1})	Average Power (W.kg^{-1})
Trunk	Extension	1.67 (0.70)	1.42 (0.71)	2.35 (1.23)
	Flexion	2.25 (0.70)	2.13 (0.76)	3.43 (1.40)
Hip	Extension	2.40 (0.76)	2.11 (0.84)	3.80 (1.56)
	Flexion	1.45 (0.41)	0.84 (0.27)	1.44 (0.44)
Knee	Extension	1.61 (0.34)	1.62 (0.32)	2.79 (0.86)
	Flexion	1.28 (0.30)	1.34 (0.35)	2.39 (0.76)
Ankle	Plantarflexion	0.33 (0.09)	0.16 (0.06)	0.47 (0.18)
	Dorsiflexion	0.20 (0.06)	0.08 (0.03)	0.28 (0.11)
Shoulder	Internal Rotation	0.48 (0.10)	0.93 (0.20)	1.17 (0.27)
	External Rotation	0.36 (0.07)	0.70 (0.15)	0.90 (0.19)
Elbow	Extension	0.63 (0.11)	0.75 (0.17)	1.15 (0.29)
	Flexion	0.56 (0.11)	0.64 (0.15)	1.01 (0.26)

(a) Trunk

Fast-speed (210°.s^{-1}) responses are summarized in Table XI. Trunk values showed a similar pattern to the medium speed outputs in that flexors remained significantly stronger than extensors. The effects of gravity on the movement response were significant, as in the extension phase the subjects were required to work against gravity whereas during flexion they were aided by gravity. At a higher testing velocity there is less time for the subject to overcome the effects of gravity and the result is significantly lower torque, work and power outputs in extension; this despite the fact that the muscle groups involved in extension were shown at the slow speed to possess the potential for greater outputs. It is thus obvious that understanding of maximal torque and work output requires appreciation of these maxima across the velocity spectrum.

(b) Lower-Extremity

Hip extension values for torque, work and power were the highest of all the LTs examined at the fast isokinetic speed, exceeding even those of the trunk. Extensors of the hip appeared to be least significantly affected by increased testing velocity from the slow to the fast speed. The peak torque value for hip extension was 74% of the value at the slow speed, while for trunk extension the peak torque value was only 44% as high. More efficient performance at higher testing velocities may well be related in part to the training effects of certain activities on the hip musculature. Many hip movements take place at higher velocities in daily living activities and require great force production. The CYBEX 6000 testing procedures have also been shown to better isolate the extensor group in the supine position.

The knee extensor group (quadriceps) showed a large drop-off in peak torque and also in total work responses with an increase in velocity. Peak torque was 52% of the slow speed value while total work was down to 48% of that elicited at the slow speed. These findings are explained by the force-velocity relationship (Hill, 1938). The practical application is that with a velocity increase for concentric contraction, fewer cross bridges are formed and thus less force is produced (Perrin, 1993). Figure 22 shows total work responses for hip and knee LTs over the velocity spectrum. Peak torque values decreased as testing velocity increased.

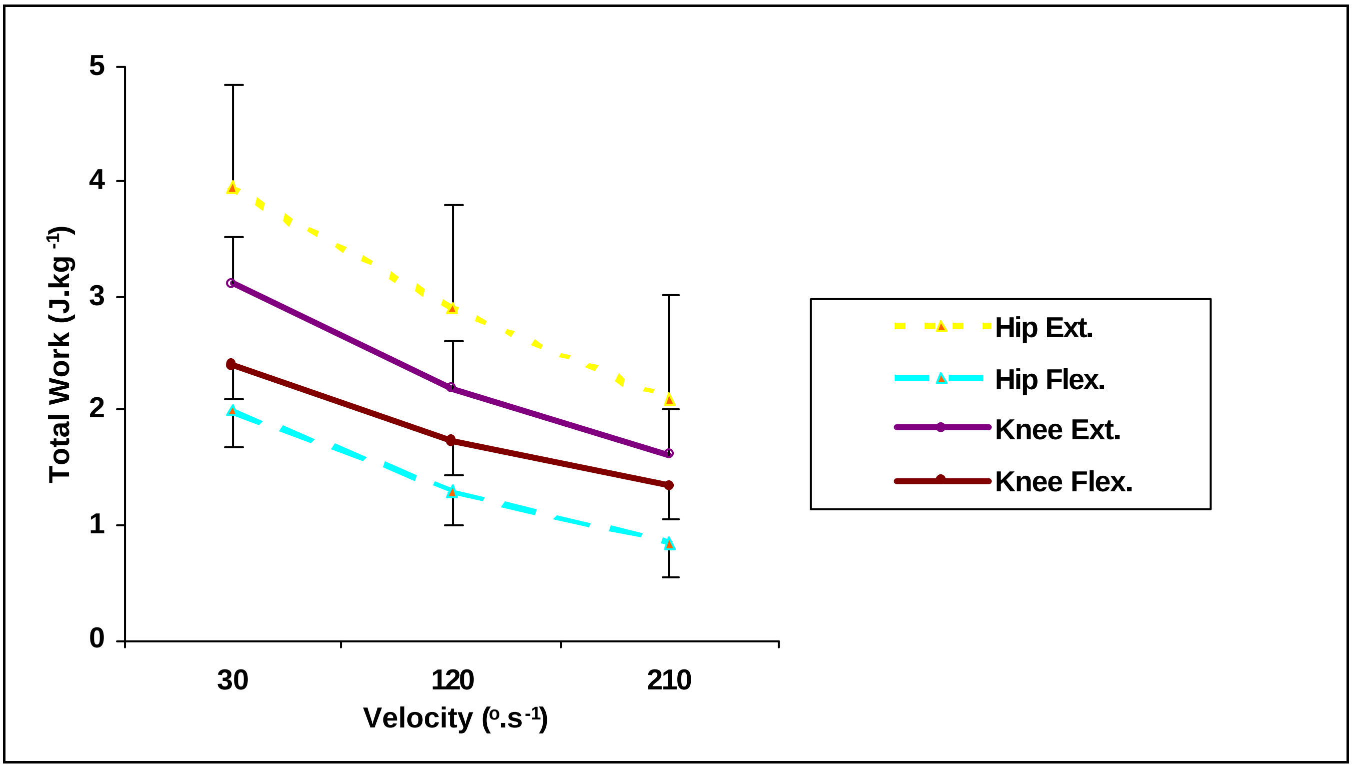

Figure 22: Comparison of hip and knee total work responses over the velocity spectrum.

The hip and knee muscle groups were both significantly affected by the force-velocity relationship with knee extensors and hip flexors (48% and 58% respectively) showing the highest total work decrements. These findings follow previous research in which decrements in knee extensors have been shown to be significant (Cress **et al.**, 1992; Charteris, 1999b). Knee flexion showed the most gradual "drop-off" in work output over the velocity spectrum.

The fast isokinetic speed displays a different trend to the slow and medium speeds when the ankle is considered. Responses were significantly lower for both plantar- and dorsiflexion when compared to those found in the literature. The dorsiflexorion values for peak torque, which were congruent with the findings of a large section of isokinetic research at the slow and medium speeds, were shown to be significantly different at the fast isokinetic speeds. These findings are explained by considering the type of footwear worn by the infantrymen. Many of the subjects were inhibited from exerting maximal force during ankle plantarflexion/dorsiflexion, the result being that these data should be viewed with circumspection.

Angular excursion was an important consideration when assessing work values for LTs. In order to ensure that all subjects were completing testing through comparable ranges of motion, randomized data were selected and compared at the slow and fast isokinetic speeds using the STATGRAPHICS programme. Related t-tests showed no significant differences between ranges of motion completed by the infantrymen, thus permitting relevant work comparisons across the velocity spectrum. For example, the hip sagittal plane range of motion showed a mean value of 106.3° at the slow speed and 105.8° at the fast speed.

(c) Upper-Extremity

Movements involving the shoulder are often performed at high rotational speeds. For example, Dillman **et al.** (1993) show that rotational speeds of the shoulder can peak at between 6100 and 9000$^{\circ}.s^{-1}$ in actions like baseball pitching or throwing. Shoulder values did not decrease as significantly as the lower-extremity and trunk LTs at the fast isokinetic speed. Many military tasks require high rotational speeds at the shoulder joint in, for example, grenade throwing. It could be argued that there are some training effects on shoulder isokinetic responses as a result of the training programmes used by the SANDF. However, the practice of grenade throwing may not be carried out regularly enough to elicit significant effects on the responses of infantrymen when considering the entire upper-extremity.

Speed-related decrements in isokinetic strength responses can be shown to have a greater effect on the lower- than the upper-extremity values. In the lower-extremity LTs (hip, knee and ankle) the mean decrements for total work were 57% across the velocity spectrum. The upper-extremity LTs (shoulder and elbow), showed a mean decrement rate of 39%. These data follow the findings of Berg **et al.**, (1982) who state that incremental velocity has a less pronounced effect on upper- than lower-extremity values.

Reciprocal Ratios: Laboratory Tests

“Reciprocal” ratios form the basis of comparison between agonist and antagonist muscle groups. Perrin (1993) has highlighted the importance of training both dominant and non-dominant muscle groups which produce actions about a joint. These are variously known as agonist-antagonist ratios, reciprocal ratios or dominance ratios. These terms are used interchangeably in this thesis. By assessing ratios such as the quadriceps-to-hamstrings (Q/H) and biceps-to-triceps (B/T) ratio for torque, work and power it becomes possible to make generalizations about normal relationships and to advise subjects on possible training programmes to achieve, or restore, normal relationships. Table XII shows the reciprocal ratios in respect of the laboratory tests whose raw data were the subject of Tables VI, IX and XI.

Table XII: Reciprocal Ratios for Laboratory Tests (LTs)

LT Ratios	Speed								
	$30^{\circ}.s^{-1}$			$120^{\circ}.s^{-1}$			$210^{\circ}.s^{-1}$		
	Torque	Work	Power	Torque	Work	Power	Torque	Work	Power
Trunk: Ext/Flex *	1.18	1.03	1.04	0.94	0.84	0.84	0.76	0.69	0.73
Hip: Ext/Flex	1.70	1.99	2.04	1.56	2.24	2.20	1.69	2.53	2.68
Knee: Ext/Flex	1.62	1.32	1.30	1.41	1.29	1.25	1.28	1.26	1.17
Ankle: Plantar/Dorsi	2.03	1.85	1.85	1.83	1.91	1.93	1.63	2.08	1.71
Shoulder: Int/Ext	1.33	1.39	1.42	1.40	1.39	1.41	1.37	1.34	1.31
Elbow: Ext/Flex	1.18	1.14	1.16	1.13	1.18	1.16	1.13	1.20	1.18

*** Note:** these ratios, in respect of the trunk, are substantially influenced by the absence of gravity-correction and must be reviewed in that context.

(a) Trunk

Thorstensson and Nilsson (1982) have argued that the effects of increments in velocity and changes in the length-tension relationship on trunk isokinetic responses are similar to those of the extremities. Peak torque responses for trunk flexion and extension therefore showed expected decrements with increased testing velocity. Charteris (1999a) found that both flexors and extensors show overall torque (and hence work output) decrements with increases in speed, but pointed out that unless these decrease at the same rate, the reciprocal ratios will either increase or decrease, depending upon their relative rates of decrement as speeds increase. In the present study, trunk extension/flexion ratios exhibit this trend: higher decrements are evidenced in the trunk extensors than the flexors. Extensors “drop off” by 36% from the slow to the medium speed, while the flexors show a 22% decrement. The medium to the fast speed shows a similar trend, as extensors decrease by 46% and flexors by 40%. The change in the reciprocal ratio can thus be attributed to greater decrements in extensor than in the flexors responses. These data are explained by considering the trunk LT where the subject is required to work not only against gravity, but also against the mass of head, arms and trunk (HAT) while attempting to produce maximal force. The result is that the flexors of the trunk are aided by the effects of gravity and the mass of HAT (which can account for approximately 75% of body mass) to such an extent as to alter the order of dominance for this particular laboratory test.

Davies and Gould (1982) assessed isokinetic trunk responses of male athletes (mean age: 21yr) in the standing position. The trunk extensor-to-flexor reciprocal ratio for peak torque at the slow speed in their study was 1.25. The ratio in the present study was 94% congruent with this value. At the medium isokinetic speed of testing the reciprocal ratio established by Davies and Gould (1982) was 0.91 for extension to flexion peak torque. Data collected on infantrymen in the present study show a high level of congruence with the comparative study, with a 97% level of congruence at the medium speed of testing. Total work and average power reciprocal ratios showed a high level of congruence with the findings of Charteris' (1999a) study on male manual workers. Total work responses at the medium speed were within 5%, while the average power reciprocal ratios were 89% congruent for these sets of data. The infantrymen would therefore appear to compare favourably with similar subjects from different samples involved in similar types of manual activity and training.

(b) Lower-Extremity

Increases in test velocity appear to reduce torque values in the quadriceps to a greater degree than the hamstrings group (Perrin, 1993). Although gravity correction was not used in the present study it is still possible to make assessments of reciprocal ratios based on the findings of this research. In knee extension/flexion, the Q/H ratio is similar to the values proposed in previous research. The ratios were as follows: 1.60 for peak torque, 1.30 for total work and 1.25 for average power. Perrin (1993) suggests that the hamstrings group produces between 60% and 75% of the outputs of the quadriceps for torque. The slow speed responses of infantrymen assessed here was 63%, very similar to the findings of other researchers. At the medium and fast speeds the outputs for hamstrings were 70 and 78% respectively, findings similar to those in the gravity-uncorrected literature on knee assessment.

Ankle plantar/dorsiflexion ratios were; 2.03 (torque), 1.85 (work) and 1.85 (power) at the slow speed. The ratios show significant changes with increased test velocity and the fast speed values were; 1.63 (torque), 2.08 (work) and 1.71 (power). The change in the torque ratio are attributed to the "drop-off" in the plantarflexors at a more rapid rate than the dorsiflexors. Research has shown that when considering the hip extensor/flexor dominance ratios, the flexors should produce between 60% and 70% of the outputs generated by the extensors. Subjects were more consistent in work outputs for extension and appeared to be more comfortable performing the hip extension phase of the test. The supine testing position for hip extension/flexion may be one reason for significantly lower outputs during the flexion phase. The design of the UBXT makes it more difficult to exert a maximal force during flexion and control the movement of the lower-extremity.

When considering knee reciprocal ratios it is essential to assess peak torque, total work and average power to ensure that the capabilities of the subjects are adequately evaluated. The table below shows a comparison of knee extensor/flexor ratios derived from the present study against knee data presented by Charteris (1999b).

Table XIII: Comparison of knee extensor/flexor ratios: present study compared to Charteris (1999b) at slow isokinetic speed.

Measure	*Present Study Knee E to F 30°.s^{-1}*	*Comparative Study Knee E to F 30°.s^{-1}*	*Congruence [1]*
Peak Torque (Nm.kg^{-1})	1.62	1.75	93%
Total Work (J.kg^{-1})	1.32	1.54	86%
Average Power (W.kg^{-1})	1.30	1.52	86%

[1] (Present Study Value/Charteris' (1999a) Value x 100)

These data showed that the infantrymen compared favourably to the subjects from the comparative study, when tests involved in extension and flexion of the knee joint were considered. Relative weakness of the quadriceps muscles is deemed to be undesirable, as this could result in rapid performance decrements during activities like long route marches, with an increased likelihood of injury. The congruence of the present data with that reported by Charteris (1999a) in respect of torque, work and power was over 86% in all slow speed cases and the reciprocal ratios in the present study were congruent with the findings of Perrin (1993) that the hamstrings produce about 60% of the torque generated by the quadriceps muscles at slow isokinetic velocities.

(c) Upper-Extremity

The ratios which displayed the least agonist-antagonist disparity were those evidenced in the upper-extremity LTs. Elbow extensor/flexor dominance ratios at the slow speed were

1.18 (torque), 1.14 (work) and 1.16 (power). In work carried out on male intercollegiate athletes by Charteris (1999b) elbow extensor/flexor dominance ratios were 0.99 (torque), 0.94 (work) and 0.93 (power). In the present study the higher values for the extensor group (principally triceps brachii and anconeus) than the flexor group (principally biceps brachii and brachioradialis) are an anomaly as researchers tend to propose a ratio closer to 1.0 (Charteris and Goslin, 1986). As stated previously, this may be explained in terms of the weakness identified in the upper-extremity by SANDF. However, not all the literature agrees. Hortobagyi and Katch (1990) for example, provide peak torque data which are highly congruent with present findings.

Shoulder ER/IR reciprocal ratios were 1.33 (torque), 1.39 (work) and 1.42 (power) at the slow isokinetic speed. Work carried out by Ivey **et al.**, 1985; Alderink and Kuck, 1986; Connelly Maddux **et al.**, 1989 and Pawlowski and Perrin, 1989 shows external rotators producing 65% of the internal rotator torque over a wide range of testing velocities. In the present study the external rotators produced 75% of the internal rotator peak torque. Weaknesses in the internal rotator muscles probably account for the disparity in reciprocal ratios for work shown in Table XIV, where the congruence between the ratio for the present study and work carried out by Connelly Maddux **et al.** (1989) was 81% at the slow speed and 82% at the fast speed.

Table XIV: Comparison of reciprocal ratios for total work responses for shoulder internal/external rotation at slow and fast speeds against Connelly Maddux **et al.**, (1989). *

Isokinetic Speed	Present Study Reciprocal Ratio: Work	Comparative Study Reciprocal Ratio: Work	Congruence[1]
Slow	1.39	1.72	81%
Fast	1.34	1.63	82%

[1] (Present Study Value/Connelly Maddux **et al.**, (1989) Value x 100)
* Although testing speeds were not identical, they were deemed comparable

These data allow for a useful comparison between subjects of a similar age (see page 79) and may suggest the need to place greater emphasis on shoulder strengthening in the SANDF, as upper-extremity training is often neglected. The following figures show the dominance ratios for total work for the slow, medium and fast speed LTs. These figures facilitate the identification of general trends of dominance and also allow for closer scrutiny of the LT responses of SANDF personnel. The order of dominance ratios for total work displays a similar trend through the velocity spectrum. The hip extension/flexion ratio shows the highest dominance for work at all three testing velocities (Figures 23 to 25).

In respect of Figures 23 to 25 the following relationships are shown: hip (extension/flexion), ankle (plantarflexion/dorsiflexion), shoulder (internal/external), knee (extension/flexion) at all speeds. Trunk ratios are extension/flexion at the slow speed and flexion/extension at the medium and fast speeds.

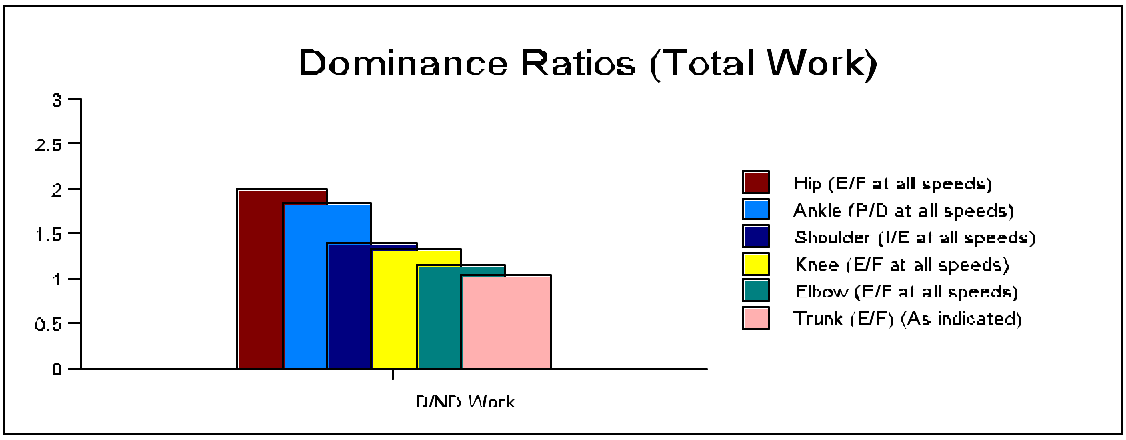

Figure 23: Slow Speed (30°.s^{-1}) Isokinetic dominance ratios (stronger/weaker), for work

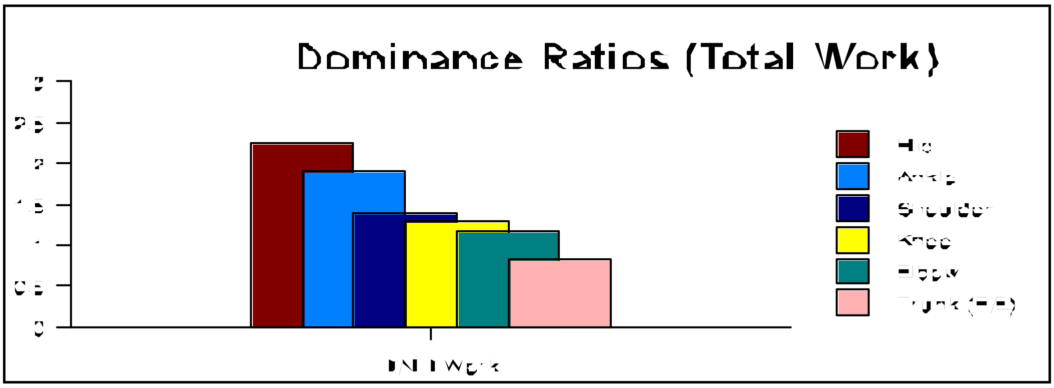

Figure 24: Medium Speed (120°.s^{-1}) Isokinetic dominance ratios (stronger/weaker), for work

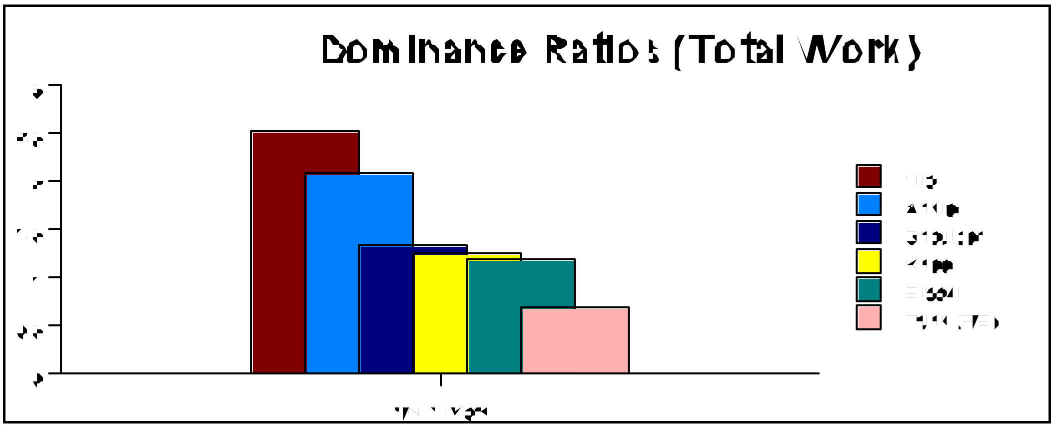

Figure 25: Fast Speed (210°.s^{-1}) Isokinetic dominance ratios (stronger/weaker), for work

Plantarflexion is normally significantly greater than dorsiflexion. This is due to the muscle size difference between these reciprocal groups. The dominance of plantarflexion over dorsiflexion is marked in the prone position with the knee extended (Perrin, 1993). In trunk testing the ratio for total work at the medium speed actually saw a change in the dominant group: flexors dominated the extensor group. In contrast, the hip extensors were markedly stronger; the ratio exceeding 2:1 as velocity increased.

The faster “drop-off” of in the quadriceps as a result of increased test velocity explains the lower knee extensor/flexor ratios for work (Figures 24 and 25). Quadriceps are also required to work against gravity during the extension of the knee; a factor which has been shown to impact upon isokinetic responses. The elbow mirrored the trend observed by Berg **et al.** (1985) that flexors and extensors of the upper-extremity decrease at the same rate. For this reason, the elbow reciprocal ratio remains fairly constant for work at all speeds. Trunk extension can be shown to “drop-off” at a very rapid rate, as the flexors produce higher relative outputs at the medium and fast speeds, with dominance also changing.

This project aimed to obtain benchmark isokinetic data on a hitherto unstudied population, that of the demographically reorganised SANDF. From isokinetic studies around the world dating from the late 60's, but biased largely towards the USA, it is known that reciprocal ratios for peak torque may range from below 0.5 to above 3.0 depending upon the movement, speed and joint tested. Very little research has been done on reciprocal ratios for work output through extensive ranges of motion. Accordingly, the test hypothesis in respect of reciprocal ratios would reveal the direction and extent of these ratios in the LTs tested. The statistical test in respect of H_o1(a) aimed to assess whether reciprocal muscle groups produced equal isokinetic responses through the velocity spectrum. Analysis by means of two-way ANOVA (direction over speed) for agonist/antagonist responses showed significant differences between agonist and antagonist responses in all tests with the exception of slow speed trunk values (peak torque) for flexion and extension. This isolated anomaly is not regarded as kinesiologically meaningful. The case has been made (see page 22, Chapter II) that total work output through full ranges of motion constitute a far better measure of strength expression than does peak torque registered at a single point. Moreover the trunk flexion data are inflated and extension data attenuated by the considerable torque due to the mass of HAT (see page 70). This factor is exacerbated at higher speeds because it is easier to "throw" oneself into trunk flexion at speed than to extend the trunk maximally at unaccustomed high speed. As expected, speed exerted a significant impact on isokinetic responses with all tests showing statistically significant performance decrements between the slow and medium, and between medium and fast testing speeds. The step-wise increments in testing speeds used thus had the desired effect of maximizing the difference between each of the conditions during the LTs.

Upper-to Lower-Extremity Ratios

Increments in testing velocity have been shown to influence isokinetic responses and in turn, reciprocal ratios. How these increments affect upper- to lower-extremity ratios has not been widely researched. However, Charteris' (1999b) study on intercollegiate athletes found that because lower-extremity peak torques decreased at a faster rate than those of the upper-extremity there were significant speed related increases in flexor, extensor, and combined flexor plus extensor upper- to lower-extremity peak torque ratios. Data from the present study exhibit a similar trend, as shown in Table XV.

Table XV: Upper- to lower-extremity torque, work and power ratios across the velocity spectrum. (Means, with SD in brackets).

	U/L: (Flexors)			U/L: (Extensors)			U/L: Combined (Elbow F+E/ Knee F+E)		
Measure	Slow	Medium	Fast	Slow	Medium	Fast	Slow	Medium	Fast
Peak Torque (Nm.kg^{-1})	0.37 (0.08)	0.38 (0.09)	0.46 (0.13)	0.26 (0.06)	0.31 (0.07)	0.48 (0.13)	0.30 (0.06)	0.34 (0.07)	0.47 (0.11)
Total Work (J.kg^{-1})	0.53 (0.14)	0.49 (0.16)	0.51 (0.20)	0.44 (0.09)	0.44 (0.10)	0.73 (0.20)	0.47 (0.09)	0.46 (0.12)	0.62 (0.16)
Average Power (W.kg^{-1})	0.41 (0.11)	0.40 (0.17)	0.47 (0.21)	0.37 (0.08)	0.38 (0.11)	0.47 (0.32)	0.38 (0.08)	0.39 (0.09)	0.45 (0.18)

In respect of H_o2, two-way analysis of variance showed combined flexor plus extensor responses of the lower-extremity to be significantly greater than those of the upper-extremity (F-ratio:1017.56, $p \leq 0.0000$) and this holds across the velocity spectrum. This was confirmed for flexion (upper- vs lower-extremity) and extension (upper- vs lower-extremity) separately. This is to be expected, as upper-extremity musculo-skeletal links are weaker than those of the lower-extremity. As isokinetic speed was increased over the velocity spectrum, the combined U/L ratios showed lower-extremity responses to be "dropping-off" more rapidly than was the case for upper-extremity responses. In contrast to the study of Charteris (1999b), where this was only the case for torque, the present study showed a similar trend for work and power outputs. This may in part be attributed to the greater increments in testing speed in the present study, than were used in Charteris' (1999b) study. However, although not identical, upper- to lower-extremity responses for these data allowed for comparisons to be made. These comparisons provide some explanation as to where the reported SANDF upper-extremity weaknesses may be evidenced in military personnel. The U/L ratios for total work responses ($J.kg^{-1}$) for extension showed the same values as Charteris' (1999b) study (0.44 $J.kg^{-1}$). In contrast, the U/L ratios for flexors show lower levels of congruence for total work (74%). This is in all likelihood as a result of lower levels of elbow flexor strength in this particular sample of SANDF personnel. As stated previously, this may in large part be attributed to selection of training programmes, where greater emphasis is placed on exercises which will entrain the extensors of the elbow than the flexors.

2. OCCUPATION-SIMULATING TEST RESPONSES

Note: The details of the statistical analyses relating to $H_o1(b)$ can be found on page 179 (Appendix G).

Work-simulation software increases the functionality of the CYBEX 6000 Testing and Rehabilitation System by mirroring real-life occupational working conditions (CYBEX 6000 User's Guide, 1993). Despite this functionality, work-simulation packages have not yet been widely exploited by researchers. A great number of testing protocols may be followed when using the package, with accommodation for great diversity in subject set-up and test movements reflecting occupational demands more naturally. The present data therefore have relevance to the field of isokinetics, as they establish benchmark values for diverse OSTs. The tests used here included pulling/pushing, valve-tightening, wrench-turning and gripping. As in the laboratory tests, three testing speeds (slow, medium and fast) were used to assess efficiency of subjects in OSTs over a velocity spectrum.

Slow Isokinetic Speed

Table XVI: Occupation-Simulating Test (OST) responses at Slow Isokinetic Speed (30°.s^{-1}): comparisons across joints tested. (Means, with SD in brackets).*

Joint	Motion	Peak Torque ($Nm.kg^{-1}$)	Total Work ($J.kg^{-1}$)	Average Power ($W.kg^{-1}$)
Pulling/ Pushing	Pulling	4.82 (0.83)	5.73 (0.93)	1.76 (0.58)
	Pushing	3.50 (0.51)	4.36 (0.68)	1.28 (0.32)
Valve- Tightening	Left Rotation	1.15 (0.19)	1.94 (0.28)	0.44 (0.07)
	Right Rotation	1.09 (0.18)	1.84 (0.28)	0.45 (0.17)
Wrench- Turning	Left Rotation	0.26 (0.05)	0.42 (0.08)	0.09 (0.02)
	Right Rotation	0.24 (0.05)	0.37 (0.08)	0.08 (0.02)
Gripping	Squeezing	0.91 (0.20)	0.14 (0.07)	0.20 (0.07)

* None of these tests involved gravity-correction

Slow speed (30°.s^{-1}) OST data are shown in Table XVI. Due to the nature of the pulling/pushing test, the body mass-relative values recorded for torque, work and power are significantly higher than those of any of the other OSTs. The pulling action allows for the use of a number of different muscle groups of the upper- and lower-extremity, as well as the large muscle groups of the trunk. The infantrymen were able to choose their own techniques in the pulling/pushing test, with only the placement of the leading foot being controlled. In contrast to the LTs, in which the centre of the joint is aligned with the fulcrum of the input lever arm, OSTs are completed in the absence of such alignment.

In the valve-tightening test subjects were free to complete the action in a personally selected manner. This test enabled subjects to recruit muscle groups of the forearm, upper-arm and the shoulder regions as they saw fit to complete the movement. Given the size of the relevant adapter, subjects generally found the valve easier to manipulate than the wrench.

The wrench-turning test relied on much smaller upper-extremity muscle groups to turn the adapter through a much smaller range of motion. Relative values for torque, work and power, were therefore lower for this test than for the valve-tightening test. Moreover, subjects were also restricted via the use of velcro strapping to ensure that any forearm and upper-arm muscle groups (but not those of the torso) were responsible for force production. The adapter used for the wrench-turning test was small and was considered uncomfortable by many of the subjects. This factor may well have influenced the test responses of the infantrymen, but more accurately reflects responses under “real-world” conditions.

The gripping OST involved assessment only through a very limited range of motion of fist-clenching. Total work responses are therefore low for this OST. Peak torque values are reflective of the strength expression of the muscles of the hand and the forearm which are significantly influenced by the type of training which the infantrymen complete. Everyday training and combat exercises involve extensive use of the hands and forearms, thus assisting force production in a test of grip strength.

Medium Isokinetic Speed

Table XVII: Occupation-Simulating Test (OST) responses at Medium (120°.s^{-1}) Isokinetic Speed: comparisons across joints tested. (Means, with SD in brackets).

Joint	Motion	Peak Torque (Nm.kg^{-1})	Total Work (J.kg^{-1})	Average Power (W.kg^{-1})
Pulling/ Pushing	Pulling	3.82 (0.91)	4.48 (1.06)	4.82 (1.19)
	Pushing	3.16 (0.66)	3.42 (0.75)	3.50 (0.79)
Valve-Tightening	Left Rotation	0.96 (0.17)	1.64 (0.27)	1.44 (0.26)
	Right Rotation	0.91 (0.15)	1.52 (0.24)	1.29 (0.25)
Wrench-Turning	Left Rotation	0.22 (0.04)	0.36 (0.07)	0.32 (0.06)
	Right Rotation	0.20 (0.05)	0.32 (0.08)	0.29 (0.07)
Gripping*	Squeezing	0.71 (0.24)	0.10 (0.06)	0.27 (0.11)

***Note:** Gripping at the medium isokinetic speed: 60°.s^{-1}.

Medium speed OST outputs are provided in Table XVII. The pulling/pushing test was affected by the increase in dynamometer speed, as the difference between pushing and pulling responses diminished. The speed increase of 90°.s^{-1} resulted in the following change: whereas the difference between pulling and pushing relative torque at the slow speed was 27%, the medium speed showed a difference of only 17% . Work outputs showed a different trend than responses for peak torque. Pulling work output was 24% higher than pushing at the slow and medium speeds of testing. Average power values showed an expected increase at the medium isokinetic speeds, as movement time was decreased during these maximal repetitions.

Valve-tightening responses showed expected velocity-related decrements in peak torque and total work. Peak torques for left and right rotation both decreased by 17% from the slow to the medium speed. Work values showed decrements of 16% for left rotation and 17% for right rotation. Average power values showed expected increments due to differences in movement time.

The wrench-turning test showed the following decrements: peak torque values were 15% lower in left rotation and 17% in right rotation. Work values also decreased by 16% for left rotation and 14% for right rotation. The highest decrements in torque and work outputs were evidenced in the gripping OST. Peak torque decreased by 22% and total work by 19% at the medium speed. Slower speed OSTs allow for greater time for force production and highest values are recorded under these testing conditions.

Fast Isokinetic Speed

Isokinetic testing at higher velocities has already been shown to affect torque, work and power outputs for LTs, following the force-velocity relationship (Hill, 1938). Following the explanation given previously, power outputs shown in Table XVIII increase for all but one of the OST movements (pulling). It is interesting to note the drop-off in the pulling/pushing outputs for total work. The total work for pulling showed a decrement of 55%, while the pushing responses were 50% of the slow speed value. This OST provided some difficulties for subjects with regard to “catching” the machine speed, as many subjects appeared to find this testing velocity difficult to complete.

Table XVIII: Occupation-Simulating Test (OST) responses at Fast ($210^{\circ}.s^{-1}$) Isokinetic Speed: comparisons across joints tested. (Means, with SD in brackets).

Joint	**Motion**	**Peak Torque (Nm.kg^{-1})**	**Total Work (J.kg^{-1})**	**Average Power (W.kg^{-1})**
Pulling/ Pushing	Pulling	2.55 (1.15)	2.59 (1.09)	4.51 (2.01)
	Pushing	2.39 (0.63)	2.15 (0.65)	3.61 (1.12)
Valve- Tightening	Left Rotation	0.89 (0.18)	1.49 (0.25)	2.18 (0.40)
	Right Rotation	0.82 (0.14)	1.38 (0.27)	2.03 (0.37)
Wrench- Turning	Left Rotation	0.20 (0.04)	0.33 (0.07)	0.53 (0.11)
	Right Rotation	0.18 (0.04)	0.29 (0.07)	0.47 (0.10)
Gripping*	Squeezing	0.59 (0.26)	0.08 (0.05)	0.33 (0.15)

***Note:** Gripping at the fast isokinetic speed: $90^{\circ}.s^{-1}$.

Peak torque values showed decrements of 47% for pulling and 32% for pushing during the fast speed OSTs. Higher decrements in the pulling values could be related to the selection of the pulling action as at the slow speed the subject is better able to maintain balance in the completion of the test movement. At the fast speed of testing subjects struggled to maintain equilibrium and significantly lower responses were recorded.

The valve-tightening OST showed 23% decrements over the velocity spectrum for both peak torque and total work during left rotation and 25% decrements for right rotation. These values would imply a high level of symmetry between the muscle groups involved in left and right rotation, when the valve-tightening test is considered, with both “dropping-off” at a similar rate. The wrench-turning test showed similar decrements for peak torque: 23% for left rotation and 25% for right rotation from the slow to the fast speed. Total work values decreased by 23% for left rotation and 22% for right rotation for the wrench-turning.

Gripping peak torque values showed a decrement of 35%, while total work decrements were 43% lower from the slow to the fast speed of testing. The valve-tightening, wrench-turning and to a lesser extent, the gripping OSTs, which were dependent on the upper-extremity musculature, were less affected by changes in testing velocity than was the case for the pulling/pushing OST which relied on much larger muscle groups for greater force production.

Figure 26 shows a comparison between very similar types of movements for total work responses collected at the slow, medium and fast speeds for the wrench-turning and valve-tightening OSTs. The decrease in work for wrench-turning was such that the fast work output was 78% of the slow speed (left rotation), while the valve-tightening test (left rotation), decreased to 77% of the slow speed value. Percentage decrements are useful means of assessing whether subjects are able to work as effectively at a higher testing velocity. The figure suggests that work output was similarly influenced by velocity changes for wrench-turning and valve-tightening.   Pulling/pushing and gripping showed a different trend to the wrench-turning and valve-tightening tests when velocity increased. Work outputs for these tests dropped-off by 53% and 57% respectively. The discrepancy in pulling/pushing values was largely related to the failure of subjects to "catch" the machine speed. The decrements in gripping responses can be explained by considering the specific action involved, as increased velocity is not associated with higher strength outputs during the fist-clenching action.

Opposite-direction comparisons: Occupation-simulating tests

The nature of the occupation-simulating isokinetic tests is such that there is no alignment of the dynamometer's fulcrum with the centre of a joint being tested as is characteristic of LTs. While this precludes attributions of strength expression to specific muscle-groups about well-defined musculo-skeletal levers (the essence of LTs), it has the decided advantage of incorporating actions that more closely approximate "real-world" strength expression (the essence of OSTs).

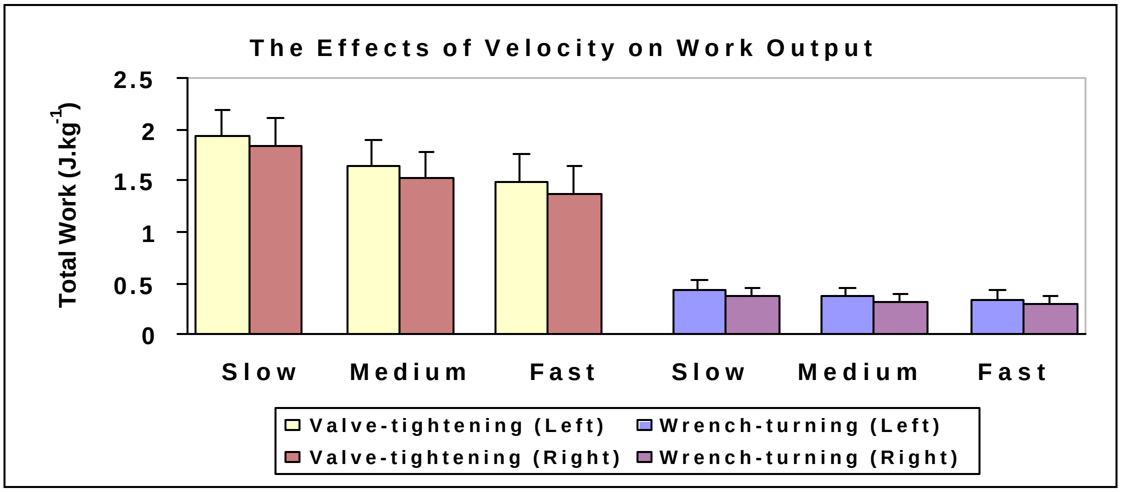

Figure 26: Changes in total work outputs over the velocity spectrum for the valve-tightening and wrench-turning OSTs

The valve-tightening and wrench-turning tests primarily involve the musculature of the upper-extremity while the test of pulling/pushing involves virtually the whole body in both the pulling and pushing actions. In terms of the opposite-direction ratios observed, pulling/pushing showed the highest dominance for total work and average power across the velocity spectrum. The fast speed does show variability in torque which could well have been as a result of some subjects not “catching the machine speed” of $210^{\circ}.s^{-1}$ effectively. Analysis of coefficients of variation show that at the fast speed it is pulling peak torque (C.V. 0.46) that is the source of the variability rather than pushing peak torque (C.V. 0.30). Subjects were shown to have greater difficulty maintaining balance during the fast speed pulling action than was the case for the pushing action.

Table XIX: Opposite-Direction Ratios for Occupation-simulating Tests (OSTs)

OST Ratios	Speed								
	$30^{\circ}_{1}.s^{-}$			$120^{\circ}.s^{-1}$			$210^{\circ}.s^{-1}$		
	Torque	**Work**	**Power**	**Torque**	**Work**	**Power**	**Torque**	**Work**	**Power**
Pulling/Pushing	1.39	1.33	1.40	1.22	1.32	1.39	1.04	1.18	1.23
Valve-tightening: Left/Right	1.06	1.06	1.02	1.06	1.08	1.13	1.09	1.11	1.09
Wrench-turning: Left/Right	1.10	1.17	1.21	1.09	1.12	1.12	1.14	1.14	1.15

Related t-tests were run to assess opposite-direction peak torque, total work and average power responses. Significant differences were observed in all but one of the t-tests (fast speed torque), highlighting the dominance of pulling over pushing.

Ratios for the valve-tightening and wrench-turning tests were more consistent across the speeds and showed some similar trends to the upper-extremity LTs (the shoulder and elbow tests). The effects of velocity were shown to have less influence on the peak torque outputs. T-test analyses showed that peak torque values were only nominally different in the valve-tightening and wrench-turning tests at both the slow and medium speeds with no significant differences evidenced. However, the subjects did perceive the task to be significantly easier when asked to give a rating on the RPE scale (discussed later). Valve-tightening essentially involves similar muscle groups to those involved in the tests of shoulder external/internal rotation and elbow extension/flexion. Nominal differences in left and right rotation may well be explained in terms of the use of the dominant hand as the major mover when making maximal efforts during the left turn (see previous chapter).

The following figures provide a detailed summary of the dominance ratios established during the OSTs. Slow, medium and fast speed ratios are highlighted for total work outputs. As stated previously, the gripping test only involved the closing action, with the result that no reciprocal ratios apply in respect of the gripping OST.

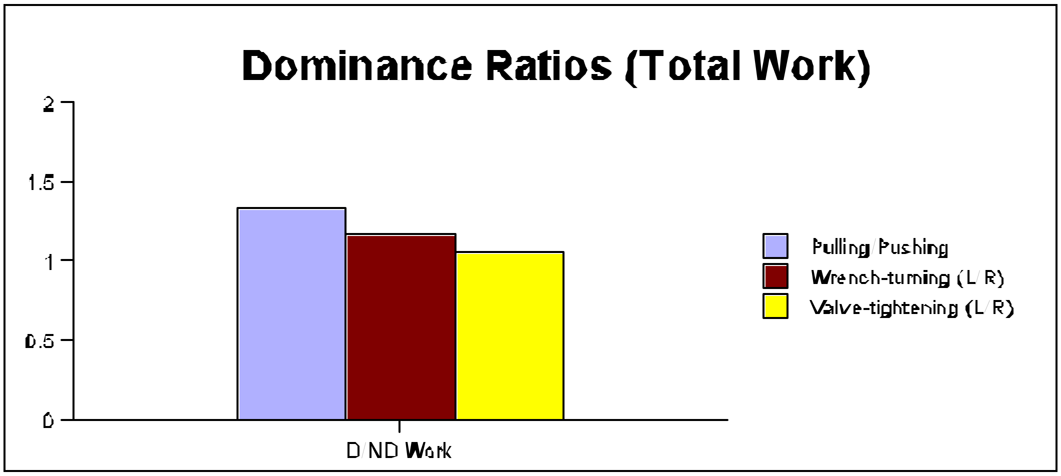

Figure 27: Slow Speed (30°.s^{-1}) Isokinetic dominance ratios (stronger/weaker), for work

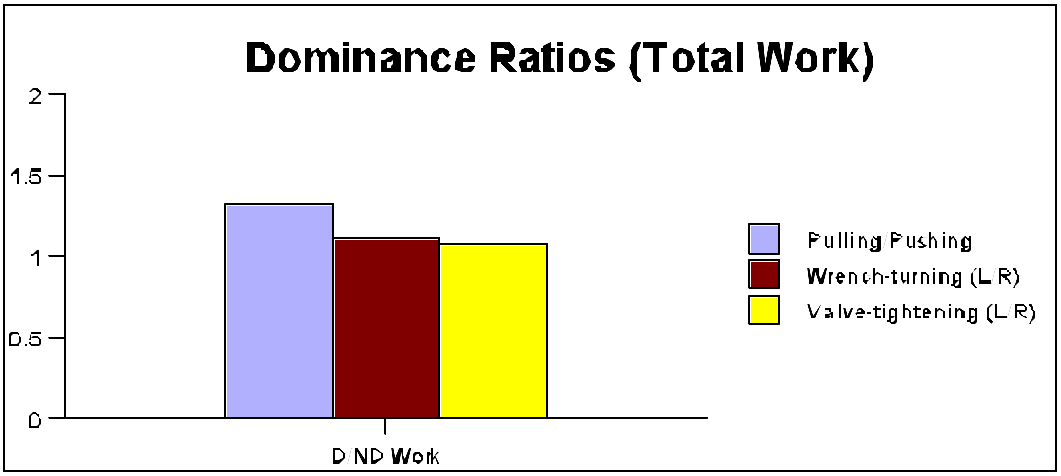

Figure 28: Medium Speed (120°.s^{-1}) Isokinetic dominance ratios (stronger/weaker), for work

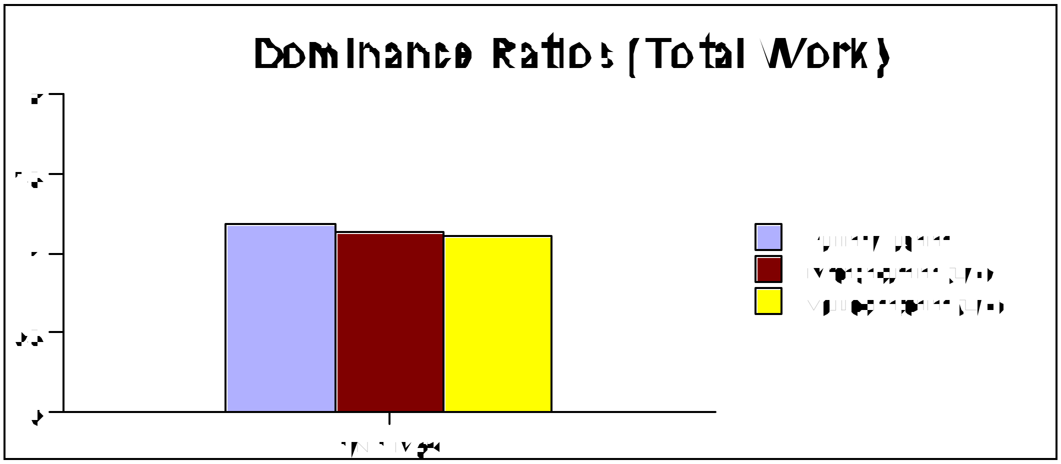

Figure 29: Fast Speed (120°.s^{-1}) Isokinetic dominance ratios (stronger/weaker), for work

Pulling was consistently dominant over pushing at all test velocities (Figures 27 to 29). The total work ratio for pulling/pushing was highest at the slow speed of testing, but decreased with an increase in testing velocity. The pulling action has already been shown to be more difficult to control as a result of the nature of the test and the problems associated with standardization of the starting point of the repetitions. In contrast to pushing, where the subject needs to maintain a ‘natural’ flow of movement in order not to overbalance, the pulling action was carried out in very different ways by individuals in this group of subjects. Related t-test analysis showed significant differences between pulling and pushing total work at all speeds (with $p \leq 0.03$).

Related t-test analyses showed significant differences at all speeds for wrench-turning total work (with $p \leq 0.04$). The dominance of left over right rotation for work may well be explained by considering the wrench-turning action, with subjects favouring left side turning. During this movement subjects are supinating the forearm and were thus completing a much more natural movement. In contrast, pronation of the forearm was taking place in the right turning action and showed lower work outputs across the velocity spectrum.

Statistical analyses of valve-tightening showed no difference between opposite-direction rotations for slow speed total work responses ($p=0.11$). Subjects exhibited similar outputs for left and right tightening actions (Figure 27). However, medium and fast speed work values (Figures 28 and 29) do show significant differences. Dominance of left over right valve-tightening could be related to the arm and hand dominance of the subjects tested, with the dominant hand being in the optimal position during valve-tightening to the left.

3. COMPARISON OF LTs AND OSTs

The trunk, hip (LTs) and pulling/pushing (OST) tests all involved the movement of large muscle groups in the expression of maximal strength. Figure 30 shows a comparison of the work decrements in these tests and allows for the identification of a number of similarities between these particular LTs and OST.

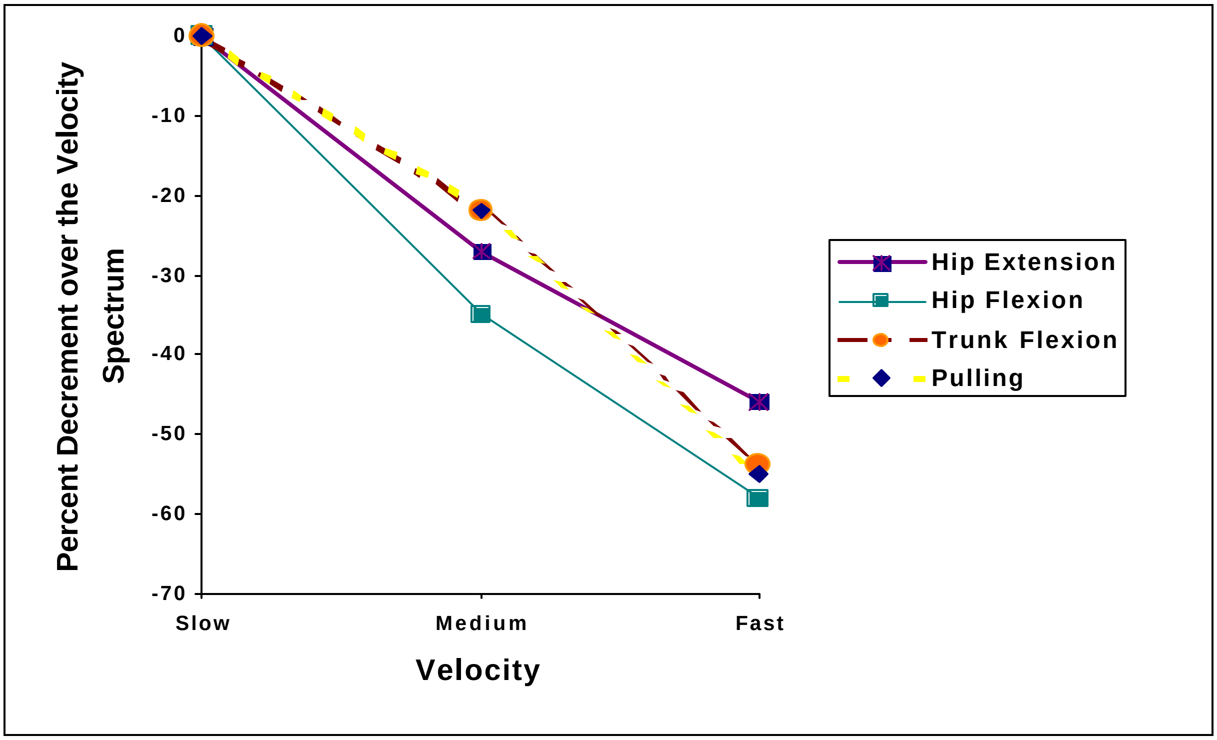

Figure 30: Changes in total work output over the velocity spectrum for trunk, hip and pulling/pushing tests.

When tests requiring whole body movements are evaluated, the velocity has a clear influence on isokinetic responses. Although these tests relied on different movements and protocols, the results still show similarities in decrements of total work output. For example, the value for hip flexion exhibited a 58% decrease, while the pulling action showed a 55% "drop-off" across the velocity spectrum. Tests involving whole body movements therefore appear to by significantly influenced by velocity, regardless of the alignment of dynamometer with the subject involved in testing.

Relationship between LTs and OSTs

LTs are fundamentally different in many ways from OSTs, the most significant difference involving the alignment of the dynamometer with the centre of the joint being tested in the LTs. In respect of H_o3 (a), isokinetic responses were expected to be poorly related between these markedly different test formats. STATGRAPHICS was used to run correlation analyses to evaluate the strength of the relationship between selected LTs and OSTs. These relationships are reported below for work values across the velocity spectrum.

The highest correlation (0.62 in respect of medium speed trunk extension vs pulling test) still does not account for a large percentage of the variance between these two tests. Although a number of the correlations show statistically significant differences (i.e. $r \neq 0$), the meaning in biological terms is negligible. Silverstein (1978; 1988) has shown that "unexplained variance" may be calculated using the formula $1-r^2$. The low correlations observed in the present study thus reflect very high coefficients of non-determination, even for those correlations that were statistically significant between LTs and OSTs (Table XX).

Table XX: Correlation analyses of selected LTs and OSTs for total work.

Analyses of:	Slow Speed r	 $1-r^2$	Medium Speed r	 $1-r^2$	Fast Speed r	 $1-r^2$
Trunk (Extension) vs Pulling	0.32*	>89%	0.62*	>62%	0.45*	>79%
Trunk (Flexion) vs Pushing	0.17	-	0.39*	>84%	0.46*	>78%
Knee (Extension) vs Pushing	0.34*	>88%	0.41*	>83%	0.43*	>81%
Knee (Flexion) vs Pulling	0.41*	>83%	0.40*	>83%	0.30	-
Elbow (Extension) vs Valve-tightening (Right)	0.24	-	0.27	-	0.46*	>78%
Elbow (Extension) vs Valve-tightening (Left)	0.07	-	0.16	-	0.41*	>83%
Elbow (Flexion) vs Valve-tightening (Right)	0.26	-	0.19	-	0.53*	>71%
Elbow (Flexion) vs Valve-tightening (Left)	0.15	-	0.11	-	0.35*	>88%
Shoulder (External Rotation) vs Valve-tightening (Right)	0.38*	>86%	0.30*	>91%	0.21	-

* Denotes significant correlation: **$p \leq 0.05$**
Note: coefficients of non-determination ($1-r^2$) are very large, showing that the specificity of strength expression responses is very high

Because LTs and OSTs correlate at best between r = 0.30 and r = 0.62, estimates of the performance of subjects based on the responses in any one of the tests are 62% to 91% inaccurate. Although these LTs and OSTs were deemed to be in comparable “kinesiological families” (for example, the pulling action synonymous with trunk extension), the correlations were low, thus further highlighting the need to consider specificity of strength when making global assessments of the capabilities of SANDF personnel.

4. SELECTED PHYSIOLOGICAL AND PSYCHOPHYSICAL RESPONSES

Increases in work output are normally associated with increases in heart rate. In a sample of infantrymen training on a regular basis, recorded peak values of heart rate are expected to be lower than would be the case for a sample of sedentary subjects.

McArdle **et al.** (1991) highlight the factors which influence heart rate: oxygen consumption, temperature, emotion, food intake, body position during testing, the active muscle groups, nature and intensity of activity and type of muscle contraction. All these factors could have influenced the cardiac responses of the infantrymen, but their assessment did not fall within the scope of the present study.

(a) Cardiac Frequency

Procedures for the collection of heart rate responses were standardized for both the laboratory and occupation-simulating tests. Readings were taken at the completion of each bout. Subjects were allowed a period of familiarization with the heart rate monitor to ensure that the reference heart rate recorded was optimal. Reference heart rate refers to the reading taken just prior to the commencement of the first testing session. The mean reference heart rate of the group was 79 b.min^{-1} (SD: 9.5).

Table XXI: Mean heart rate responses during the laboratory and occupation-simulating tests (Values in brackets are SD).

		HEART RATES						
Test Battery	**Test**	**Slow Speed (30°.s^{-1})**	**Relative to Reference Heart Rate$^{(1)}$**	**Medium Speed (120°.s^{-1})**	**Relative to Reference Heart Rate**	**Fast Speed (210°.s^{-1})**	**Relative to Reference Heart Rate**	**Sig. Level $^{(3)}$ ***
LTs	**Knee**	137 (18.78)	1.73	128 (16.26)	1.62	122 (17.23)	1.54	0.0004*
	Trunk	143 (18.61)	1.81	142 (17.71)	1.80	140 (19.34)	1.77	0.7855
	Ankle	104 (14.89)	1.32	93 (13.08)	1.18	88 (11.87)	1.11	0.0000*
	Shoulder	119 (24.91)	1.51	116 (17.21)	1.47	108 (16.05)	1.37	0.0239*
	Hip	127 (18.31)	1.61	117 (19.83)	1.48	114 (19.47)	1.44	0.0036*
	Elbow	98 (18.80)	1.24	108 (16.35)	1.37	98 (14.99)	1.24	0.0000*
OSTs	**Valve-tightening**	153 (17.71)	1.94	147 (20.66)	1.86	144 (19.24)	1.82	0.0713
	Pulling/Pushing	145 (21.70)	1.84	147 (17.53)	1.86	146 (20.77)	1.85	0.8667
	Wrench-turning	129 (20.38)	1.63	125 (17.95)	1.58	118 (20.00)	1.49	0.0561
	Gripping $^{(2)}$	**(30°.s^{-1})**	-	**(60°.s^{-1})**	-	**(90°.s^{-1})**	-	
		103 (13.84)	1.30	97 (13.14)	1.23	95 (14.79)	1.20	0.0304*

Notes:
1 Ratio for Observed Mean/Reference Mean
2 Gripping was carried out at different testing speeds
3 Statistical Analysis by means of one-way ANOVA (Mean Heart Rate over Speed) *** $p \leq 0.05$**

Analysis of mean heart rates by one-way ANOVA (mean heart rate over speed) showed significant decrements of mean heart rates for six of the tests over the velocity spectrum. The tests which did not show decrements over the velocity spectrum were the trunk, valve-tightening, pulling/pushing and wrench-turning tests. These tests include whole body actions and elicit larger muscle groups. Although presentation of test speeds was randomized and recovery phases maximized, the above tests would appear to place greater demands on the infantrymen, regardless of testing speed. The principal muscles involved in valve-tightening are the anterior chest, shoulder and arm muscles and posterior shoulder, upper-back and arm muscles. This movement thus involves a large cross-sectional area of muscle in close proximity to the heart. The mean heart rate values increased 1.94 times from the reference value. It is probable also that an increase in intra-thoracic pressure could contribute to the higher cardiac frequencies of the valve-turn test. Greater intra-thoracic pressure results in greater aortic pressure and a concomitant affect on immediate post-exertional heart rate.

The other tests which showed the largest increases in heart rates were the pulling/pushing test and the trunk test. The pulling/pushing and trunk extension/flexion assessments involved very large muscle groups. The requirements for oxygen to the working muscle are thus increased as the subject meets the demands of the task. The mean heart rates increased by 1.84 (from reference for pulling/pushing) and by 1.81 (from reference for trunk extension/flexion).

In addition to the size of the muscle groups involved there appears to be a relationship between proximity of active muscle groups to the heart and heart rate. For example, in the case of the valve-tightening and trunk tests, the mean increments in working heart rate over reference values were 1.87 and 1.79 respectively. These tests both involved large active muscle groups through a large ROM. It may be that proximity of working muscles to the heart can be shown to have an influence, as the hip and wrench tests, which also involved large muscle groups through a large ROM showed lower mean heart rate increases of 1.51 and 1.57 respectively. The ankle (1.2), elbow (1.28) and gripping (1.24) tests involve small muscle groups which are distal to the heart and these evidenced the lowest increments in mean working heart rates over the reference values further highlighting the influence of proximity of active muscle groups to the heart.

In contrast to the OSTs and LTs involving larger muscle groups working at high intensity, the tests of elbow extension/flexion, gripping and the ankle plantar/dorsiflexion show the lowest increases in heart rate from the reference mean value. The nature of the tests is probably one of the best explanations for the observed results. In ankle testing, the subjects were prone with the knee extended. The range of motion and the relative cross-sectional area of the ankle musculature were both small. In a similar way, the tests of the elbow and gripping were dependent on smaller muscle groups to complete the action. The gripping test passed through a small range of motion and involved only the clenching action. Although subjects were completing a maximal effort, the muscle groups involved were smaller, with lower overall demands from the active muscle groups.

Figure 31 shows a summary of the mean heart rate values collected in OSTs. The valve-tightening elicited the highest mean heart rate during the slow and medium speed testing. The pushing/pulling test had the highest mean heart rates during the medium and fast speed tests. The lowest heart rates were recorded during the gripping test. The intensity of effort required as well as the nature of the test have been shown to be critical factors in the assessment of heart rate data. Another important trend which this figure highlights is the minimal drop-off in heart rate with increased velocity.

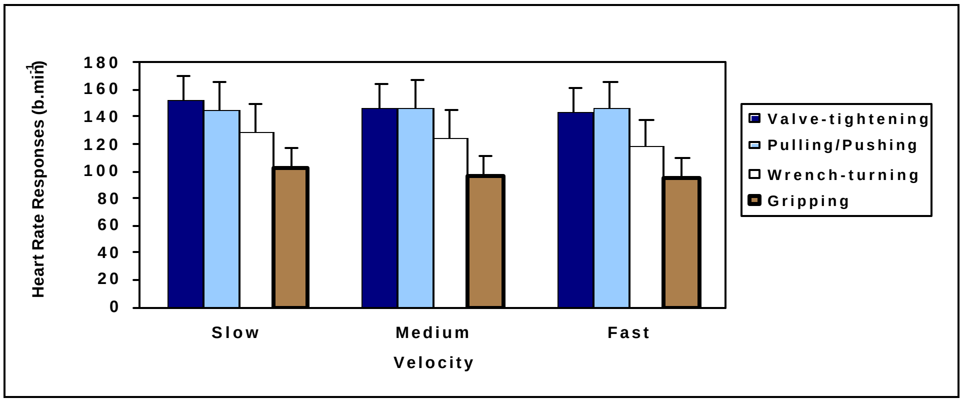

Figure 31: Mean Heart Rates: occupation-simulating tests.

Note: Related t-test analyses showed significant differences between all OST mean heart rates with the exception of the valve-tightening and pulling/pushing tests across the velocity spectrum ($p \leq 0.05$).

The valve-tightening and pulling/pushing tests are proximal to the heart and have been shown to involve "whole body" movements. The heart rate responses for these particular OSTs were hence very similar. The distal wrench-turning and gripping tests showed much lower mean heart rates and did not involve "whole body" actions, the result being significantly lower working heart rates ($p \leq 0.05$).

(b) Psychophysical Responses: Ratings of Perceived Exertion (RPE)

Borg (1982) found, across a spectrum of working situations, that individual perceptions of exertion during physical work are informative: ratings of perceived exertion are useful indicators of physical work involved. In order to ensure accuracy of rating clear instructions and rigorous administration are critical.

The rating of perceived exertion was standardized for both laboratory and occupation-simulating tests, records being taken at the completion of each work bout. Subjects were given specific guidelines as to the use of the scale, including verbal explanations given in English and Xhosa (the most commonly spoken African language in the sample). Borg (1982) identified one major drawback with ratio-scaling methods in that they do not provide any direct "levels" for inter-individual comparisons. Some subjects may rate tasks significantly differently when conditions change very slightly. When assessing RPE values it is therefore necessary to carefully scrutinize the data before making generalizations about the way the subjects perceived certain tasks. It is possible to identify some trends over the slow, medium and fast speed which are evident in Table XXII.

Table XXII: Mean RPE responses to isokinetic laboratory and occupation- simulating tests (with SD in brackets).

		Speed		
Test Battery	**Ratings of Perceived Exertion (RPE) :**	**Slow ($30°.s^{-1}$)**	**Medium ($120°.s^{-1}$)**	**Fast ($210°.s^{-1}$)**
LTs	**Knee**	15 (1.96)	12 (2.53)	10 (2.82)
	Trunk	16 (2.02)	12 (2.04)	10 (1.97)
	Ankle	14 (2.30)	11 (1.99)	9 (1.65)
	Shoulder	16 (2.10)	12 (2.00)	10 (2.34)
	Hip	16 (2.20)	12 (2.34)	10 (1.64)
	Elbow	15 (2.95)	12 (1.75)	9 (1.79)
OSTs	**Valve-tightening**	16 (1.72)	13 (2.32)	11 (2.52)
	Pulling/Pushing	15 (2.15)	12 (1.92)	10 (2.50)
	Wrench-turning	16 (1.67)	12 (1.99)	10 (2.61)
		($30°.s^{-1}$)	**($60°.s^{-1}$)**	**($90°.s^{-1}$)**
	Gripping [1]	13 (2.41)	11 (2.24)	11 (2.57)

[1] Gripping was carried out at different testing speeds

Analysis of these ratings by one-way ANOVA (RPE over speed) shows significant differences in perceived exertion as speed increases, except in the case of the gripping test. Gripping RPE at the medium and fast speeds was not significantly different with subjects perceiving the tasks to be very similar in terms of level of exertion.

Highest RPEs were recorded during the slow speed LTs and OSTs. The infantrymen perceived the slow speed tests to be more difficult and adjusted their ratings for each of the medium and fast speeds. Subjects associated testing velocity with the difficulty of the task, focusing on the changes in speed rather than on the actual requirements of, for example, the wrench-turning or valve-tightening test. All slow speed tests showed RPE means of 13 or above, with the valve-tightening, trunk, wrench-turning, shoulder and hip tests being perceived as the most demanding (mean RPE ratings of 16). The least demanding task at the slow speed was perceived to be the gripping test. This could well be as a result of the set-up of the gripping task which only involved the closed grip or squeezing action. Subjects perceived the task demands for this particular OST to be minimal. At the medium speed, all RPE means were between 11 and 13, with the valve-tightening OST showing the highest value (13). The gripping OST and ankle LT showed the lowest mean ratings at the medium speed, where both tests were rated at 11. The fast speed mean ratings were between 9 and 11 for all LTs and OSTs.

A comparison of heart rates and RPE values for selected LTs and OSTs is presented in Figures 32 and 33. The RPE scale, if effectively explained and standardized, usually correlates highly with heart rate. A multiplication factor of 10 is used to predict the heart rate of the subject based on their perceived exertion.

The hip and the shoulder were chosen to allow for the identification of trends for both upper- and lower-extremity LTs. Figure 32 suggests that the subjects perceived the slow speed tests to be consistently more exerting than the medium and fast speed tests. Related t-tests were carried out to assess the differences between RPE-predicted and measured heart rates during all LTs and OSTs. RPE values were multiplied by 10 to get a predicted value and then compared to observed mean heart rates. At the slow speed predicted heart rate was significantly higher than measured mean values in 5 out of 6 LTs ($p \leq 0.0001$). The medium speed RPE responses in contrast showed no significant difference in 3 of 6 LTs ($p \leq 0.05$) which would suggest that subjects were better able to predict their work output at this speed. The fast speed LTs showed subjects under-predicting mean heart rate responses in 4 of 6 LTs ($p \leq 0.0009$).

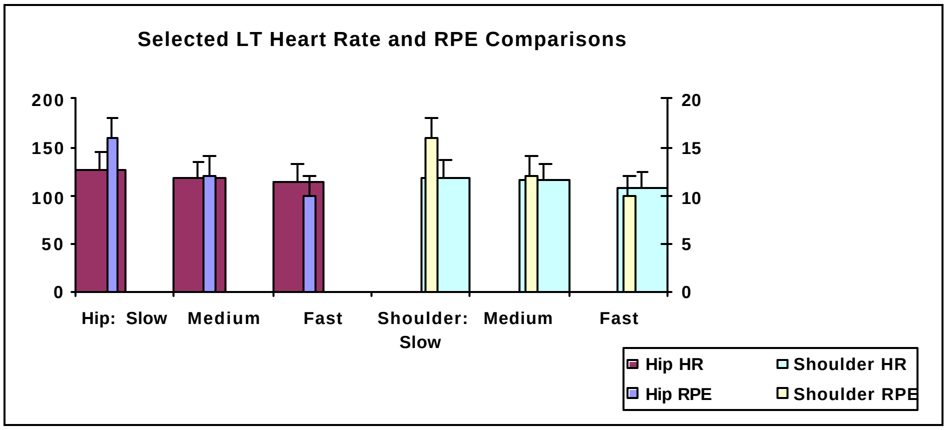

Figure 32: Hip and shoulder Heart Rate and RPE. comparisons

Figure 33, which shows a selected OST comparison, is similar to Figure 32 for the selected LT comparison, as RPE ratings were significantly lower at the fast speed. Valve-tightening was chosen as it involved a “whole body” action and gripping because it involved a small range of motion and small muscle groups. Related t-test analyses did not highlight dominant trends for OSTs as was the case for LTs. The slow and medium speed RPE responses under-predicted observed heart rates in 2 of 4 OSTs ($p \leq 0.04$). All subjects felt the tests at faster isokinetic speeds were significantly easier to complete than was the case at the slower isokinetic speeds due to a shorter work output period. The values for the fast speed significantly under predicted the observed heart rates in 3 of 4 OSTs ($p \leq 0.0008$). The rest time should still be regarded as the major factor affecting heart rate, as a change to the order of testing would probably have resulted in different responses. For example, if all the slow speeds were completed by subjects followed by a rest period, the heart rates may well have correlated more highly with the RPE values.

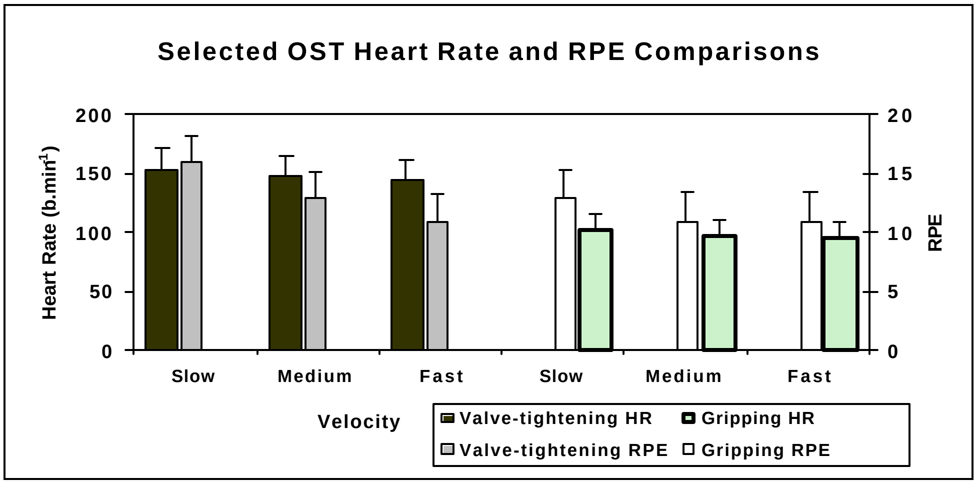

Figure 33: Valve-tightening and Gripping Heart Rate and RPE. comparisons

Correlations between heart rate and RPE responses were carried out using the STATGRAPHICS programme and results are shown in Table XXIII. In this software package the relationship is evaluated under an hypothesis of zero correlation. Of 10 tests each conducted at 3 speeds only one correlation was significant (that is significantly above zero; see Table XXIII) and even in this instance (r = 0.36) the coefficient of non-determination was 87%.

Table XXIII: Correlation between Heart Rate and RPE over the velocity spectrum: LTs and OSTs.

Test Battery	Test:	Correlation (r) Slow ($30°.s^{-1}$)	Medium ($120°.s^{-1}$)	Fast ($210°.s^{-1}$)
LTs	**Knee**	0.14	0.17	0.27
	Trunk	0.07	0.13	0.20
	Ankle	0.07	0.11	0.09
	Shoulder	0.09	0.04	0.07
	Hip	0.16	0.02	0.28
	Elbow	0.02	0.08	0.13
OSTs	**Valve-tightening**	0.12	0.25	0.16
	Pulling/Pushing	0.16	0.36 *	0.27
	Wrench-turning	0.08	0.07	0.04
		($30°.s^{-1}$)	**($60°.s^{-1}$)**	**($90°.s^{-1}$)**
	Gripping [1]	0.08	0.08	0.03

[1] Gripping was carried out at different testing speeds

* Denotes significant correlation: **$p \leq 0.05$**

Although RPE ratings have been shown to correlate highly during tests of cardiovascular endurance (Borg, 1982), apparently the same cannot be said for muscular strength assessments used here, probably because the isokinetic tests did not exert a cumulative affect on the overall level of fatigue of the subjects. Furthermore, it is possible that the subjects tended to rate RPE in accordance with the rest of their particular group.

5. STRAIN-GAUGE DYNAMOMETRY

Isometric tests are useful for a number of reasons, not least among them the ease of testing and the cost-effectiveness of equipment. Strain-gauge dynamometers are inexpensive when compared to isokinetic dynamometers (like the CYBEX 6000), making this form of strength evaluation and assessment more practical and likely in South Africa. Isometric dynamometry can be used in military, industrial and sporting environments as it requires inexpensive equipment and limited experience on the part of the test administrator. In the present study two trials were completed to ensure maximal responses. This was deemed necessary to enable subjects to become familiar with the requirements of the task. Related t-tests showed no significant differences between the first and second trials for each of leg, back and grip responses. The following table thus shows the mean data for the best trial of leg, back and dominant hand grip-strength for the group (N=42), as these data were deemed reflective of maximal responses of subjects.

Table XXIV: Responses relative to strain-gauge tests of leg, back and grip-strength, (Means, with SD in brackets).

Test	Best Trial (kg f)
Leg Strength	129.55 (25.60)
Back Strength	105.71 (18.00)
Grip Strength	44.26 (5.70)

Subjects were strongest in tests of leg strength followed by back and dominant hand grip strength values. The testing procedures (highlighted in Chapter III) were aimed at standardizing the starting position for relevant tests and strict adherence was ensured in respect of the starting angle for the leg and back lift tests. Changes in these starting angles have been shown to significantly affect force production as a result of differential recruitment of muscles of the lower-back and lower-extremities.

Strain-gauge dynamometers have been used to assess military subjects in different populations. A number of factors have been shown to influence leg strength in post-march situations. Knapik **et al.** (1993) found that leg strength was lower following a loaded route march. The decrease in leg strength was seen to be related to the repeated eccentric work required to decelerate the shank while walking. Their study (mean age: 29.7 yr. (SD 4.3) and body mass: 87.8 kg (SD 10.3)) collected leg, upper-torso, back and hand grip strength of subjects, providing a useful base for comparison with the present study.

Table XXV: Values recorded in the present study compared to the work of Knapik **et al.** (1993) relative to body mass.

Source	Subjects	Leg strength ($kg.kg^{-1}$)	Back strength ($kg.kg^{-1}$)	Hand grip strength ($kg.kg^{-1}$)
Present Study	Infantrymen (SANDF)	1.91	1.55	0.65
Knapik **et al.** (1993)	Special Forces (US Army)	1.92	1.08	0.69
Congruence[1]		99%	144%	94%

[1] (Present Study Value/Knapik **et al.** (1993) Value x 100)

Table XXV shows a high level of congruence between the relativised leg and grip strength isometric tests. A large proportion of the variability between the data from the present study and the Knapik **et al.** (1993) study in absolute terms was thus attributed to the differences in morphology of the subjects used. US Army Special Forces would be expected to exhibit higher mass-relative levels of strength than SANDF infantrymen, due in large part to the differences in morphology. It is however interesting to note that SANDF soldiers actually exhibit higher values for back strength than Special Forces subjects in the Knapik **et al.** (1993) study, with the congruence level being 144%.

In order to assess whether these data offer reliable estimates of maximal strength, correlation analyses were carried out between isometric values (collected using strain-gauge dynamometry) and isokinetic peak torque values (collected using the CYBEX 6000). Table XXVI shows the relationship between these values. “Back”, ”leg” and “grip” values refer to isometric tests, while the tests of the trunk, knee and gripping are slow speed isokinetic torque responses (LTs and OSTs). None of these correlations was significant.

Table XXVI: Correlation analysis for isometric and isokinetic values.

	Back vs Trunk	Leg vs Knee	Leg vs Hip	Grip vs Gripping
Correlation (r):	0.19	0.32	0.29	0.04

These correlations suggest that generalizations with regard to isometric data should be made cautiously. Isometric and isokinetic tests correlate at best between r = 0.04 and r = 0.32 thus leaving 90% to 99% of the variance unaccounted for. Low correlations suggest that use of strain-gauge dynamometry to evaluate military personnel is not the best method, as reliability of these data vary markedly with small changes in protocol. Isometric tests may well be the most practical for the SANDF, and indeed a number of industries, but will not ensure a true a reflection of the strength capabilities of infantrymen. Even in a controlled laboratory environment, isokinetic strength evaluations have been shown to have limitations when assessing infantrymen. However, these remain the most reliable means of strength assessment and generalizations with regard to capabilities of personnel would be flawed if isometric testing was used as the modality of choice. These data add further credence to the view that specificity of strength needs to be carefully considered when evaluating strength responses, be they isometric or isokinetic. A subject performing well in one test, for example, the trunk flexion/extension test, will not necessarily exhibit similar values for the back strength isometric test.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Military personnel are subjected to various demands in both the training and combat environment. Following strenuous activity, infantrymen are frequently required to complete critical tasks with a high level of efficiency and accuracy. A great deal of study has focussed on the effects of load carriage on performance, but little attention has been given to post-march strength decrements and endurance in these evaluations. Isokinetic strength evaluations can be carried out in two ways: as laboratory-tests (LTs), where the centre of the joint being tested, for example the elbow, is aligned with dynamometer input arm, or as occupation-simulating tests (OSTs) where the CYBEX 6000 "work-simulation" package is used to test specific tasks like valve-tightening.

A particular upper-extremity muscular weakness has been identified in the SANDF and strength responses for the upper-extremity were expected to be disproportionally lower than those of the lower-extremity in isokinetic testing. Agonist and antagonist responses were expected to be significantly different for all LTs, except elbow measures, with upper-extremity responses displaying markedly different trends from those observed in the literature. LTs were expected to correlate poorly with OSTs as a consequence of the specificity of strength principle and the fact that very different conditions pertain. The LTs require specific alignment of the centre of the joint being tested (for example, the elbow joint for flexion/extension) with the dynamometer input arm, whereas the non-alignment of the dynamometer input arm with a specific joint centre in the OSTs was expected to profoundly influence strength expression.

Strength assessments can be carried out in a number of ways, but isokinetic dynamometry remains one of the most widely used testing modalities. The majority of the focus of isokinetic testing has been the lower-extremity, and more specifically the knee (Perrin, 1993). Far less data are available on the upper-extremity and almost no work has been carried out on the CYBEX 6000 “work- simulation” package. Normative databases do exist for certain populations, especially for European and American subjects, but virtually no comparative data are available for South Africans. Despite differences between samples, it is still possible to assess the performance of infantrymen relative to subjects of a similar age who are involved in regular physical activity. Perrin (1993) offers a comprehensive database of isokinetic responses which facilitates some comparative evaluations. One limitation of these data is the reliance on peak torque (T_{max}) as the chosen criterion for the evaluation of subjects. Peak torque is not always the best indicator of strength expression as it merely represents a maximal point somewhere on the isokinetic torque curve. Work values are essentially a lot more meaningful, as they represent maximal strength expression through an entire range of motion. Charteris’ (1999a; b) studies provided some useful material for comparison as these data were collected on South African subjects from industrial and sporting backgrounds and included values for peak torque, total work and average power outputs.

PROCEDURES

The present study assessed “laboratory” and “occupation-simulating” isokinetic and concomitant psychophysical responses of military personnel. Peak torque, total work and average power outputs were measured on a sample of 42 SANDF infantrymen using the CYBEX 6000 isokinetic dynamometer. Subjects were required to complete ten testing bouts including six laboratory tests (LTs): knee, elbow, shoulder, hip, ankle and trunk, and four occupation-simulating tests (OSTs): gripping, valve-tightening, wrench-turning and pulling/pushing). All data were coded by means of a numbering system to ensure anonymity of results.

Prior to testing, subjects received a letter of information and were required to sign informed consent forms. The contents of both the letter of information and the informed consent instrument were verbally explained to ensure that subjects understood fully the requirements of the testing procedures and that they participated freely. Subjects were also encouraged to report any injuries and reminded that they were at liberty to leave the study at any stage should they deem it necessary. Borg’s (1971) Rating of Perceived Exertion (RPE) scale was verbally explained in both English and Xhosa (the selected African language) to ensure understanding.

The subjects then carried out a self-paced warm-up for two minutes (at low resistance) on a cycle ergometer before commencing with the maximal tests. The order of testing was randomized for all groups and the setup time for each subject was minimized. Since none of the subjects had previous experience in isokinetic dynamometry all were thus given verbal instructions and a familiarization trial in order to accustom themselves to the techniques involved. Each period of familiarization involved sub-maximal practice trials at each of the selected machine speeds. This was done in respect of all 10 tests.

Following this familiarization period, subjects were asked to exert four maximal efforts at each of the three test-speeds. They were encouraged to exert maximally through the entire range of motion and for the entire duration of the testing. Verbal encouragement and knowledge of results were provided whenever possible. No further incentives were offered to the subjects involved in the testing, although feedback on results was guaranteed.

Cardiac frequency was measured using telemetric heart-rate monitoring. Post-exertional readings were taken during the rest intervals between each bout at the slow, medium and fast testing speeds. Subjects were allowed a period of familiarization to ensure that reference heart rates were not excessively elevated prior to exposure to the isokinetic tests and that they were aware of the general operation of these devices. Following the recording of post-exertional heart rates, psychophysical ratings were recorded using Borg's (1971) RPE scale.

RESULTS

Elbow flexion/extension responses highlighted a particular weakness in the flexors. A ratio of 1.0 was expected between these reciprocal muscle groups (See Table XV, Chapter IV and Appendix A). This may well be attributed to the training programmes used in the SANDF if greater emphasis is placed on activities which differentially entrain the extensors of the elbow. Upper- to lower-extremity ratios were also assessed using the responses for the elbow and knee. These comparisons add further support to the contention that the elbow flexors may exhibit a weakness in strength expression, as the ratios for the U/L extensor responses compared favourably with those found by others in similar research.

The pulling/pushing OST showed the highest values of all the tests. The use of a whole-body action in this test significantly affects the strength expression of subjects, as does the variability in the technique employed to complete the pulling/pushing action. LTs were expected to correlate poorly with OSTs due to the differences in testing procedures and alignment of subjects. The highest correlation was r = 0.62 ("explaining" [see Silverstein 1978; 1988] barely 38% of the variance), with many of the correlations being lower than r = 0.20 (See Table XX, Chapter IV).

Heart rate and RPE responses were assessed to augment this strength expression profile of SANDF personnel. Tests involving whole-body actions, for example the valve-tightening and the pulling/pushing tests, elicited the highest mean working heart rates at all test speeds across the velocity spectrum (See Table XXI, Chapter IV). The valve-tightening test showed a 1.94-fold increase in mean heart rate values over the reference value. This may well be related to increased intra-thoracic pressure. Closer evaluation of RPE showed similar trends for all LTs and OSTs. Subjects tended to base perceptions of exertion on the dynamometer speed, the result being that slow speed tests all received very similar ratings, regardless of the nature of the movement. Correlations between heart rates and RPE were low (ranging from $r = 0.03$ to $r = 0.36$), supporting the contention that subjects may have been influenced by the responses of the rest of the group when responding.

Strain gauge dynamometry was also used to assess isometric strength in the present study. Responses were collected for grip, leg and back strength. Although these data were shown to be comparable to those from similar studies on military personnel, the reliability was considered questionable due to the variability of results with minor changes to the testing protocol. Isokinetic and isometric responses showed low correlations (See Table XXVI, Chapter IV), suggesting that data from isometric tests should be used with caution in evaluations of strength capabilities: at least isoinertial, isometric and isokinetic modalities should not be conflated as they measure very different phenomena.

CONCLUSIONS

The present study has added to the field of isokinetics in establishing benchmark data on a sample unique to South Africa. Strength responses of this sample from the indigenous military personnel have been comprehensively evaluated and in this regard important data were collected.

In respect of $H_o1(a)$ the results force rejection of the null hypothesis (μ T W P $_{\text{(Agonists)}}$ = μ T W P $_{\text{(Antagonists)}}$ at all speeds tested): statistical analysis showed significant differences between all agonist and antagonist responses with the exception of trunk flexion extension/flexion peak torque at the slow speed. The reason for this is discussed on page 91. An anomaly in agonist vs antagonist responses was identified in the upper-extremity values: elbow flexion/extension values were expected to produce a reciprocal ratio very close to 1.0, but instead showed a ratio of 1.14 for total work (see page 89).

In respect of $H_o1(b)$ the results similarly force rejection of the null hypothesis (μ T W P $_{\text{(Right and Pushing)}}$ = μ T W P $_{\text{(Left and Pulling)}}$ at all speeds tested): all opposite-direction motions, whether bilateral or unilateral in nature, were significantly different. The pulling/pushing OST allows for recruitment of the large trunk extensor muscles in the pulling action and was thus dominant over the pushing action. Valve-tightening and wrench-turning were both greater in left rotation as a result of the ability of subjects to rely on the supination of the forearm in these movements and the positioning of the dominant hand in the optimal position to elicit strength (see page 107). Supination has been shown to produce greater strength responses than is the case for pronation of the forearm. Thus left rotation showed an expected dominance over right rotation.

Comparable upper-to-lower-extremity responses were assessed in respect of H_o2. Although responses of the more gracile upper-extremity were expected to produce lower mean responses than the lower-extremities the extent of this difference was not known. These data highlighted a particular weakness in the elbow flexor group which may well be related to the training programmes used for SANDF infantrymen. Upper- to lower-extremity responses thus force rejection of the null hypothesis:

$\mu\ T\ W\ P_{\text{(Upper-extremity)}} = \mu\ T\ W\ P_{\text{(Lower-extremity)}}$.

Although many of the LTs and OSTs involved expression of strength through a similar ROM and utilizing common muscle groups, they were expected to show low correlations in respect of $H_o3(a)$ due to the specificity of strength principle. Correlation analysis thus forces rejection of the null hypothesis ($Rho_{\text{LTs; OSTs}} = 0$) in 16 of 27 instances where significant differences were observed. However, although these correlations were statistically significant they displayed a relationship which was of no kinesiological value: it would not be possible to predict the performance of a subject for an OST based on data from an LT and *vice-versa*.

RPE ratings have been shown to correlate highly with heart rates in tests of cardiovascular endurance (Borg, 1982). Muscular strength assessments do not appear to show similar trends to cardiovascular testing. In the present study heart rate and RPE data were expected to show low correlations in respect of $H_o3(b)$ due to the lack of a cumulative affect on the overall level of fatigue of subjects. Correlation analysis thus forces retention of the null hypothesis ($\text{Rho}_{\text{HR; RPE}} = 0$) in 29 of 30 instances where no significant differences were observed. The use of RPE as a predictor of working heart rate in isokinetic muscle tests should therefore be approached with circumspection.

RECOMMENDATIONS

Based on the findings of the present study, a number of recommendations are made:

(1) The SANDF should further assess the capabilities of the diverse ethnic groups involved in the infantry throughout the country.

(2) Strength evaluations should be carried out across the spectrum of personnel, from those involved in basic training to those involved in military relief operations.

(3) There is a need to consider the training programmes used. This will address the identified imbalances in reciprocal muscle groups, particularly in the upper-extremity, where the elbow flexors may need to be targeted.

(4) Comparative studies should be carried out based on those already completed on infantrymen from other countries so as to establish some baseline performance levels for the SANDF. Although the needs of the infantrymen in the SANDF are

different to those of personnel in other forces, there are still a number of possibilities for collaborative work.

(5) RPE ratings should not be recorded in a group context if valid results are required.

(6) A more reliable isometric strength test set-up needs to be devised.

(7) The SANDF is becoming increasingly focussed on the role of female personnel and data from the present study lends itself to comparisons against similar testing presently underway on females. This is especially worthwhile with regard to OSTs, where actions are more suited to the assessment of personnel for both non-combatant and combat-related tasks. A greater understanding of indigenous strength expression characteristics would thus be beneficial to the Training Personnel in the SANDF and allow for a more combat-ready force. Further use of the CYBEX 6000 "Work-Simulation" package is also proposed, as closer simulation to military tasks would be more beneficial than would be the case for extended testing using LTs.

(8) The subjects of the present study were not participating in a route-march or a timed obstacle run prior to isokinetic testing as the focus of this investigation was not on the effects of fatigue on strength expression. By inducing fatigue prior to isokinetic testing, it may well be possible to gauge strength decrements following prolonged loaded marching.

(9) Changes to the testing protocol could well produce a greater understanding of the decrements in strength which are closely related to the effects of load carriage or combat training. Subjects could be required to produce isokinetic responses in pre- and post-fatigue testing sessions. By studying strength decrements over an extended training session it may well become possible to make more detailed analyses of the strength capabilities of SANDF personnel, thereby gaining a greater insight into the potential of the "African Warrior".

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APPENDICES

APPENDIX A: NORMATIVE DATA TABLES

Isokinetic standard score norms - males (knee extension). Adapted from Charteris and Goslin (1979).

STANDARD SCORE	T_{MAX} RIGHT (Nm)	T_{MAX} DOMINANT (Nm)
100	263.4	239.2
90	241.1	218.8
80	218.6	198.5
70	196.2	178.3
60	173.7	158.0
50	151.3	137.6
40	128.9	117.4
30	106.4	97.1
20	84.1	76.7
10	61.6	56.5
0	39.2	36.2

Isokinetic Standard Score Norms for the Elbow (for use in assessing either flexion or extension efforts of male subjects). Adapted from Charteris and Goslin (1986).

STANDARD SCORE	MAX TORQUE (Nm)	TOTAL WORK (J)	MEAN POWER (W)
100	78.2	128.3	30.3
90	71.8	117.0	27.6
80	65.4	105.6	24.9
70	58.9	94.3	22.2
60	52.5	82.9	19.5
50	46.1	76.6	16.8
40	39.7	60.3	14.1
30	33.3	48.9	11.4
20	26.8	37.6	8.7
10	20.4	26.2	6.0
0	14.0	14.9	3.3

APPENDIX B: PSYCHOPHYSICAL RESPONSE SCALES

Borg's (1971) Rating of Perceived Exertion (RPE) scale

Rating of Perceived Exertion	(Borg, 1971)
6	
7	VERY, VERY LIGHT
8	
9	VERY LIGHT
10	
11	FAIRLY LIGHT
12	
13	SOMEWHAT HARD
14	
15	HARD
16	
17	VERY HARD
18	
19	VERY, VERY HARD
20	

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APPENDIX C: RESEARCH PROTOCOL

INFORMED CONSENT

Department of Human Kinetics and Ergonomics

SUBJECT CONSENT FORM

I, ______________________________ , having been fully informed of the research entitled:

LABORATORY AND OCCUPATION-SIMULATING ISOKINETIC AND PSYCHOPHYSICAL RESPONSES OF MILITARY PERSONNEL

(Jonathan P. James)

do hereby give my consent to act as a subject in the above named research.

I am fully aware of the procedures involved as well as the potential risks and benefits attendant to my participation as explained to me verbally and in writing. In agreeing to participate in this research, I waive any legal recourse against the researchers or Rhodes University, from any and all claims resulting form personal injuries sustained.
This waiver shall be binding upon my heirs and personal representatives. I realise that it is necessary for me to promptly report to the researchers any signs or symptoms indicating any abnormality or distress. I am aware that I may withdraw my consent and may withdraw from participation in the research at any time. I am aware that my anonymity will be protected at all times, and agree that the information collected may be used and published for statistical or scientific purposes.

I have read the information sheet accompanying this form and understand it. Any questions which may have occurred to me have been answered to my satisfaction.

(PRINT NAME) SUBJECT	(SIGNED)	(DATE)
(PRINT NAME) PERSON ADMINISTERING INFORMED CONSENT	(SIGNED)	(DATE)
(PRINT NAME) WITNESS	(SIGNED)	(DATE)

GENERAL TESTING PROTOCOL:

ISOKINETIC TESTING OF MILITARY PERSONNEL

1. DEMOGRAPHIC DATA

Collection of subject data will be done at the commencement of the testing session:

The following will be collected: age, stature, body mass, body fat percentage and body mass index (BMI) and reciprocal ponderal index (RPI) then calculated.

2. INFORMED CONSENT AND LETTER OF INFORMATION TO SUBJECTS

Prior to testing the subjects, all volunteers, will be asked to sign an informed consent form. The contents of the informed consent will be explained verbally and in the written information document supplied to the subject. The subject, researcher and witness will sign the informed consent form.

3. WARM-UP

The subjects involved in the testing will be required to complete a warm-up programme before commencing with the maximal exertion. For this, 5 minutes of light activity will be completed on the Monark™ cycle ergometer at a low resistance (2 kg) and a stretching programme will be followed for both the upper- and lower-extremities. The warm-up is aimed at minimizing the risk of injury in the study.

4. FAMILIARIZATION

The subjects will complete a number of familiarization trials in the present study. Due to the nature of isokinetic testing and the inexperience of subjects involved, the practice bouts are deemed essential for the accurate collection of data. No subjects have previous experience in isokinetic testing and the machine-type strength assessment thus demands a period of familiarization. Three trials will be conducted at each of the machine speeds for the laboratory- and occupation-simulating tests. Subjects will be reminded not to over-exert in the familiarization test, as this would influence the actual maximal collection of data.

5. STRENGTH MEASURES

PROCEDURES

Testing positions will be standardized according to the instruction manual provided by CYBEX (Lumex Inc.). The dynamometer adjusted for subject leg and arm length and the subject data recorded for re-test in the event of data loss or machine complications.

ORDER OF TESTING

Subjects will be required to perform 10 maximal tests and the order will be set-up so as to allow for maximum recovery time in the rest phases. The rest period involves the time it takes to set-up the dynamometer (with the relevant attachments) and the time taken to test the other two subjects. The time will be approximately 15 minutes between each test for the subject concerned.

6. PSYCHOPHYSICAL RESPONSES

PERCEPTUAL MEASURES

Perception of exertion ratings will be taken using Borg's (1971) RPE scale. An adapted African language (Xhosa) version will be used for subjects who are not fluent in English.

Care will be taken to adequately define the procedures of the rating scale to the subjects involved in the testing. Measures will be taken at the completion of each maximal testing bout and recorded for data reduction

CARDIOVASCULAR MEASURES

Heart rate responses will be recorded during the maximal testing using a POLAR™ heart rate monitor. Readings are taken at the end of the four maximal repetitions. Reference heart rate and recovery heart rate are also taken at the commencement and completion of the study.

TEST PROTOCOL

1.) The test protocol will be verbally explained to you (the subject) before the testing commences.

2.) The following information will be obtained:

Age	Dominance (Arm and Leg)
Body Mass	Activity level and Training
Body Fat Percentage	
Stature	

3.) A warm-up will be carried out on a Monark™ Cycle ergometer before maximal testing commences.

4.) The procedures of the CYBEX 6000 will be explained to you

5.) The specific test movements, for example knee extension, will be explained. The RPE scale will be clarified.

6.) Maximal testing will follow on the CYBEX 6000. The order for testing will be as follows:

Session 1:	**Session 2:**
1.) Trunk test (LT)	1.) Ankle test (LT)
2.) Valve-tightening test (OST)	2.) Shoulder test (LT)
3.) Knee test (LT)	3.) Elbow test (LT)
4.) Pulling/pushing test (OST)	4.) Gripping test (OST)
5.) Wrench-turning test (OST)	5.) Hip test (LT)

7.) Prior to the each test you will be placed into the correct position and given the an opportunity to become familiar with test procedures.

8.) You will then commence the testing. The instructions "are you ready?", followed by "Go" will start testing each time.

8.) Verbal encouragement will be given.

9.) Following testing a rest period will be allowed.

10.) The next bout of maximal testing will follow on the CYBEX 6000. You will be placed into the correct position and the instruction above will be repeated.

11.) This procedure will be completed for all ten tests.

Letter of information:

LABORATORY AND OCCUPATION-SIMULATING ISOKINETIC AND PSYCHOPHYSICAL RESPONSES OF MILITARY PERSONNEL

(Jonathan P James)

LETTER OF INFORMATION

Dear ___________________

Thank you for volunteering to be a subject in this Master's Research Project. You will be part of a group of subjects who will participate in isokinetic testing on the CYBEX 6000 Isokinetic Dynamometer. Testing will take place in two sessions and you will be given comprehensive feedback on your results.

The testing will take place in the Department of Human Kinetics and Ergonomics and will be supervised by a senior academic. You will be required to perform several test procedures. The first session will involve the following tests: trunk, valve-tightening, knee, pulling/pushing and wrench-turning. The second session will involve the following: ankle, hip, shoulder, elbow and gripping tests.

You will be permitted to stop or leave the study at any time, should you wish. Some of the benefits which you will get from this study include: a measure of your peak torque, work and power outputs of your knee, elbow, shoulder, ankle, trunk, hip, gripping, pulling/pushing, wrench-turn and valve-turn testing. As an infantryman this information can be used to assist you in your training to reduce your chances of injury and improve your combat readiness.

Jonathan James (MSc Student)

SUBJECT DEMOGRAPHIC AND DATA SHEETS:

Department of Human Kinetics and Ergonomics

Laboratory and occupation-simulating isokinetic and psychophysical responses of military personnel

(Jonathan P James)

Subject detail sheet:	***Cybex Code:***
Name: **(For records purposes only)**	
Age:	
Body Mass (kg)	
Body Fat % (BI)	
Stature (mm)	
Dominance: Arm	
Dominance: Leg	

***Cybex Code:*____________**

Data Collection: **Session 1**

Isometric Testing: Back strength data

Trial 1:	Trial 2:

Test	Speed	$Nm.kg^{-1}$	$W.kg^{-1}$	$J.kg^{-1}$
Trunk	$30°.s^{-1}$			
	$120°.s^{-1}$			
	$210°.s^{-1}$			
Valve	$30°.s^{-1}$			
	$120°.s^{-1}$			
	$210°.s^{-1}$			
Knee	$30°.s^{-1}$			
	$120°.s^{-1}$			
	$210°.s^{-1}$			
Pull-Push	$30°.s^{-1}$			
	$120°.s^{-1}$			
	$210°.s^{-1}$			
Wrench	$30°.s^{-1}$			
	$120°.s^{-1}$			
	$210°.s^{-1}$			

***Cybex Code:*___________**

Data Collection: **Session 2**

Isometric Testing: Grip strength data

Trial 1:	Trial 2:

Isometric Testing: Leg strength data

Trial 1:	Trial 2:

Test	*Speed*	*Nm.kg^{-1}*	*W.kg^{-1}*	*J.kg^{-1}*
Ankle	30°.s^{-1}			
	120°.s^{-1}			
	210°.s^{-1}			
Shoulder	30°.s^{-1}			
	120°.s^{-1}			
	210°.s^{-1}			
Elbow	30°.s^{-1}			
	120°.s^{-1}			
	210°.s^{-1}			
Gripping	30°.s^{-1}			
	60°.s^{-1}			
	90°.s^{-1}			
Hip	30°.s^{-1}			
	120°.s^{-1}			
	210°.s^{-1}			

Heart rate and RPE responses:

Cybex code:	
Session:	One
Group:	
Reference Heart Rate:	

Test	Speed	Heart Rate	RPE rating
Trunk	$30°.s^{-1}$		
	$120°.s^{-1}$		
	$210°.s^{-1}$		
Valve	$30°.s^{-1}$		
	$120°.s^{-1}$		
	$210°.s^{-1}$		
Knee	$30°.s^{-1}$		
	$120°.s^{-1}$		
	$210°.s^{-1}$		
Pull-push	$30°.s^{-1}$		
	$120°.s^{-1}$		
	$210°.s^{-1}$		
Wrench	$30°.s^{-1}$		
	$120°.s^{-1}$		
	$210°.s^{-1}$		

Heart rate and RPE responses:

Cybex code:	
Session:	Two
Group:	
Reference Heart Rate:	

Test	Speed	Heart Rate	RPE rating
Ankle	$30°.s^{-1}$		
	$120°.s^{-1}$		
	$210°.s^{-1}$		
Shoulder	$30°.s^{-1}$		
	$120°.s^{-1}$		
	$210°.s^{-1}$		
Elbow	$30°.s^{-1}$		
	$120°.s^{-1}$		
	$210°.s^{-1}$		
Gripping	$30°.s^{-1}$		
	$60°.s^{-1}$		
	$90°.s^{-1}$		
Hip	$30°.s^{-1}$		
	$120°.s^{-1}$		
	$210°.s^{-1}$		

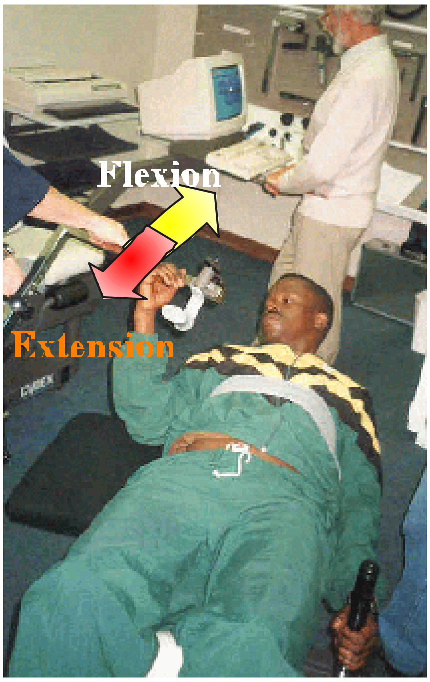
APPENDIX D: STRENGTH MEASUREMENT PROCEDURES

ISOKINETIC DYNAMOMETRY: LABORATORY TEST PROCEDURES

SET-UP: KNEE LT

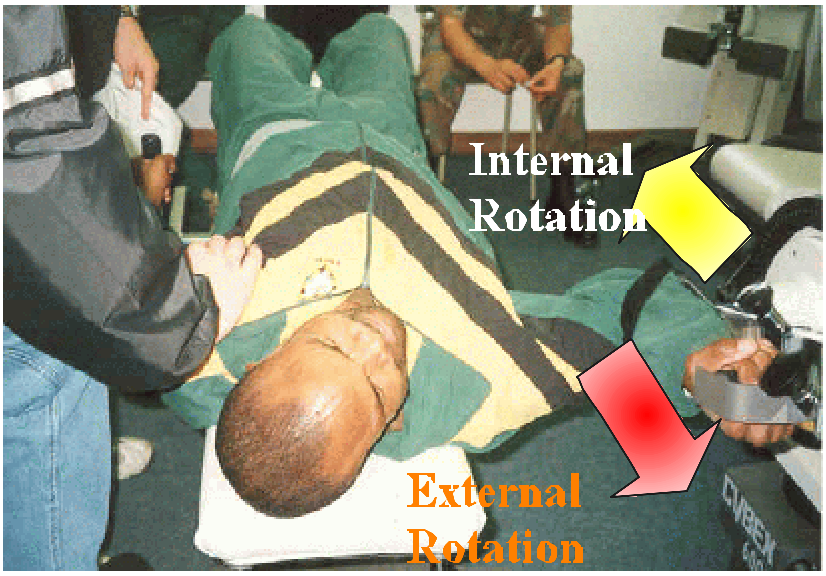
Set-up procedure: Knee. Entire range of motion assessed was approximately 95°.

SET-UP: ELBOW LT



Set-up: Elbow. Entire range of motion assessed was 150°.

SET-UP: SHOULDER LT

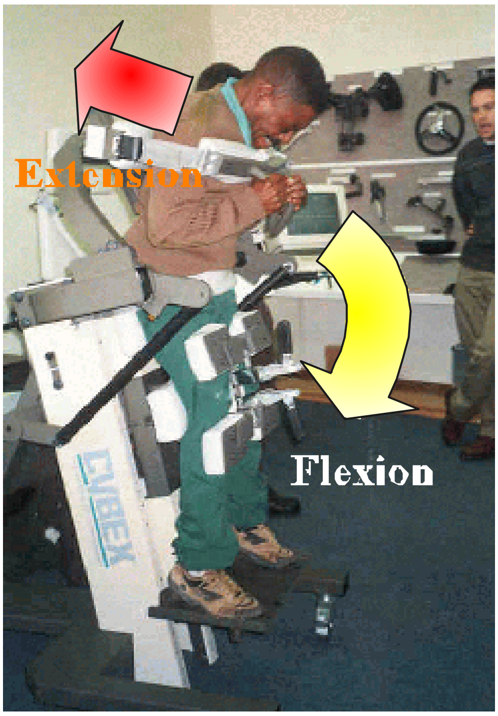


Set-up: Shoulder. Entire range of motion assessed was approximately 160°.

SET-UP: ANKLE LT

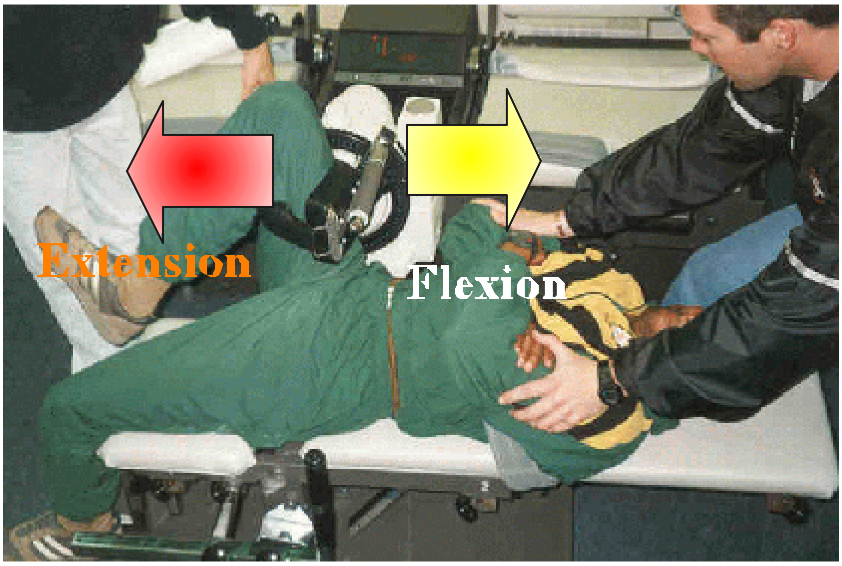
Set-up: Ankle. Entire range of motion assessed was 70°.

SET-UP: TRUNK LT



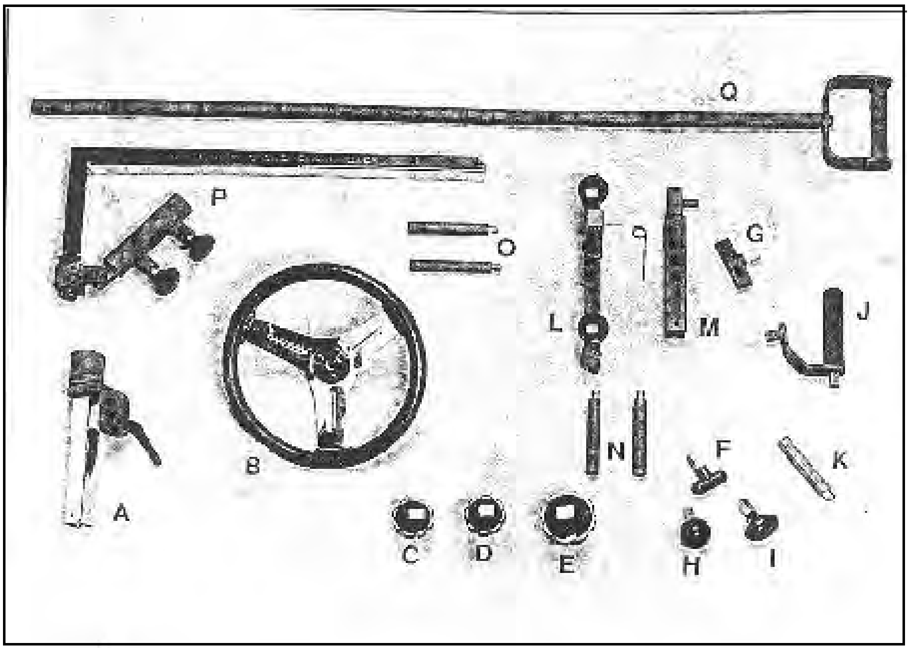
Set-up: Trunk. Entire range of motion assessed 100°.

SET-UP: HIP LT



Set-up: Hip. Entire range of motion assessed was approximately 125°.

CYBEX 6000 “work-simulation” Package (CYBEX, Division of Lumex, Inc., Ronkonkoma, New York).



CYBEX 6000 “Work-Simulation” Accessories

A. Universal Worksim Arm

B. Wheel/Valve Adaptor

C. Small Fluted Knob

D. Small Fluted Knob (Large Offset)

E. Large Fluted Knob

F. Small “T” Handle

G. Large “T” Handle

H. Spherical Knob

I. Oval Knob

J. Multi-Grip/Screwdriver Adaptor

K. Universal Tool Adaptor

L. Stationary Gripper Arm

M. Gripping Device

N. ½” Diameter Handle

O. 3/4" Diameter Handle

P. Push/Pull Input Arm

Q. Simulation Handle

Not shown - 1/8" Allen Wrench

STRAIN-GAUGE DYNAMOMETERY:

Rogers P.F.I Strength Testing Protocol

Leg Lift:

In the leg lift the knees are flexed, but the trunk is held erect. Unless standardized so that the starting angle is 102°, and the direction of the push vertical, this test produces meaningless results.

Back Lift:

In the back lift the legs are straight, but the trunk is flexed over the dynamometer. Unless standardized so that the starting angle is 156°, and the knees fully extended, this test produces invalid results.

Hand Grip:

Have the subject grasp the dynamometer in the appropriate (dominant) hand. The grip is taken between the fingers and the palm at the base of the thumb. The grip width of the dynamometer can be adjusted for proper fit.

APPENDIX E: TEST FEEDBACK

ISOKINETIC DYNAMOMETRY FEEDBACK

LABORATORY AND OCCUPATION-SIMULATING ISOKINETIC AND PSYCHOPHYSICAL RESPONSES OF MILITARY PERSONNEL

(Jonathan P James)

SUBJECT: ______________

TEST RESULTS:

TABLE I: Laboratory Tests

Test	Movement	Peak Torque ($Nm.kg^{-1}$)	Total Work ($J.kg^{-1}$)	Average Power ($W.kg^{-1}$)
Knee	**Extension** **Flexion**			
Shoulder	**Internal Rotation** **External Rotation**			
Elbow	**Extension** **Flexion**			
Hip	**Extension** **Flexion**			
Trunk	**Flexion** **Extension**			
Ankle	**Plantarflexion** **Dorsiflexion**			

Note: Data refers to the value as a percentage of your body mass.

HOW DO YOU COMPARE? ____

____

____

____

____

____

TABLE II:OCCUPATION-SIMULATING TESTS

Test	Movement	Peak Torque ($Nm.kg^{-1}$)	Total Work ($J.kg^{-1}$)	Average Power ($W.kg^{-1}$)
Valve-tightening	**Left** **Right**			
Wrench-turning	**Left** **Right**			
Gripping	**Closed**			
Pulling/ Pushing	**Pulling** **Pushing**			

HOW DO YOU COMPARE? ____
____
____
____
____
____

TRAINING SUGGESTIONS:____
____
____
____
____

Thank you for your participation in this study and the effort you put into the Isokinetic Testing. It was much appreciated. If there are still some questions which you would like answered, you can contact me at the address provided below.

Jonathan James
MSc Student
DEPARTMENT OF HUMAN KINETICS AND ERGONOMICS
RHODES UNIVERSITY
GRAHAMSTOWN

APPENDIX F: SUMMARY REPORTS

Example print-out from the CYBEX Computer

Sample print-out from the STATGRAPHICS programme

APPENDIX G: STATISTICAL TABLES

Two-way analysis of variance (direction over speed) of agonist/antagonist responses for LTs across the velocity spectrum.

Measure	*Variance Analysis Source*	*SS*	*DF*	*MS*	*F*	*P*
Trunk Flex/Ext:	**Between:**	**105.5252**	**2**	**52.7626**	**111.333**	**.0000***
Peak Torque (Nm.kg^{-1})	**Within:**	**.34100**	**1**	**.3410**	**.720**	**.4062**
Total Work (J.kg^{-1})	**Between:**	**360.5411**	**2**	**180.2705**	**372.940**	**.0000***
	Within:	**9.1428**	**1**	**9.1428**	**18.915**	**.0000***
Average Power (W.kg^{-1})	**Between:**	**223.9719**	**2**	**111.9859**	**140.564**	**.0000***
	Within:	**19.1842**	**1**	**19.1842**	**24.080**	**.0000***
Hip Flex/Ext:	**Between:**	**18.3299**	**2**	**9.1649**	**24.278**	**.0000***
Peak Torque (Nm.kg^{-1})	**Within:**	**70.7126**	**1**	**70.7126**	**187.318**	**.0000***
Total Work (J.kg^{-1})	**Between:**	**94.4054**	**2**	**47.2027**	**96.452**	**.0000***
	Within:	**160.9761**	**1**	**160.9761**	**328.932**	**.0000***
Average Power (W.kg^{-1})	**Between:**	**145.2036**	**2**	**72.6018**	**95.448**	**.0000***
	Within:	**143.7520**	**1**	**143.7520**	**188.989**	**.0000***
Knee Flex/Ext:	**Between:**	**71.4472**	**2**	**35.7263**	**218.740**	**.0000***
Peak Torque (Nm.kg^{-1})	**Within:**	**32.3431**	**1**	**32.3431**	**198.041**	**.0000***
Total Work (J.kg^{-1})	**Between:**	**67.3057**	**2**	**33.6528**	**196.341**	**.0000***
	Within:	**16.2844**	**1**	**16.2844**	**95.009**	**.0000***
Average Power (W.kg^{-1})	**Between:**	**143.9217**	**2**	**71.9608**	**235.189**	**.0000***
	Within:	**6.9567**	**1**	**6.9567**	**22.737**	**.0000***
Ankle Plantar/Dorsi:	**Between:**	**13.0505**	**2**	**6.5252**	**327.490**	**.0000***
Peak Torque (Nm.kg^{-1})	**Within:**	**5.5269**	**1**	**5.5269**	**277.384**	**.0000***
Total Work (J.kg^{-1})	**Between:**	**5.0135**	**2**	**2.5067**	**311.427**	**.0000***
	Within:	**1.7151**	**1**	**1.7151**	**213.081**	**.0000***
Average Power (W.kg^{-1})	**Between:**	**1.9490**	**2**	**.9745**	**67.842**	**.0000***
	Within:	**2.7281**	**1**	**2.7281**	**189.920**	**.0000***
Shoulder Int/Ext:	**Between:**	**.9684**	**2**	**.4842**	**55.774**	**.0000***
Peak Torque (Nm.kg^{-1})	**Within:**	**1.3029**	**1**	**1.3029**	**150.079**	**.0000***
Total Work (J.kg^{-1})	**Between:**	**6.6332**	**2**	**3.3166**	**81.371**	**.0000***
	Within:	**6.0481**	**1**	**6.0481**	**148.386**	**.0000***
Average Power (W.kg^{-1})	**Between:**	**27.7087**	**2**	**13.8543**	**491.983**	**.0000***
	Within:	**2.4347**	**1**	**2.4347**	**86.460**	**.0000***
Elbow Flex/Ext:	**Between:**	**2.1807**	**2**	**1.0903**	**81.375**	**.0000***
Peak Torque (Nm.kg^{-1})	**Within:**	**.5166**	**1**	**.5166**	**38.555**	**.0000***
Total Work (J.kg^{-1})	**Between:**	**14.0354**	**2**	**7.0177**	**211.175**	**.0000***
	Within:	**1.0556**	**1**	**1.0556**	**31.765**	**.0000***
Average Power (W.kg^{-1})	**Between:**	**26.2471**	**2**	**13.1235**	**375.995**	**.0000***
	Within:	**.58966**	**1**	**.5896**	**16.894**	**.0001***

Two-way analysis of variance (direction over speed) of opposite-direction responses for OSTs across the velocity spectrum.

Measure	*Variance Analysis Source*	*SS*	*DF*	*MS*	*F*	*P*
Pulling/Pushing: Peak Torque (Nm.kg^{-1})	**Between:**	**118.320**	**2**	**59.160**	**81.012**	**.0000***
	Within:	**30.396**	**1**	**30.396**	**41.623**	**.0000***
Total Work (J.kg^{-1})	**Between:**	**304.330**	**2**	**152.165**	**189.103**	**.0000***
	Within:	**57.629**	**1**	**57.629**	**71.619**	**.0000***
Average Power (W.kg^{-1})	**Between:**	**372.611**	**2**	**186.306**	**141.264**	**.0000***
	Within:	**53.609**	**1**	**53.609**	**40.648**	**.0000***
Valve-Tightening Left Rotation/Right Rotation: Peak Torque (Nm.kg^{-1})	**Between:**	**3.046**	**2**	**1.523**	**54.650**	**.0000***
	Within:	**0.183**	**1**	**0.183**	**6.584**	**.0109***
Total Work (J.kg^{-1})	**Between:**	**8.304**	**2**	**4.152**	**61.171**	**.0000***
	Within:	**0.902**	**1**	**0.902**	**13.295**	**.0003***
Average Power (W.kg^{-1})	**Between:**	**106.577**	**2**	**53.289**	**506.122**	**.0000***
	Within:	**0.171**	**1**	**0.171**	**1.622**	**.2040**
Wrench-Turning Left Rotation/Right Rotation: Peak Torque (Nm.kg^{-1})	**Between:**	**0.021**	**2**	**0.021**	**11.260**	**.0009***
	Within:	**0.118**	**1**	**0.589**	**31.514**	**.0000***
Total Work (J.kg^{-1})	**Between:**	**0.093**	**2**	**0.933**	**15.832**	**.0001***
	Within:	**0.289**	**1**	**0.145**	**24.589**	**.0000***
Average Power (W.kg^{-1})	**Between:**	**0.076**	**2**	**0.076**	**15.192**	**.0001***
	Within:	**7.249**	**1**	**3.625**	**722.408**	**.0000***