BIOMECHANICAL CHARACTERISTICS OF THE LOWER EXTREMITIES OF AMPUTEE VERSUS NORMAL SUBJECTS

MASTER OF APPLIED SCIENCE

CON HRYSOMALLIS

1991

DEPARTMENT OF PHYSICAL EDUCATION AND RECREATION

FACULTY OF GENERAL STUDIES

FOOTSCRAY INSTITUTE OF TECHNOLOGY

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ABSTRACT

The purpose of this study was to determine whether biomechanical characteristics of the non-amputated leg of unilateral lower extremity amputees significantly differed from the dominant leg of normal subjects. A comparison was made of the mean peak isokinetic knee extensor and ankle plantar flexor torques and mean performance in one-legged static and countermovement vertical jumps.

Peak isokinetic torque was measured by a Cybex II at 60 degrees.s^{-1}. Vertical jump performance was captured on video tape and analysed using the Peak 2D Motion Measurement System. The heights of the jumps were calculated from the difference in the position of the centre of gravity of the body as determined by the segmentation method. Stump anthropometrics, Hanavan's (1964) model, and density data from Dempster (1955) were used to calculate the volume, mass, and position of the centre of gravity of the residual limb of the amputee subjects.

Four unilateral lower extremity amputees, age 31.5 $\pm$ 4.9 years and height 179.7 $\pm$ 2.3 cm, were compared with four normal subjects, age 31.1 $\pm$ 4.1 years and height 179.2 $\pm$ 1.8 cm. The results revealed that the mean peak isokinetic knee extensor (190 $\pm$ 19 Nm) and ankle plantar flexor (84 $\pm$ 20 Nm) torques for the amputees were less than but not significantly ($p<0.05$) different from the mean peak isokinetic knee extensor (199 $\pm$ 15 Nm) and ankle plantar flexor (115 $\pm$ 21 Nm) torques of the normal subjects. The normal subjects

attained a higher mean rise of the centre of gravity of the body during one-legged countermovement (14.6 $\pm$ 2.6 cm) and static (11.1 $\pm$ 0.5 cm) jumps than the amputee subjects (13.1 $\pm$ 1.9 cm for countermovement, 10.6 $\pm$ 1.1 cm for static jumps) but the difference was not significant ($p<0.05$)

It was concluded that the normal subjects did not have superior knee extensor or ankle plantar flexor strength and unilateral lower extremity amputees would not be disadvantaged in their standing one-legged jumping ability.

ACKNOWLEDGEMENTS

I would like to express my gratitude to Dr. William Morrison for his inspiration and invaluable guidance as supervisor. Many thanks are extended to Tim Wrigley and Ian Fairweather for their technical assistance. My appreciation is also extended to my brother Nick for his help during the pilot work. I would also like to acknowledge Neil Diamond for his assistance with the statistical analysis and Joanne Beck for typing this thesis. Thanks also to Tim Bach and Dr. John Carlson for their help. Financial support during the latter part of this study was provided by a Footscray Institute of Technology - Industry Postgraduate Research Scholarship for which I am grateful. Finally, sincere thanks to the subjects for their time and effort.

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CHAPTER 1

1.0 INTRODUCTION

A German neurosurgeon, Sir Ludwig Guttman was largely responsible for initiating organized sport for individuals with disabilities. In 1944, at the Stoke Mandeville Hospital in Buckingham, Guttman introduced his therapy of wheelchair sport and recreation for patients with spinal cord disabilities (Paravics, 1990).

Australia's involvement in wheelchair sport began when Doctor David Cheshire, Spinal Unit Director of the Austin Hospital, Heidelberg, along with the Paraplegic and Quadriplegic Association organized the first games for the disabled in Melbourne in 1960. There were approximately 50 competitors from around Australia. At the more recent National Games for the disabled in Adelaide in 1986, there were over 200 competitors (Paravics, 1990).

Paravics has been the organization that controls and organizes wheelchair sport in Victoria. It has provided sporting and recreational activities for people with spinal cord injury, spina bifida or poliomyelitis. Recently, international policy has been changed to permit individuals with other non-spinal disabilities to compete in the same events; for example, amputees play basketball (Paravics, 1990).

Early instances of organized activities for amputees occurred in Germany for ex-servicemen after the First World War. Later, an organization in the USA provided golf for leg and/or arm amputees. In several European countries and the USA, skiing has become popular for amputees (Williams and Sperryn, 1976).

The Victorian Amputee Association first held games for the disabled in October, 1980, in which competitors participated in golf, swimming, athletics, snooker, table tennis and squash. Now amputees play a large variety of sport at state, national and international levels. In recent times amputees have been classified into disability levels for competition. For example, a single below-knee amputee was Class C (Beebe, 1981).

Demographic data have not been generated for Australia but in the USA investigations have shown that approximately 17 amputees exist per 10,000 people (Glattly, 1964). Amputation has been the result of trauma, congenital deformities, and disease including carcinoma. Lower extremity amputation can occur at various levels: partial foot, below-knee, above-knee or hip disarticulation and may involve one or both lower limbs. It was believed that the number of below-knee amputees have increased because of the ageing population and surgical removal of limbs related to peripheral vascular disease (Winter and Sienko, 1988). Bone cancer has contributed to an increase in the number of above-knee amputees (DiAngelo, Winter, Ghista, and Newcombe, 1989).

An indication of participation of lower extremity amputees in sporting and recreational activities can be gauged from Table 1. Kegel, Carpenter, and Burgess (1978) surveyed 134 lower extremity amputees, 103 males and 31 females. Of these, 87 were below-knee, 27 above-knee, and 20 bilateral amputees. The ages of the subjects at time of amputation ranged from three to 89 years with a mean of 45 years. The time from amputation to this survey ranged from six months to 12 years.

Of the amputees surveyed, 82 (61%) were active in various sports and 65 (49%) participated in more than one activity. Age and amputation level played a role in determining whether amputees participated in sports. Those that did participate in sport had a younger mean age and lower level of amputation. Only 6% used special prostheses or assistive devices for sports. Examples of these devices were swimming fins for scuba diving and special straps or outriggers for skiing.

Table 1. Avocational activities of lower extremity amputees.

	Below-knee	Above-knee	Bilateral	Total
Fishing	46	11	5	62
Swimming	29	11	4	44
Dancing	28	8	5	41
Hunting	19	4	1	24
Bowling	15	5	-	20
Golf	15	5	-	20
Hiking	11	3	1	15
Baseball	9	3	2	14
Basketball	7	3	1	11
Running	6	2	1	9
Snowskiing	4	3	-	7
Football	4	2	1	7
Skating	4	1	1	6
Horseback riding	-	3	1	4
Gardening	3	-	1	4
Miscellaneous*	6	6	1	13

* Miscellaneous included waterskiing, motorcycling, soccer, flying a sailplane, frisby, cutting wood, cheerleading, boating, ping pong, and uneven parallel bars.

Kegel et al., 1978.

In another survey, 100 lower extremity amputees, 85 males and 15 females, were questioned on participation in recreational activities (Kegel, Webster, and Burgess, 1980). There were 58 below-knee, 25 above-knee, and 17 bilateral amputees. The mean age at the time of the amputation and the survey was 35 and 45 years respectively. Table 2 displays the recreational activities the amputees participated in immediately prior to and after amputation.

Table 2. Recreational activities of amputees.

Activity	Before amputation	After amputation
Fishing	38	43
Swimming	42	40
Bowling	30	27
Hunting	33	24
Golf	17	21
Baseball	34	17
Horseback riding	15	16
Basketball	27	12
Volleyball	24	12
Waterskiing	17	8
Snowskiing	6	10
Tennis	9	6
Football	26	4
Jogging	17	3

Kegel et al., 1980

The extent of amputee participation in recreational activities was in agreement with the previous survey. Gender was not a significant factor in determining whether amputees were active. The younger amputees were more involved in recreation. Unlike the previous survey, the level of amputation was not a determining factor in the activity level. It was found that 60% of each group of subjects with below-knee, above-knee, and bilateral amputations were active.

It was apparent that lower extremity amputees had a high participation rate in sporting and recreational activities, yet a review of the literature revealed that biomechanical research on specific population groups was limited. Most of the biomechanical research conducted on lower extremity amputees has focused on gait: walking (Hoy, Whiting, and Zernicke, 1982; Lewallen, Quanbury, Ross and Letts, 1985; Winter and Sienko, 1988) and running (Miller, Enoka, McCulloch, Burgess, and Frankel, 1981; Enoka, Miller and Burgess, 1982; Miller, 1987).

Hoy et al. (1982) analyzed the gait of five child unilateral lower extremity amputees. Stride kinematics and knee joint kinetics were examined for three different speeds of walking, two types of prosthetic feet, and intact versus prosthetic limbs.

The walking gait, joint angles, and joint moments in the sagittal plane at the knee and hip joint of six above-knee and six below-knee amputees was compared with 17 normal subjects (Lewallen et al., 1985). The joint moments of the amputees' intact limb were found to be normal or below normal. The moments about the joints in the free and supported amputated limb were lower than the intact limb.

Winter and Sienko (1988) collected synchronized cinematographic and force plate data from eight below-knee amputees during walking. EMG activity was recorded from five residual muscles (gluteus maximus, biceps femoris, semitendinosis, rectus femoris and vastus lateralis) from three of the subjects. All subjects were found to have more active hip extensors during early and mid-stance phases which resulted in above-normal energy generation by these concentrically contracting muscles. This compensation made up for the loss of the major energy generation by the plantar flexors at push-off.

Vertical ground reaction force-time histories of ten lower extremity amputee runners were analyzed by Miller et al. (1981). It was found that the maximum force recorded on the prosthetic limb, while between two and three times body weight, did not significantly differ from that on the intact limb.

Enoka et al. (1982) analyzed the running gait of ten unilateral below-knee amputees. Examination was made of the temporal and length characteristics of the running strides and the angular displacement patterns of the intact and prosthetic limbs. Six of the subjects satisfied the criterion for running, that being, having alternating periods of single support and complete non-support in their strides.

Miller (1987) determined resultant flexion/extension lower extremity joint moments of four below-knee amputees during the running stance. It was found that the resultant hip extensor moment on the amputated side was greater in magnitude and duration than on the intact side. It was suggested that the increased moment may help control knee flexion and promote knee extension of the residual limb.

There has been limited biomechanical research conducted on specific population groups. Most of the biomechanical research on lower extremity amputees has concentrated on kinematic and kinetic parameters associated with gait. It was evident that data on simple and complex movements involving unilateral lower extremity amputees were sparse.

1.1 Statement of the Problem

Do the biomechanical characteristics of the non-amputated leg of unilateral lower extremity amputees significantly differ from the dominant leg of normal subjects? The aim of this investigation was to compare performance in single joint motions and complex, multijoint movements. More specifically a comparison was made of:

(i) Peak isokinetic torque generated by the ankle plantar flexors and knee extensors.

(ii) Performance in one-legged vertical jumps with and without a preparatory countermovement.

1.2 Hypotheses

The null hypotheses were:

(i) Peak isokinetic torque of the ankle plantar flexors and knee extensors of unilateral lower extremity amputees would not significantly differ from that of normal subjects.

(ii) Performance in one-legged vertical jumps, with and without a preparatory countermovement, of unilateral lower extremity amputees would not significantly differ from that of normal subjects.

1.3 Significance of the Study

The proficiency with which motor tasks are executed has been found to be dependent on several factors. Physiological, psychological, and biomechanical parameters all influence the effectiveness with which a movement pattern is accomplished. There are limited data on the biomechanical characteristics of the lower extremities of unilateral amputees. There has been increased interest and participation in disabled sports. This study was designed to obtain a better understanding of the capabilities of amputees so as to encourage and facilitate their participation in sporting and recreational activities.

1.4 Limitations of the Study

The limitations of this investigation were as follows:

(i) Subject population was limited to physically active males

(ii) Amputee subjects were selected on the basis of availability and willingness to participate in the investigation

(iii) The videotape data were subject to inaccuracies inherent with the recording and digitizing processes.

1.5 Assumptions

To perform this investigation it was necessary to make certain assumptions. It was assumed that:

(i) For both jumps, the subjects completely understood the procedures and exerted maximal effort when requested.

(ii) The action of jumping vertically involved movements in the sagittal plane. Any minor deviations from this plane would be insignificant.

(iii) Videotape data were captured at a constant rate.

(iv) Dempster's (1955) and Hanavan's (1964) anthropometric data used in the determination of the centre of mass generated valid values.

1.6 Definition of Terms

The following terms were defined in accordance with their particular usage in this investigation.

Countermovement jumps (CMJ): Vertical jump which commenced with the subject in an upright stationary position, then without an observable pause, crouched and propelled upwards.

Cybex II: Cybex® II commercial dynamometer (Lumex, Incorporated Bay Shore, New York) used to assess isokinetic torque.

Isokinetic: Constant angular speed of body segment.

Limb-lever system: Input adaptor (lever) of Cybex II and body segment attached to it.

Normal subjects: Individuals with no amputations to the lower extremities.

Sampling rate: Number of frames acquired per second.

Static jump (SJ): Vertical jump which commenced with the subject in a stationary crouch position with no allowance for a preparatory countermovement.

Take-off: The instant the metatarsal heads of the foot lost contact with the force platform.

Torque: Product of the length of the lever arm and the force perpendicular to the lever arm.

Unilateral lower extremity amputees: Individuals with above-ankle amputations of one leg.

Vertical jump: Upward propulsion of the body. Unless specified otherwise, referred to two-legged propulsion.

Vertical jump performance: The height attained by the CGB from take-off to the apex of the jump.

1.7 Abbreviations

ANOVA:	Analysis of variance
CGB:	Centre of gravity of the body
cm:	centimetres
EMG:	Electromyogram
FIT:	Footscray Institute of Technology
FT:	Fast-twitch
ft.lb:	Foot pounds, 1 ft.lb = 1.356 Nm
Hz:	Hertz
Kg:	Kilograms
l^{-1}	per litre
m:	meters
mm:	millimetres
ms:	milliseconds
Nm:	Newton metres

p:	level of significance
r:	correlation coefficient
<u>r</u>:	length of movement arm
ROM:	Range of Motion
s:	seconds
s^{-1}:	per second
s^{-2}:	per second squared
SHD:	Super Heavy Duty
ST:	Slow-twitch
UBXT:	Upper-Body Exercise and Testing Table
USA:	United States of America
VHS:	Video Home System
$\bar{x} \pm$ SD:	mean $\pm$ standard deviation
2D:	Two Dimensional
%:	percent

CHAPTER 2

LITERATURE REVIEW

2.1 ISOKINETICS AND CYBEX II

Isokinetics has been the term applied to muscle contractions that accompany constant angular speed of a limb. Hinson, Smith, and Funk (1979) provided mathematical proof that constant angular speed of a limb was not accompanied by a constant linear rate of muscular contraction.

Isokinetic devices have been developed to keep limb motion at a constant, preselected speed. When the preselected speed is attained, any effort applied to the lever arm of the device encounters an equal counterforce. Increased muscular output produces increased resistance rather than acceleration. The resistance developed is proportional to the torque exerted (Moffroid, Whipple, Hofkosh, Lowman and Thistle, 1969)

The concept of isokinetic exercise was developed by Perrine (1969). Since its inception, isokinetic exercise has become increasingly popular in clinical, athletic, and research settings. It has been used as a rehabilitation tool in clinical setings, as a training and testing device for athletes and as a method of examination of the relationships between torque and angular velocity, and muscle agonist/antagonist action (Coplin, 1971; Markhede and Grimby, 1980; Fugl-Meyer, 1981).

The Cybex II has been widely used for the evaluation of voluntary muscular concentric contractions (Cybex, 1988). Cybex II provides measurements of torque in conjunction with the joint angle throughout the ROM. A dual-channel recorder is attached to the torque transducer and to an internal electrogoniometer within the Cybex II mechanism. Since speed and resistance are controlled, objective measures of torque can be obtained (Costain and Williams, 1984).

2.1.1 Acceleration and Deceleration in Isokinetic Movements

Cybex II does not provide resistance or measure torque until the limb segment attempts to exceed the preselected speed. An acceleration phase has been detected during the initiation of a movement (Hislop and Perrine, 1967). This is necessary for the limb to attain the preselected speed of the dynamometer (Osternig, 1975). The faster the preselected speed, the greater the initial ROM containing accelerated movement (Sawhill, 1981). The accelerating limb may actually exceed the preselected speed and is subsequently decelerated by the dynamometer.

Artifact appears in Cybex II torque data as a result of the initial deceleration and subsequent speed fluctuations of an initially overspeeding limb-lever system. The artifact is in the form of a prominent initial torque "overshoot" spike. The damping circuit in the Cybex II suppresses the overshoot artifact, but it may also suppress the muscular torque signal as well (Sapega, Nicholas, Sokolow and Saraniti, 1982).

Investigations have found that when a damp setting is used, the torque curve shifts relative to the time base and is no longer synchronized with the goniometric tracing (Sinacore, Rothstein, Delitto and Rose, 1983). Angle-specific torque measurements are questionable when a damp setting is used, especially at high speeds (Rothstein, Lamb and Meyhew, 1987).

It has been stated that for accurate analysis, torque data only from the constant speed portion of the ROM be considered. The ROM analyzed excludes the initial and final portions where overshoot (Perrine and Edgerton, 1978) and final decelerations of the limb-lever system (Osternig, Sawhill, Bates and Hamill, 1983) have been reported.

2.1.2 Advantages of Isokinetic Devices

The use of Cybex II to evaluate muscular performance has been proposed to overcome some of the limitations of other methods such as isometric measures and one-repetition maximum contractions with free weights. The torque produced by muscle contraction is continuously registered during movement at constant angular speed. The rotary torque input shaft of the Cybex II simplifies the task of isolating muscle groups so that extraneous muscle contributions are minimized by stablization means (Perrine, 1986). There is an inherent safety factor in Cybex II. An individual does not encounter more resistance than they can handle because the resistance is equal to the force applied (Davies, 1984). This device optimally loads the muscles and joints through the ROM, accommodating to pain and fatigue, thereby minimizing potential for injuries.

2.1.3 Strength and Slow Speeds of Isokinetic Testing

Strength had no inherent definition when applied to muscle performance and has to be defined operationally (Rothstein et al., 1987). In the context of isokinetic testing, slow speeds of 60 degrees.s^{-1} or below have been used as a measure of muscular strength (Davies, 1984). Muscular strength has been associated with the maximum force or tension generated by a muscle or muscle group. Tension is a uniaxial force generated when a muscle pulls on a tendon. It can only be measured if some type of dynamometer is attached directly to the tendon. Numerous authors [e.g.Hill (1970)] have employed invasive means to assess in vitro muscular tension. When tension is measure directly, it is not influenced by mechanical factors such as the lever arm. Muscle tension can not be measured directly by isokinetic devices. The torque recorded by an isokinetic device is an indirect reflection of the tension a muscle is generating (Rothstein et al., 1987).

2.1.4 Fast Speeds of Isokinetic Testing

In the literature pertaining to isokinetic devices, the term "power" has been used inappropriately. Any tests faster than 60 degrees.s^{-1} have been considered to be power tests (Davies, 1984). However, by definition, power is work per unit time (Kreighbaum and Barthels, 1985).

It has been proposed that the reason for testing at fast contractile speeds was because the angular speeds of various sport activities were very fast (Davies, 1984). It has been suggested that faster speeds of joint motion on the Cybex II approximate those needed for functional activities such as gait. For normal adults during free cadence gait (speed = 133cm.s^{-1}), it was found that the knee extensors became active during the last 12% of the gait cycle and during this stage the knee extended at a rate of 233 degrees.s^{-1} (Wyatt and Edwards, 1981).

Cybex II has a maximum speed setting of 300 degrees.s^{-1}. Many functional activities involve speeds greater than those which can be measured by this device. Ingen Schenau, Bobbert, Huijing and Woittiez (1985) measured angular velocities of plantar flexion of 12 trained subjects performing maximal SJs. The mean maximal angular velocity was found to be 970 degrees.s^{-1}.

Isokinetic limb movements do not occur normally since functional movements are not constant speed (Rothstein et al., 1987). As previously stated, the faster the preselected speed, the greater the ROM containing accelerated movement (Sawhill, 1981). It has been suggested that measurements should not be taken from the first or last 0.125s of the torque curve. This is where overshoot and damping error occur. At some high test speeds the torque curves may be briefer than 0.25s, thus resulting in insufficient torque duration to obtain accurate peak torque readings (Cybex, 1980).

2.1.5 Validity and Reliability of Cybex II Measurements

The validity (Moffroid et al., 1969) and reliability (Johnson and Siegel, 1978; Mawdsley and Knapik, 1982) of Cybex II measurements have been substantiated. Moffroid et al. (1969) placed successive loads (five, 10, 20, 30, 40, 50, 60 pounds) on the isokinetic device at the same distance (two-foot lever arm) and position. From this test protocol a linear relationship was obtained. To determine the validity when the same load (30 pounds) was placed at various angular positions through an arc of 180 degrees, the calculated torque was correlated with the obtained torque. The coefficient of validity of predicted-to-obtained torque measurements was found to be high ($r=0.999$).

Johnson and Siegel (1987) measured the peak knee extension torque in 40 female subjects aged 17 to 50 years, at 180 degrees.s^{-1} . Six test trials on each of three consecutive days were administered. Reliability was determined by interclass correlations using a two-way ANOVA design. It was found that the major portion of variance was accounted for by subjects (92.85%). Of much less importance was the two sources of error variance: days (5.10%) and trials (2.05%). The average correlation for the mean of the last three trials per day for the three days was 0.98.

Various testing protocols have been used for the assessment of peak isokinetic torque. Johnson and Siegel (1978) found that a protocol of three submaximal trials followed by three maximal warm-up trials was required before reproducible measures were manifested. Mawdsley and

Knapik (1982) assessed 16 subjects (12 men and four women) aged from 20 to 50 years, for peak isokinetic knee extension torque at 30 degrees.s^{-1} . Six maximal trials were elicited in each of the three sessions separated by two weeks. It was found on the average, that there were no significant differences in mean peak torque across trials or across sessions. The pattern of peak torque values within test sessions differed and it was recommended that at least one maximal warm up trial should be permitted if subjects were to be tested in one session only. Both studies used non-reciprocal contractions.

2.1.6 Gravitational Effect on Isokinetic Movements

With movements in the vertical plane, the limbs not only work against the dynamometer but are also either aided or opposed by gravity. A correction for the gravitational forces acting on the moving limb and lever arm has to be made to eliminate this potentially large error (Winter, Wells and Orr, 1981; Fillyaw, Bevins and Fernandez, 1986).

Winter et al. (1981) had four male subjects perform two minutes of submaximal alternating knee flexion and extension at three different speeds (20, 40, and 60 degrees.s^{-1}). When the gravitational forces were not taken into account, the error in mechanical work varied from 26 to 43% in extension and from 55 to 510% in flexion.

Fillyaw et al. (1986) compared peak isokinetic knee extension and flexion torque values uncorrected for gravity with peak torque values corrected for gravity. Twenty-five female university soccer players with a mean age of 19 years were tested at 60 and 240 degree.s^{-1}. Correcting for gravity yielded increases in mean extension peak torque of 4.5ft.lb (6.1Nm) at 60 degrees.s^{-1} and 7ft.lb (9.5Nm) at 240 degrees.s^{-1} over the uncorrected torque values. For knee flexion, gravity correction yielded approximately an 8ft.lb (11Nm) decrease in peak torque at each speed. Gravity corrected values were determined as recommended by Nelson and Duncan (1983).

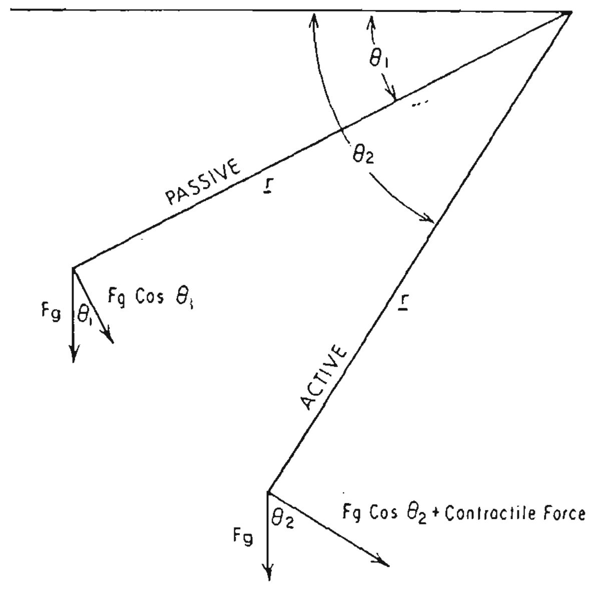
An accurate and simple technique to correct isokinetic torque recordings for the effects of gravity was presented by Nelson and Duncan (1983). The torque resulting from the weight of the limb-lever system was recorded when the limb-lever system was allowed to fall passively against the resistance of the dynamometer. The gravitational torque at the specific angular position was calculated and this correction factor was added to the peak torque generated by muscle groups opposed by gravity or subtracted from the peak torque generated by muscle groups aided by gravity.

To illustrate this technique, the authors used knee extension as an example. As the lower leg fell passively at any angle of knee flexion (Θ1), the torque (TgΘ1) due to gravity (Fg) was equal to (FgCosΘ1) multiplied by the length of the movement arm (r) [Figure 1]; that is,

$$Tg\Theta 1 = Fg\ Cos\Theta 1\ (\underline{r})$$

$$Fg = \frac{Tg\Theta 1}{(\underline{r})\ Cos\Theta 1}$$

Figure 1. Correction of isokinetic peak torque for the effect of gravity



Gravitational torque (PASSIVE) and combined gravitational and active muscular torque (ACTIVE). $F_g Cos\theta_1 (\underline{r})$ is the maximal torque resulting from the force of gravity during the passive fall when the limb and the input arm are θ_1 degrees from the horizontal. ($F_g Cos\theta_2$ + contractile force) $\underline{r}$ is the torque recorded during a maximal contraction when the limb and the input arm are θ_2 degrees from the horizontal.

Nelson and Duncan, 1983.

The contribution of gravitational force to torque recorded at any given angle ($\Theta 2$) for an active maximum effort contraction ($Tg\Theta 2$) was,

$$Tg\Theta 2 = \underline{r}\,(FgCos\Theta 2)$$

$$= \frac{Tg\Theta 1 \quad (Cos\Theta 2)\underline{r}}{(\underline{r}Cos\Theta 1)}$$

$$= \frac{Tg\Theta 1\ Cos\Theta 2}{Cos\Theta 1}$$

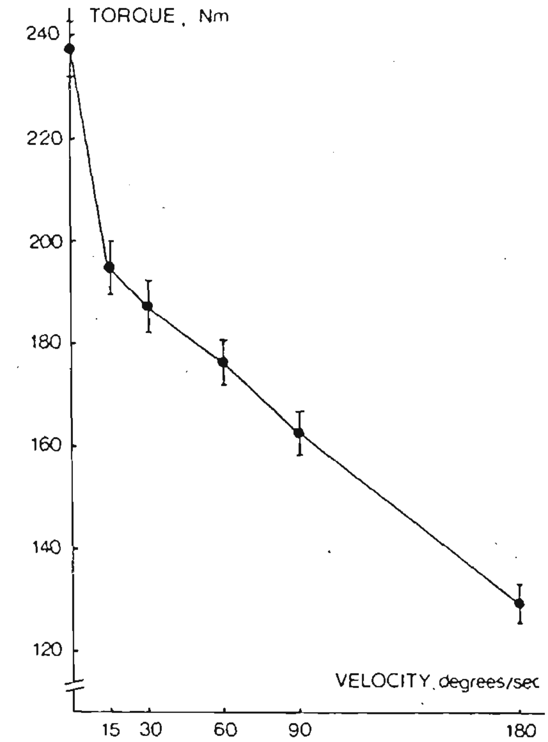
2.1.7 Isokinetic Torque - Velocity Relationship

Studies have demonstrated that as the speed of isokinetic testing is increased, peak isokinetic torque values tend to decrease (Moffroid et al., 1969; Thorstensson, Grimby and Karlsson, 1976; Barnes, 1980; Yates and Kamon, 1983). Peak isokinetic torque also occurs later in the ROM as velocity increased (Thorstensson et al., 1976; Osternig et al., 1983). Muscle length and joint angle define a joint position for optimal performance. At high angular velocities the joint may pass this point before maximum tension is developed (Coyle, Costill and Lesmes, 1979).

When considering the torque-velocity relationship researchers have investigated the peak torque generated within the ROM (Thorstensson et al., 1976; Lesmes, Costill, Coyle and Fink, 1978; Barnes, 1980) and the torque produced at a constant angle (Moffroid et al., 1969; Osternig, 1975; Perrine and Edgerton, 1978; Ivy, Withers, Brose, Maxwell and Costill, 1981; Yates and Kamon, 1983).

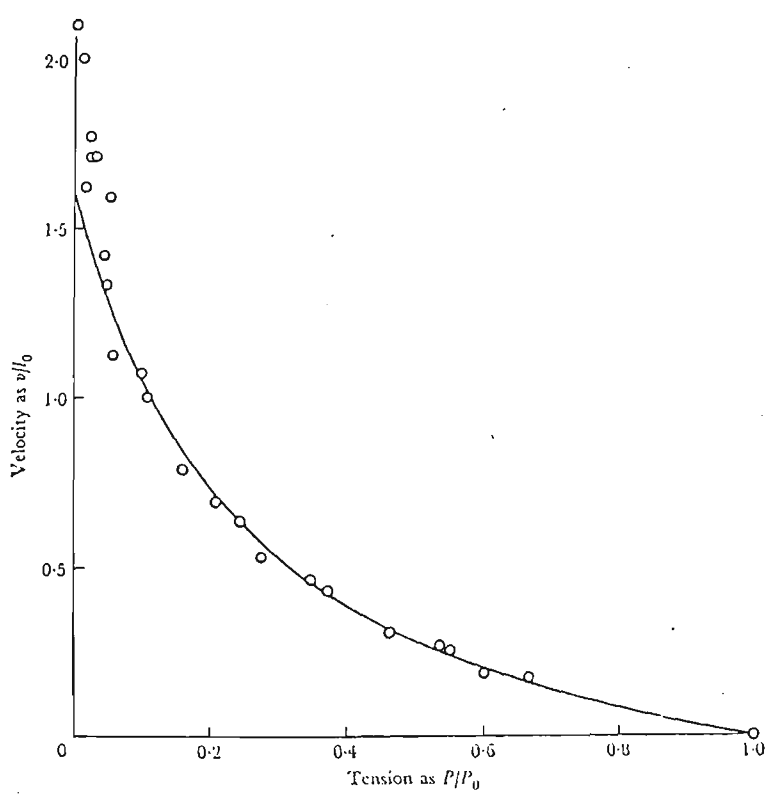
Conflicting results have been presented for in vivo torque-velocity relationship for both peak torque generated within the ROM and the torque produced at a constant angle. Thorstensson et al. (1976), Ivy et al. (1981) and Yates and Kamon (1983), demonstrated a relationship (Figure 2) similar to Hill's (1938) classical in vitro force-velocity relationship (Figure 3).

Figure 2. Torque-velocity relationship of human knee extensor muscles.



Thorstensson et al., 1976.

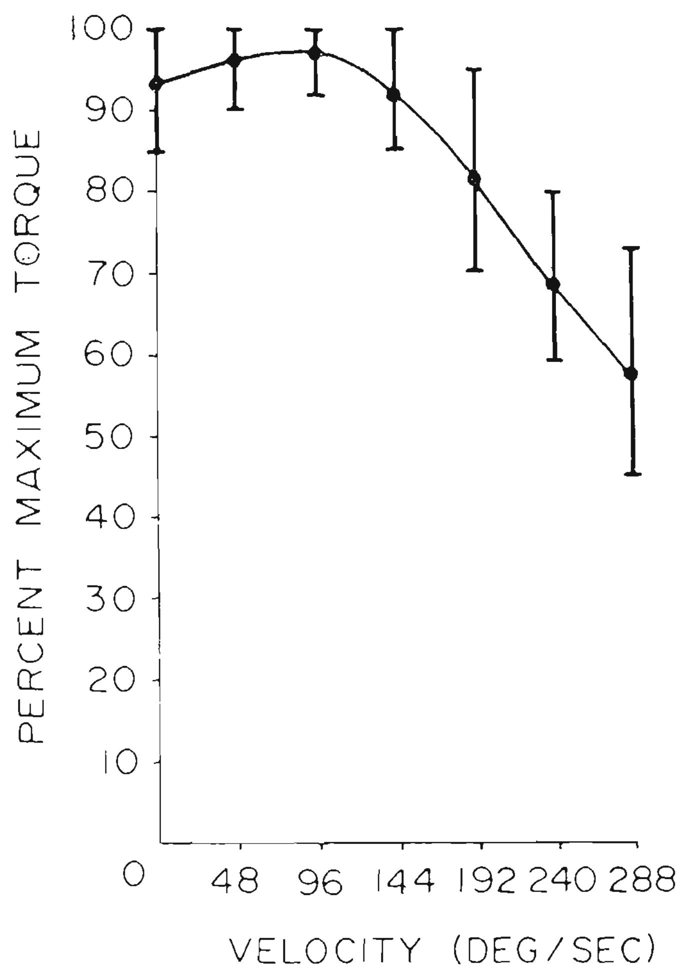
Figure 3. Force-velocity relationship of in vitro animal muscle.



Hill, 1938.

Moffroid et al. (1969), Osternig (1975), Lesmes et al. (1978), Perrine and Edgerton (1978), and Barnes (1980) found that the in vivo torque-velocity curve (Figure 4) was similar to the in vitro hyperbola at higher velocities but a plateau was observed in the torque generated at lower velocities. It was postulated that a neural mechanism limited muscle tension development at lower velocities (Perrine and Edgerton, 1978).

Figure 4. Torque-velocity relationship normalized with respect to maximum torque.



Perrine and Edgerton, 1978.

Baltzopoulos and Brodie (1989) have cautioned against comparisons between the in vitro and in vivo force-velocity curves. The velocity in the in vitro relationship represented the actual velocity of muscular contraction, where as the velocity in the in vivo relationship represented the velocity of the moving limb. A difference also existed in the control of muscle activation. For in vitro studies, stimulation was under experimental control and could be keep constant at all contractile velocities. During in vivo studies with human subjects, activation was voluntarily controlled and the possibility of variation existed (Bobbert and Ingen Schenau, 1990).

2.1.8 Muscle Fibre Type Composition and Cybex II Peak Isokinetic Torque

An individual's muscle fibre composition is an important determinant of performance in various physical activities (Gollnick, Armstrong, Saubert, Piehl and Saltin, 1972). The research investigating the relationship between muscle fibre composition and peak isokinetic torque using Cybex II has focused on the knee extensors with the biopsies performed on the vastus lateralis (Thorstensson et al., 1976; Ivy et al., 1981; Clarkson, Johnson, Dextradeur, Leszczyuski, Wai and Melchionda, 1982; Schantz, Randall-Fox, Hutchison, Tyden and Astrand, 1983; Johansson, Lorentzon, Sjostrom, Fagerlund and Fugl-Meyer, 1987).

Significant relationships between the distribution of different fibre types in vastus lateralis and peak isokinetic torque have been found. There was a trend for peak torque within the ROM to be determined by the percent FT fibres (Thorstensson et al., 1976; Ivy et al., 1981; Johansson et al., 1987). Conflicting results have also been reported. Clarkson et al. (1982) and Schantz et al. (1983) did not find a relationship.

Thorstensson et al. (1976) measured knee extensor torque in 25 healthy habitually active male subjects. Significant correlations were demonstrated between peak torque produced at the highest test speed (180 degrees.s^{-1}) and percent as well as relative area of FT fibres.

Ivy et al. (1981) assigned 15 active male subjects to three groups on the basis of the proportion of FT fibres. Subjects with predominantly FT fibres demonstrated significantly greater peak power at 120, 180, 240, and 300 degrees.s^{-1} but not at the lowest speed of 60 degrees.s^{-1}. The highest correlation between performance and percent FT fibres occurred at 180 degrees.s^{-1}.

The results of Johansson et al. (1987) also illustrated that the peak isokinetic torque at 180 degrees.s^{-1} expressed characteristics of the muscle structure. Five male sprinters and five marathon runners were evaluated for peak isokinetic torque at 30 to 180 degrees.s^{-1}. Peak torque was closely correlated to the calculated absolute FT (type 11A) fibre area of vastus lateralis, but only at 180 degrees.s^{-1}.

It was suggested (Johansson et al., 1987) that subjects with a greater proportion of FT fibres may develop peak torque at a joint angle closer to the optimal for maximal torque. FT fibres are characterized by a shorter contraction time (Barany, 1967) and a faster rate of tension development (Close, 1972).

Although the rate of rise in tension may be faster in muscle containing a high percent FT fibres as opposed to muscle containing a high percent ST fibres, Ivy et al. (1982) found no significant difference in time to peak torque between the groups. It was stated that since the angular speed of the limb was preset during isokinetic movements the angle resulting in optimal lever length for torque production was a constant point in the ROM for each subject regardless of the subject's muscle fibre composition.

Contrary to the three aforementioned studies, Schantz et al. (1983) found no significant correlation. The relationship between peak isokinetic torque, ST muscle fibre distribution and muscle cross-sectional areas were examined in 23 subjects (seven female and 11 male physical education students as well as five male body builders). Maximal knee as well as elbow extension and flexion torque at angular speeds of 30, 90, and 180 degrees.s^{-1} was measured. Maximal tension developed per unit of muscle cross-sectional area in knee and elbow extensors did not correlate significantly with percent ST fibre area and did not differ between the female and male students or bodybuilders.

Clarkson et al. (1982) also found no significant correlation between isokinetic torques (made relative to maximum voluntary contraction or per kg of body mass) and muscle fibre composition. A smaller sample size of eight male subjects were tested at 0, 30, 180, and 240 degrees.s^{-1}.

To explain the discrepancy in the results, Ivy et al. (1981) have stated that peak isokinetic torque was probably influenced by the anatomical properties of the joints and regulatory mechanisms inherent in the nervous system, as well as muscle fibre composition (Coyle et al., 1979; Perrine and Edgerton, 1978; Wilkie, 1950).

Isokinetic devices do not measure force in direct line with the tension developed within the muscle. Peak isokinetic torque is assessed during angular motion and may not always reflect actual muscular tension (Coyle et al., 1979).

2.1.9 Normative Isokinetic Data

2.1.9.1 Introduction

Normative isokinetic dynamometry data have been presented for the ankle plantar flexors (Fugl-Meyer, 1981), and knee extensors (Poulmedis, 1985) of normal subjects and for the knee extensors of unilateral lower extremity amputees (Renstrom, 1981).

Normative data are specific to the particular population group and test conditions. For meaningful comparisons certain variables must be controlled. Differences in peak torque values have been identified, resulting from technical and anatomical variations. Technical considerations were different angular speeds (Moffroid et al., 1969; Thorstensson et al., 1976; Barnes, 1980; Yates and Kamon, 1983), damp setting (Sinacore et al., 1983), correction for the effect of gravity (Fillyaw et al., 1986), and the provision of knowledge of results (Figoni and Morris, 1984).

Figoni and Morris (1984) examined the effects of knowledge of results on peak isokinetic knee extension torque of 20 male subjects (aged 27.0 ± 4.1 years) at 15 and 300 degrees.s^{-1}. The knowledge of results condition consisted of the subjects watching the torque stylus draw the blue torque curve on the Cybex II recorder's white chart sheet. Provision of knowledge of results significantly improved torque (approximately 12%) at the slow speed but not the fast speed.

2.1.9.2 Anatomical Factors

The anatomical considerations comprised of sex (Miyashita and Kanehisa, 1979), age (Murray, Gardner, Mollinger and Sepic, 1980), training status (Fugl-Meyer, 1981), limb dominance (Wyatt and Edwards, 1981), test position (Fugl-Meyer, Gustafsson and Burstedt, 1980), and starting angle (Narici, Sirtori and Mognoni, 1989).

Miyashita and Kanehisa (1979) determined peak isokinetic knee extensor torque of 569 Japanese school boys and girls, aged 13 to 17 years, and 35 swimmers of both sexes, aged 11 to 21 years. The subjects were tested at an angular speed of 210 degrees.s^{-1}. A significant sex difference in peak torque between the same age groups was found.

Age has been shown to influence peak isokinetic torque. Maximum isokinetic knee extensor of the dominant limb of 72 sedentary male subjects was measured at 36 degrees.s^{-1} (Murray et al., 1980). The subjects were divided into three age groups of 24 each: 20 to 35, 50 to 65, and 70 to 86 years. It was found that the mean peak isokinetic torque was 2227 $\pm$ 96 kg.cm (218 $\pm$ 9.4 Nm) for the youngest group, 1509 $\pm$ 129 kg.cm (148 $\pm$ 12.6 Nm) for the middle age group, and 1302 $\pm$ 83 kg.cm (128 $\pm$ 8.1 Nm) for the oldest age group.

Fugl-Meyer (1981) compared peak isokinetic plantar flexion torque of 15 trained competitive male athletes (age 24 $\pm$ 3 years) with 15 nonathletes (age 25 $\pm$ 3 years) who were inactive during working hours and leisure. The trained athletes regularly competed in at least one of the following sports: badminton, volleyball, handball, soccer, and figure skating. Plantar flexion was performed with the subjects supine, the knee in full extension, and commenced from maximum dorsiflexion position. Subjects were assessed at angular speeds of 30, 60, 120, and 180 degrees.s^{-1}. It was found at all test speeds that the mean peak isokinetic plantar flexion torque of the athletes were equal to or greater than, those of the nonathletes +2SD. For example, at 60 degrees.s^{-1}, the athletes registered 145 $\pm$ 24 Nm and the nonathletes 96 $\pm$ 22 Nm.

Wyatt and Edwards (1981) measured the peak isokinetic knee extension torque difference between dominant and nondominant legs. Both legs of 50 male and 50 female nonathletes between the ages of 24 and 34 were tested at 60, 180, and 300 degrees.s^{-1}. Lower extremity dominance was determined by the foot the subjects used to place kick a ball through two goal posts set four feet apart.

For males, the mean torque values of the dominant leg was significantly greater than the mean torque values generated by the nondominant leg at all three speeds. Dominant and nondominant knee extension torque values did not differ significantly for the females ($p<0.01$).

Different test positions have been demonstrated to influence peak isokinetic torque. Fugl-Meyer et al. (1980) measured peak isokinetic plantar flexion torque in 135 sedentary subjects (66 males and 69 females) aged between 20 and 65 years. The subjects assumed a supine position on a plinth and were tested in two positions at 30, 60, 90, 120, and 180 degrees.s^{-1}. The first position was with the knee in full extension and the second with the flexed 90 degrees. Both males and females generated significantly greater (approximately 13%) peak torques in the fully extended knee than in the flexed knee ($p<0.01$).

Narici et al. (1989) assessed peak isokinetic knee extensor torque of eight sedentary males (aged 23.8 ± 3.5 years) at two different starting angles and five angular speeds (60, 120, 180, 240, 300 degrees.s^{-1}). The first starting angle was 90 degrees before full knee extension and the second was 120 degrees before full extension. With the increased starting angle it was found that the peak torque was significantly greater at all angular speeds. At 60 degrees.s^{-1}, the peak torque was approximately 13 Nm greater for the 120 degrees starting condition than for the 90 degree starting condition.

2.1.9.3 Axis of Rotation

It has been shown that a single axis of rotation for normal ankle joint motion does not exist. Sammarco, Burstein and Frankel (1973) utilized a roentgenographic technique to determine the instant joint centres of 22 normal weight bearing ankles and six normal nonweight bearing ankles of living subjects. It was found that the instantaneous centres of rotation continuously changed from the time the motion commenced in plantar flexion to its termination at dorsiflexion. They occurred anatomically both within and without the body of the talus, some above and anterior to, as well as below the talus itself.

When evaluating plantar flexion with the Cybex II there is a change in the axis of rotation as the limb segment moved without a corresponding change of the dynamometer axis. Rothstein et al. (1987) postulated that this introduced an error into the measurement.

Peak isokinetic plantar flexion torques have been found to be significantly greater at 0 degrees (0 degrees = full extension) than at 90 degree of knee flexion (Fugl-Meyer, 1981). Table 3 shows the peak isokinetic ankle plantar flexion torque of the dominant limb of 15 male athletes. The action was performed in the supine position with the knee in full extension.

Table 3. Mean peak isokinetic plantar flexion torque of 15 male athletes.

Item		$\bar{x} \pm SD$
Age (years)		24 ± 3
Body Mass (kg)		75 ± 6
Height (cm)		181 ± 8
Peak torque at	30 degrees.s^{-1}	184 ± 28
(Nm)	60 degrees.s^{-1}	145 ± 24
	120 degrees.s^{-1}	95 ± 16
	180 degrees.s^{-1}	63 ± 11

Adapted from Fugl-Meyer, 1981.

The knee has been the most investigated joint by isokinetic testing (see Cybex, 1988). Poulmedis (1985) assessed the peak isokinetic torque of the knee extensors of 18 elite soccer players (Table 4).

Table 4. Peak isokinetic torque of the knee extensors of 18 elite male soccer players.

Item		$\bar{x} \pm SD$
Age (years)		27.8 ± 3.4
Bodymass (kg)		75.5 ± 5.2
Height (cm)		176.6 ± 5.2
Peak torque at	30 degrees.s^{-1}	247 ± 29
(Nm)	90 degrees.s^{-1}	191 ± 35
	180 degrees.s^{-1}	126 ± 26

Adapted from Poulmedis, 1985.

2.1.9.4 Amputees

There have been limited isokinetic data available on amputees. Renstrom (1981) assessed the peak isokinetic extensor torque of 24 male unilateral below-knee amputees (Table 5).

Table 5. Peak isokinetic torque of the knee extensors in 24 below-knee amputees of the amputated leg with prosthesis and of the nonamputated leg.

Leg examined	Peak torque ($\bar{x} \pm SD$) (Nm) Angular speed (degrees.s^{-1}) 30	60	120
Amputated leg with prosthesis	52 ± 7	44 ± 6	38 ± 5
Nonamputated leg	156 ± 14	140 ± 12	105 ± 11

Adapted from Renstrom, 1981.

The subjects had a mean age of 61 ± 18 years. They had recently been training at an Amputee Training Centre. The mean time from amputation to the determination of peak isokinetic torque was 28 ± 22 months (this value was for a group which also included eight women). The body mass of the subjects was not recorded.

The subjects were seated with a trunk-thigh angle of approximately 80 degrees. Movement at the knee joint was from 100 degrees flexion to full extension. The torque values were corrected for the gravitational effect of the limb-lever system. The isokinetic knee extensor torques were significantly lower in the amputated leg than in the nonamputated leg at the three test speeds ($p<0.05 - 0.01$).

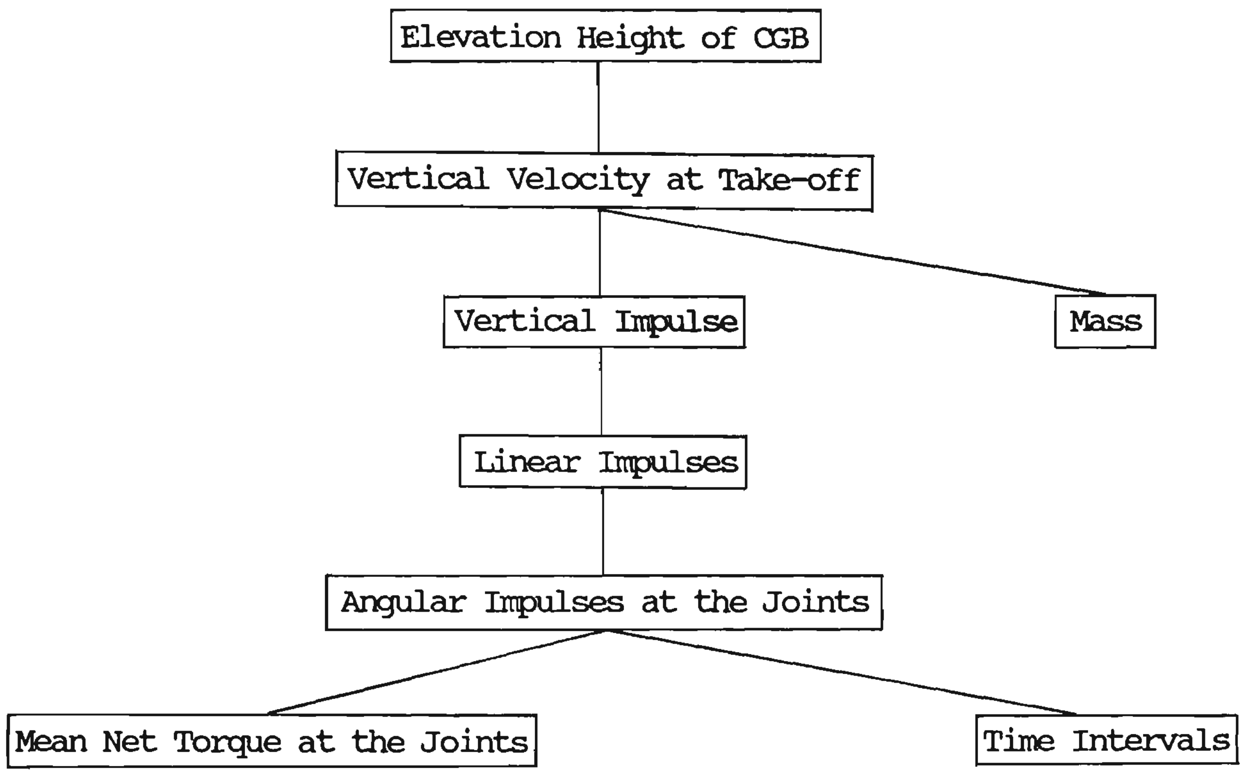
In summary, differences in peak isokinetic torque values have been identified, resulting from technical and anatomical variations. For valid comparison certain variables must be held constant. There are limited isokinetic data on amputees. No isokinetic data on young, active, unilateral amputees were available.

2.2 Vertical Jump

2.2.1 Factors Influencing Vertical Jump Performance

The height to which the CGB is elevated from take-off to the apex of flight in a maximal voluntary vertical jump has been found to be dependent on several biomechanical and physiological parameters. The jumping height is ultimately determined by the vertical velocity of the CGB at take-off. This velocity is dependent on the net linear vertical impulse and mass of the subject. The vertical impulses result from the vertical acceleration of the different segments and are determined by the angular impulses. The angular impulse experienced at a joint is the product of the mean net torque about that joint and time involved (Hay, Vaughan and Woodworth, 1981).

Figure 5. Theoretical model of the factors determining height of CGB in a vertical jump.



Adapted from Hay et al., 1981.

The net torque about a joint is the sum of torques exerted by agonists, antagonists and inert structures such as connective tissue. The force exerted by a muscle is the sum of the passive force exerted by structures parallel to the contractile components and the active force exerted by the contractile components (Bobbert and Ingen Schenau, 1988).

Force exertion has been shown to be determined by muscle activation level, muscle length, contraction velocity (Hill, 1970), precontraction state of the muscle (Cavagna, Dusman and Margaria, 1968), and skeletal muscle fibre composition (Thorstensson et al., 1976).

2.2.2 Enhancement of Muscle Performance After Stretching

Concentric work done by an active muscle has been demonstrated to be greater if the muscle is stretched prior to its shortening. Cavagna et al. (1968) carried out in vivo experiments on toad satorius muscle (Bufobufo) and frog gastrocnemius muscle (Rana esculenta) and on the forearm flexors of six male subjects aged 21 to 34 years.

The instrumentation used to obtain the force-length trace comprised of a lever driven by a compressed air piston operated by an electrovalve. This allowed for very rapid succession between stretching and shortening of the muscle. The movement was recorded via a potentiometer attached to the fulcrum of the lever and the force by a transducer. During the experiments, the upper arm was abducted at right angle to the body.

It was found that a muscle, both in vitro and in vivo, which shortened immediately after being stretched performed greater work than the same muscle if it shortened from a state of isometric contraction, with the speed, the length, and extent of shortening being constant.

The stretching of active muscles prior to shortening occurs in a vertical jump by a preparatory movement in the opposite direction of the anticipated movement. This countermovement with rapid flexion at the lower extermity joints places the extensors on stretch (Asmussen and Bonde-Peterson, 1974).

A number of factors have been proposed to explain the enhancement of muscle performance after stretching. Utilization of stored elastic energy, greater work done by the contractile component, and stretch reflex potentiation have been postulated to explain this prestretch phenomenon (Cavagna et al., 1968; Bosco and Komi, 1979a).

The utilization of elastic energy has been proposed to contribute a significant role (Asmussen and Bonde-Peterson, 1974) but its importance has also been disputed (Ingen Schenau, 1984). The utilization of stored elastic energy in a concentric contraction appears to be dependent on movement amplitude (Bosco and Komi, 1981; Bosco, Komi, and Ito, 1981), age (Bosco and Komi, 1980), and possibly gender (Komi and Bosco, 1978).

2.2.2.1 Influence of Movement Amplitude

Bosco and Komi (1981) investigated the influence of movement amplitude during prestretch on vertical jump performance. Ten male elite volleyball players aged 23.4 ± 3.2 years, performed SJs and CMJs which utilized similar movement ranges about the knee joint. The lowest point in the CMJ was recorded by an electrogoniometer and the SJ was then performed at this starting angle. Movement range varied between 27 and 90 degrees of angular displacement about the knee joint. The prestretch amplitude influenced the performance difference between CMJs and SJs. Improved performance in the concentric phase was noted with smaller prestretch amplitude. Movements of small amplitude displayed short (50 - 55ms) stretching time for the leg extensor muscles compared with higher amplitude movements (100 - 120ms).

Small amplitude jumps (those with a small degree of joint flexion) displayed greater utilization of elastic energy. This was thought to result from the shorter transition time in the stretch-shortening cycle. Bosco et al. (1981) had 14 male power trained subjects perform SJs and CMJs. Comparison was made between the two conditions which utilized similar movement ranges about the knee joint in the concentric phase. The results indicated that CMJs enhanced the mean concentric force and mean mechanical power. The higher the force at the end of prestretch, the greater this enhancement. The prestretch speed and rapid transition time in the stretch-shortening cycle were associated with enhanced performance during the concentric phase.

Further support for the influence of time delay in the stretch-shortening cycle on utilization of stored elastic energy may be obtained from a study by Thys, Faraggiana and Margaria (1972). Six subjects aged 22 to 29 years performed two types of movements. The first involved knee flexion from erect standing followed immediately by knee extension to return to the upright. The second involved an interval of 1.5s between the flexion and extension. For each condition, movement frequency was 20 cycles per minute and the degree of flexion was approximately the same. The movement was performed for approximately six minutes. The maximal speed during the extension was higher, the time of concentric work was less, the mean power and the mechanical efficiency were greater in the condition in which extension immediately followed flexion. The results suggests that optimal utilization of stored elastic energy was achieved when the shortening occurred immediately after the stretching.

Large amplitude jumps displayed an increase in the time delay between the stretch and shortening phases. Bosco and Komi (1981) proposed that the long stretch time of large amplitude movements resulted in the detachment of some of the cross bridges between the actin and myosin filaments of the muscle fibres.

Three mechanical elements have been assumed to exist in muscle. The contractile and two elastic elements, one parallel and the other in series with the contractile components (Carlson and Wilkie, 1974). The series elastic component has been thought to be located in the crossbridges (Hill, 1968) as well as in the tendon (Wilkie, 1956). This would explain the dissipation of elastic energy with large amplitude movements but Alexander and Bennet-Clark (1977) have presented evidence that in activities such as running, a greater amount of elastic energy can be stored in tendons as compared to the muscle itself.

2.2.2.2 Gender

The influence of gender on the storage capacity and utilization of elastic energy was investigated in 25 female and 16 male physical education students (Komi and Bosco, 1978). They performed SJs from a starting position of 90 degrees of knee flexion and CMJs. The maximum knee flexion for CMJs was not recorded. Examination of the energy changes indicated that in CMJs female subjects were able to utilize approximately 92% and male subjects approximately 49% of the energy produced in the prestretch phase. It was proposed that the females may be able to utilize a greater portion of elastic energy in vertical jumping.

Inconclusive results as to the influence of gender on the utilization of elastic energy were obtained in a more recent investigation. Hudson and Owen (1985) examined eight males and eight females of comparable levels of physical activity. Comparison was made between SJs and CMJs which utilized similar movement ranges about the knee joint. This was achieved with the use of an electrogoniometer. There was no significant difference between females (37%) and males (51%) in the use of stored elastic energy ($p<0.05$).

2.2.2.3 Influence of Age

The effect of age on performance of SJs and CMJs was examined in 226 subjects (113 females and 113 males) ranging in age from four to 73 years (Bosco and Komi, 1980). Peak performance was reached by both sexes between the ages of 20 and 30 years, then there was a decrease in performance as age increased. The results suggested that the elastic behaviour of muscle was also influenced by the ageing process.

2.2.2.4 Non-Elastic Mechanism

When an active muscle is forced to stretch it stores elastic energy which can be partially recovered during the shortening phase. It has been proposed that the increase in concentric work done after stretching is not only due to the utilization of elastic energy, but that the contractile component is also responsible for part of this increase (Cavagna et al., 1968; Ingen Schenau, 1984). This non-elastic mechanism is believed to be due to a greater force developed by each crossbridge between the muscle filaments (Cavagna, Mazzanti, Heglund and Citterio, 1985).

2.2.2.5 Stretch Reflex Potentiation

Another factor postulated to enhance muscular performance after prestretching is stretch reflex potentiation (Bosco and Komi, 1979a). Fast stretch of an active muscle causes substantial stretch reflex potentiation via Ia afferents from the muscle spindles resulting in an increased frequency of motor unit discharge (Prochazka, Westerman and Ziccone, 1977).

The improvement after prestretching of in vitro muscles with intact nervous connections has been attributed to a combination of the utilization of stored elastic energy and the reflex potentiation of muscle activation (Bosco and Komi, 1979a).

Support for the reflex potentiation hypothesis was found in a study by Bosco, Tarkka and Komi (1982). Five physical education students aged 29 ± 4.3 years performed maximal vertical jumps executed by the ankle plantar flexors only. The hip and knee joints were fixed with an orthopaedic cast. SJs were performed with the heels flat on the ground, CMJs were performed from a toe-standing position with a preliminary countermovement.

EMG activity was recorded from soleus and gastrocnemius. Comparison was made between SJs and CMJs which utilized similar movement ranges about the ankle joint during the concentric phase. The EMG records demonstrated significantly greater myoelectrical activity of the plantar flexors during the concentric phase in CMJs when compared to SJs. To separate the effects of utilization of elastic energy and reflex potentiation it was assumed that the force developed during the concentric phase of CMJs was linearly related to the integrated EMG activity. The contribution of elastic energy was 72% and reflex potentiation, 28%

In summary, it has been demonstrated that muscle performance is enhanced after stretching (Cavagna et al., 1968). Utilization of elastic energy has been postulated to contribute a considerable role (Asmussen and Bonde-Peterson, 1974). Movement amplitude (Bosco and Komi, 1981; Bosco et al., 1981), age (Bosco and Komi, 1980) and possibly gender (Komi and Bosco, 1978) appear to influence the storage and utilization of elastic energy in concentric contractions. Apart from the utilization of stored elastic energy, greater work done by the contractile component and stretch reflex potentiation have been proposed to contribute to the enhancement of muscle performance after stretching (Cavagna et al., 1968; Bosco and Komi, 1979a).

2.2.3 Skeletal Muscle Fibre Composition and Vertical Jump

Skeletal muscle fibre composition has been shown to influence vertical jump performance. Bosco and Komi (1979b) examined thirty-four male physical education students aged 24.3 ± 2.5 years for muscle fibre composition and performance in SJs and CMJs. FT muscle fibre distribution in vastus lateralis ranged from 19 to 76% with a mean 50.7 ± 15.1. Percent FT fibre showed significant relationship with the height of rise of the CGB in both SJs ($r=0.37$; $p<0.05$) and CMJs ($r=0.48$; $p<0.01$).

Similar results were obtained by Viitasalo and Bosco (1982). Six male students aged 20 to 27 years were separated into two groups of three according to their muscle fibre composition in vastus lateralis. The subjects in the first group had a FT fibre percent greater than 50 and jumped significantly higher in the SJ condition than the subjects with a FT fibre percent less than 50.

2.2.4 Coordination in Vertical Jumping

The vertical jump is a complex multijoint movement. Coordination is believed to be a requirement for proficient performance. Timing, sequencing and amplitude of muscle activation appear to be the bases of coordination (Bobbert and Ingen Schenau, 1988).

The two primary patterns of segmental coordination postulated for jumping have been simultaneous (Kreighbaum and Barthels, 1985) and sequential (Luttgens and Wells, 1982). In the simultaneous pattern all segments initiate extension at the same time. In the sequential pattern each distal segment initiates movement at the time of peak velocity of the adjacent proximal segment.

Research findings have been inconclusive as to which pattern of coordination is exhibited by skill jumpers. Hudson (1986) examined the coordination of segments in CMJs and SJs for ten male subjects aged 22.8 $\pm$ 3.4 years and ten female subjects aged 21.0 $\pm$ 1.9 years. All subjects were involved in jumping activities or distance running events.

Cinematographic data was used to construct a four segment model. The model consisted of head-arm-trunk, trunk, thigh, and legs. For each segment the phases of positive contribution was considered to commence with the initiation of extension and terminate with maximum angular velocity. The skilled jumpers initiated extensions and reached maximum velocity of the segments in proximal to distal order with very small time delays between adjacent segments. Thus in this study the most representative pattern of coordination for jumping was simultaneous.

Support for the sequential pattern of segmental coordination is found in a study by Bobbert and Ingen Schenau (1988). Ten skilled male volleyball players aged 23 $\pm$ 3 years performed CMJs. Ground reaction forces, cinematographic data and EMG activity from seven leg muscles were recorded.

Rectified, low-pass filtered EMG levels were assumed to reflect activation levels and rose to a maximum in the sequence: semitendinosus, long head of biceps femoris, gluteus maximus, vastus medialis, rectus femoris, soleus, and gastrocnemius. For the monoarticular extensor muscles to release as much energy as possible before toe-off, it was argued that the vertical velocity difference between the proximal and distal ends of the body segments reached their peak in a sequence: upper body, thighs, legs, and feet.

As pointed out by Gregoire, Veeger, Huijing and Ingen Schenau (1984), Vergroesen, De Boer and Ingen Schenau (1982) found large differences between the times for peak torques and that for peak power in the hip, knee, and ankle joints for CMJs. High power output in the ankle joints was also noted.

In one-legged CMJs, peak plantar flexion power has been found to be much greater than the largest power output obtained by multiplying velocities and peak torques during isokinetic plantar flexion (Bobbert, Huijing and Ingen Schenau, 1986). The maximal power output of the ankle during two-legged SJs was six times larger than the output for maximal isokinetic plantar flexion (Ingen Schenau et al., 1985).

One mechanism believed to account for this difference is the transfer of power from proximal to distal via biarticular muscles. Gregoire et al. (1984) examined the role of biarticular muscles in CMJs performed by eight male subjects.

Ground reaction forces, cinematographic data, and EMG activity from eight leg muscles were recorded. The high power output found in the ankle joint during plantar flexion was attributed to a sequential power flow from hip to knee to ankle joint. The power generated by the monoarticular extensors of the hip and knee joints was transferred distally to the ankle joints via the biarticular muscles.

Bobbert et al. (1986) estimated the contribution of biarticular muscle transfer, to work done during the push-off phase in one-legged CMJs by using a model of the muscle-tendon complex of triceps surae. Ten well trained male subjects performed one-legged CMJs with their nondominant leg. Ground reaction forces and cinematographic data were recorded. From the model it was estimated that muscle fibres, tendinous structures and biarticular transfer accounted for 30, 45 and 25%, respectively, of the total work done during the push-off phase.

In summary, the two main patterns of segmental coordination proposed for jumping have been simultaneous and sequential (Kreighbaum and Barthels, 1985; Luttgens and Wells, 1982). Studies have found inconclusive results as to which pattern of coordination was exhibited by skilled jumpers (Hudson, 1986; Bobbert and Ingen Schenau, 1988). Biarticular muscles have been suggested to transfer power from the proximal to distal segments (Gregoire et al.,1984)

2.2.5 Segmental Contribution to the Vertical Jump

Different techniques have been used to assess individual segment and joint contributions to the vertical jump. Miller and East (1976) analyzed the contribution of segment inertial forces to the vertical ground reaction force impulse during the propulsive phase.

Their investigation utilized four physically active college women aged 20 to 23 years who performed maximal CMJs with arm swing. Ground forces and cinematographic data were collected. The means and standard deviations of relative segmental contribution for four trials per subject were presented (Table 6).

Table 6. Relative contributions of segment inertial forces to the vertical ground impulse during the propulsion phase.

Segments	Subject: One	Two	Three	Four
Feet	0.8 ± 0.1	1.0 ± 0.1	1.3 ± 0.4	0.9 ± 0.3
Lower legs	5.0 ± 0.5	4.7 ± 0.3	7.2 ± 0.3	4.4 ± 0.3
Thighs	9.7 ± 1.3	9.1 ± 0.7	17.3 ± 0.6	7.1 ± 1.1
Trunk	54.5 ± 1.7	59.3 ± 2.8	46.6 ± 2.2	60.1 ± 0.6
Upper arms	9.6 ± 0.4	8.7 ± 0.4	7.8 ± 0.2	9.0 ± 0.7
Forearms and hands	11.5 ± 0.5	5.4 ± 2.8	10.8 ± 0.8	7.4 ± 0.6
Head and neck	9.6 ± 0.4	12.4 ± 1.6	8.0 ± 0.2	11.9 ± 0.3

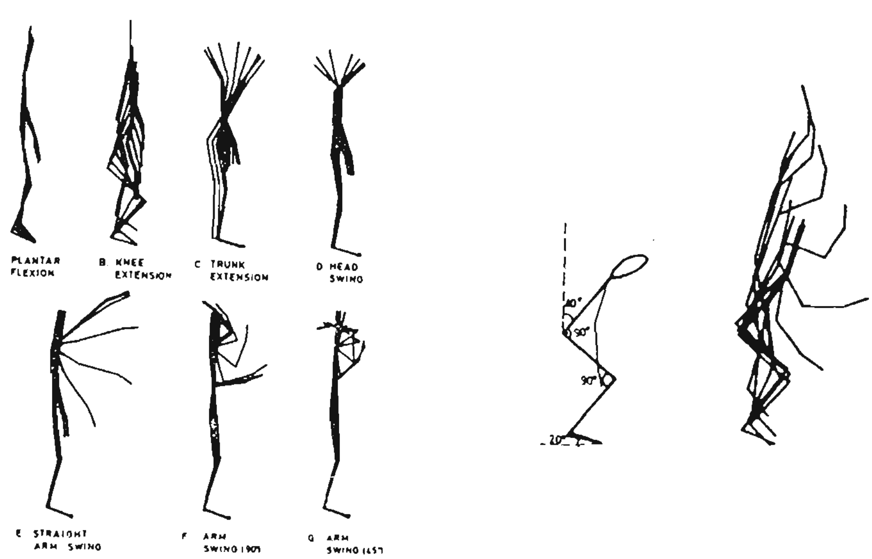
Miller and East, 1976.

This technique employed by Miller and East (1976) to assess segmental contribution was influenced by the mass of the individual segments. Therefore the trunk, because of its large mass, was considered responsible for most of the impulse generated.

Luhtanen and Komi (1978) analyzed segmental movement contribution to the forces acting on the CGB during vertical jumping. Eight skilled male jumpers (volleyball and basketball players) performed seven different isolated movements of maximum intensity.

The movements were: plantar flexion with straight knees and ankle angle of 20 degrees, knee extension from 90 degrees with fixed ankle angle of 0 degrees, trunk extension from 40 degrees of flexion, head swing backwards from full neck flexion, straight arm upward swing, upward arm swing with 90 degree elbow angle, and upward arm swing with 45 degree elbow angle. Complete maximal vertical jumps incorporating the segmental movements were also performed.

Figure 6. Schematic description of the isolated movements and the complete vertical jump.



Luhtanen and Komi, 1978.

Ground reaction forces and cinematographic data were used to calculate the positive net impulses in the segmental movements and their relative contribution to the complete jump. The results displayed the following relative segmental contribution to the vertical jump: knee extension 56%, plantar flexion 22%, trunk extension 10%, arm swing 10%, and head swing 2%.

Concern has been expressed with the isolation technique because of the difficulty with complete isolation of joint movements (Hubley and Wells, 1983). Luhtanen and Komi (1978) stated that several trials were performed and the isolated movements were accepted for analysis based on two criteria. Firstly, two observers had to agree that the movement was performed in accordance with the instructions. Secondly, the subject had to confirm that he "felt" the performance was successful.

A work-energy approach has been postulated to minimize problems associated with other techniques. Hubley and Wells (1983) used such an approach to quantify the work contributions of the muscles crossing the hip, knee and ankle joints to the total positive work done during maximal vertical jumps.

Six active male university students, mean age of 25 years, performed CMJs and SJs with the arms akimbo to minimize extraneous movements in the upperbody. Ground reaction forces and cinematographic data were used to construct a four segment model and calculate the positive mechanical work performed at each joint for the propulsive phase of the jump.

It was found that the mean relative contribution of the ankle, knee and hip muscles were approximately 23, 49 and 28% respectively. The muscles crossing the knee were the largest single contributor but the hip and ankle extensors were also important contributors.

The influence of arm swing on vertical jump performance was investigated by Khalid, Amin and Bober (1989). Twenty-eight subjects aged 23.6 ± 6.8 years performed SJs with arms akimbo, SJs with arm swing, CMJs with arms akimbo, and CMJs with arm swing. Ground reaction forces and electrogoniometric data from the knee joint were recorded.

Arm swing increased vertical jump performance by 11% for SJs and 10% in CMJs. These results were statistically significant ($p<0.05$). Analysis of kinematic knee data revealed that time for extension, angle of extension at take-off, and maximum angular velocity of flexion and extension were not significantly influenced by arm swing.

Since the difference in jumps with or without arm swing was not reflected in the kinematic knee data, it was proposed that the gain in jumping height was the result of the enhancement of the stretch-shortening cycle of the leg muscles and subsequent utilization of elastic energy.

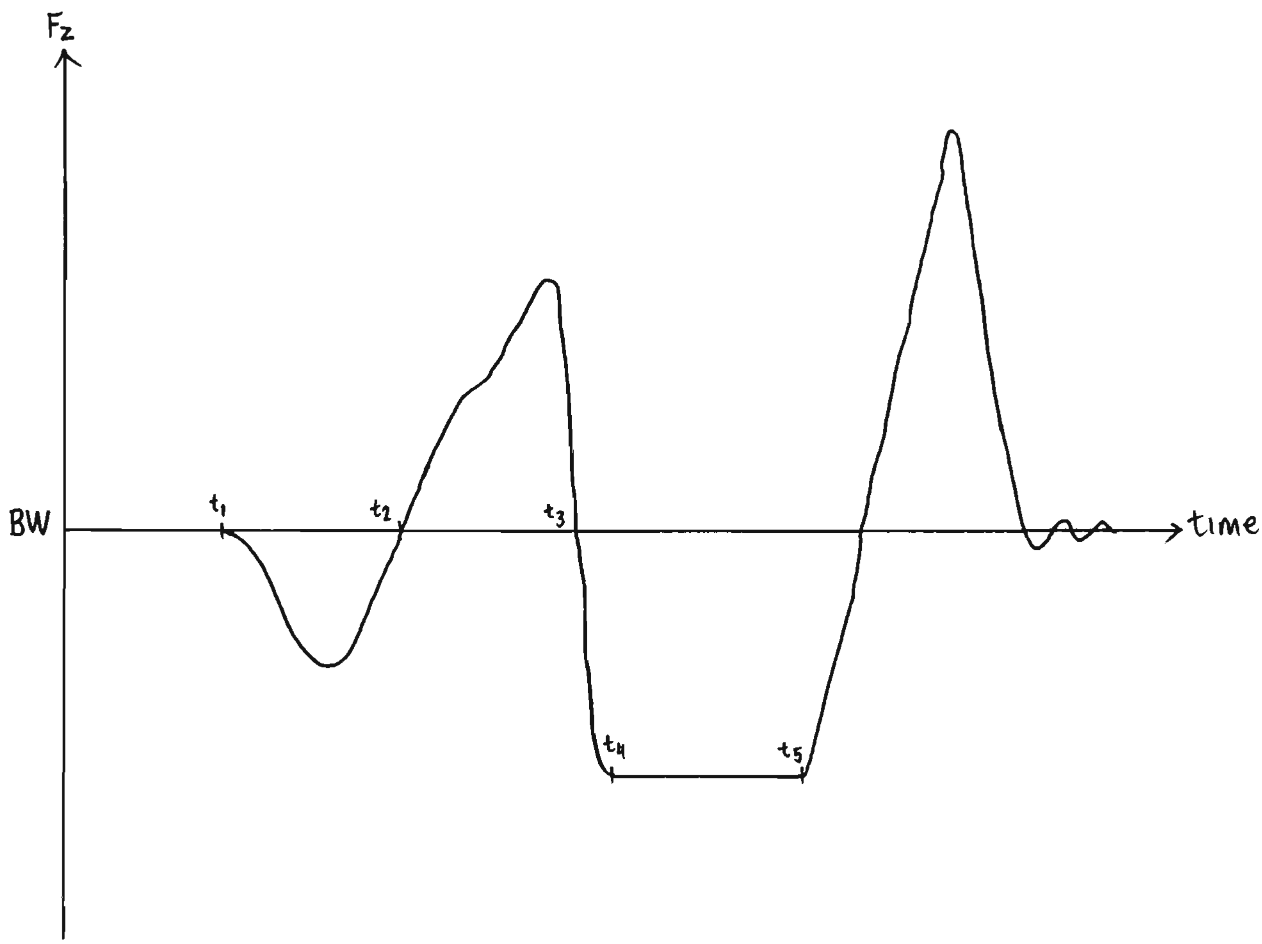
In summary, several techniques have been applied to determine individual segment and joint contributions to the vertical jump. Knee extension has been found to be the largest single contributor with hip extension and ankle plantar flexion also being important contributors

(Luhtanen and Komi, 1978; Hubley and Wells, 1983). Inclusion of arm swing was demonstrated to significantly increase vertical jump performance (Khalid et al., 1989).

2.2.6 Kinetics of a Vertical Jump

The vertical component of the ground reaction force (Fz) of a CMJ take-off is depicted in Figure 7.

Figure 7. Vertical ground reaction force of a countermovement jump take-off.



Adapted from Miller and East, 1976.

The first phase (t_1-t_2) coincides with the initial countermovement of the jump. Fz was less than BW, resulting in a preliminary underweighting. The following section (t_2-t_3) is the weighting phase where Fz is greater than BW. Final underweighting (t_3-t_4) occurrs immediately before the instant of take-off (t_4). The flight time of the jump is t_4-t_5.

Power is not necessarily a correct concept for assessing vertical jump performance. The height of a jump is determined by the take-off velocity and neither height of the jump nor take-off velocity are measures of leg power (Lightsey, 1985).

Impulse is the more appropriate parameter. It is the integral of the function of the resultant vertical force (Fz-BW) on the CGB. To improve vertical jump performance the resultant vertical force and/or time duration (t_2-t_3) need to be increased (Adamson and Whitney, 1971).

Since SJs are performed without a countermovement, the vertical force trace should not include a preliminary underweighting phase. Difficulty has been expressed in executing SJs without a countermovement. Khalid et al. (1989) analysed the electrogoniometric data which revealed very small knee flexion for SJs.

2.2.7 Vertical Jump Performance of Countermovement Jumps Versus Static Jumps

Several researchers have investigated the effect of stretching the muscles prior to shortening by comparing CMJs with SJs. CMJs utilize the stretch-shortening cycle while SJs consist almost entirely of concentric contraction. Comparison has been made between CMJs and SJs with no constraint on movement amplitude (that is, degree of knee joint flexion) (Asmussen and Bonde-Petersen, 1974; Bosco and Komi, 1979b; Bosco and Komi, 1980; Sanders and Wilson, 1989), with SJs from a preset knee joint angle not congruent with that of the CMJs (Komi and Bosco, 1978) and between CMJs and SJs which utilized similar movement amplitude (Bosco et al., 1981).

Asmussen and Bonde-Petersen (1974) compared CMJ and SJ performance of 19 subjects, 14 males and five females. Vertical jump performance was calculated from the flight time (t_{air}), measured from the vertical ground reaction force trace. This required the subjects to leave and land on the platform with the same body position. The vertical velocity (Vv) at take-off was obtained from the formula:

$$Vv = {}^{1}/_{2}\ (t_{air})\ g,$$

in which g = acceleration of gravity ($9.81ms^{-2}$)

The height of rise (h) of the CGB was then calculated:

$$h = \frac{Vv^2}{2g}$$

This method of calculation as compared to cinematographic technique has been shown to produce an error of $\pm 2\%$ (Komi and Bosco, 1978).

The subjects were instructed to keep their arms at their sides with only slightly flexed elbows. The degree of knee flexion was not recorded for either jumping condition. Vertical jump performance in CMJs was found to be significantly greater than SJs ($p<0.02$).

Table 7. Static jump and countermovement jump performance of 14 male and five female subjects.

	Bodymass (kg)	SJ (cm)	CMJ (cm)
$\bar{x}$	71.0	36.6	38.6
SD	—	7.1	8.3

Adapted from Asmussen and Bonde-Petersen, 1974.

Bosco and Komi (1979b) compared CMJs and SJs of 34 male physical education students, age 24.3 ± 2.5 years. Maximal vertical jumps were performed with the arms akimbo. The SJs were performed with no preset movement amplitude. The flight time from the vertical force trace was used to calculate vertical jump performance. CMJs resulted in a significantly higher rise of the CGB ($p < 0.001$). The mean CMJ performance was 41.6 ± 6.1 cm compared with 35.9 ± 4.7 cm for the SJ.

In a study with a relatively large sample size, Bosco and Komi (1980) assessed a total of 226 subjects (113 males and 113 females) ranging in age from 4 to 73 years. They were divided into different age groups. The male groups consisted of ten children (four to six years), 19 school boys (13 to 17 years), 35 university students (18 to 28 years), 16 school teachers (29 to 40 years), 15 hospital personnel (41 to 49 years), four hospital personnel (54 to 65 years), and 11 pensioners (71 to 73 years).

The female groups consisted of 11 children (four to six years), 15 school girls (9 to 12 years), 41 university students (19 to 26 years), 16 school teachers (34 to 40 years), 15 hospital personnel (41 to 48 years), 11 hospital personnel (51 to 64 years), and 14 pensioners (71 to 73 years).

CMJs and SJs were performed with the arms akimbo and no constraint on knee joint angle. Flight time from the vertical force trace was used to calculate vertical jump performance. All groups attained a higher rise of the CGB in the CMJs as compared to the SJs. The improvement in performance ranged between 10 to 20 % for the male groups and 12 to 23% for the female groups.

Conflicting results were presented by Sanders and Wilson (1989). Eleven male and six female subjects performed CMJs and SJs with arm swing and no constraint on the angle of knee flexion. Ten of the 17 subjects performed equivalent or greater work in the SJs than in CMJs. The authors speculated that constraining subjects to preset amplitudes may not allow for optimal timing in jumping, preventing the desired summation of forces of the elastic and contractile components at the appropriate time.

In an investigation where SJs were initiated from a preset knee joint angle of 90 degrees, Komi and Bosco (1978) assessed the vertical jump performance of fifty-seven subjects. Twenty-five female physical education students, 16 male physical education students and 16 players from the Finnish national men's volleyball team participated in the study. CMJs and SJs were performed on a force platform with the arms akimbo. The flight time from the vertical force trace was used to calculate vertical jump performance. In all groups CMJ performance was significantly greater than SJ ($p<0.01$).

Table 8. Countermovement jump and static jump performance of physical education students and volleyball players.

Jumping Condition	Female physical education students	Male physical education students	Male volleyball players
SJ (cm)	19.2 $\pm$ 3.6	35.5 $\pm$ 5.1	37.2 $\pm$ 3.7
CMJ (cm)	23.3 $\pm$ 3.5	40.3 $\pm$ 6.6	43.4 $\pm$ 5.2

Adapted from Komi and Bosco, 1978.

Bosco et al. (1981) made a comparison of CMJ and SJ performance which utilized similar movement ranges about the knee joint in the concentric phase. Fourteen male power trained athletes, age 22.9$\pm$5.4 years, performed vertical jumps on a force platform. An electrogoniometer was attached to the lateral side of the subject's knee joint. The CMJ was performed first and the starting angle for the SJ was obtained from the electrogoniometer record of the CMJ. The results indicated that CMJs enhanced the mean concentric force and mean mechanical power by 60 and 81%, respectively.

In summary, vertical jump performance of CMJs has been found to be significantly enhanced over SJs. The enhancement has been demonstrated between CMJs and SJs of various initial conditions (Asmussen and Bonde-Petersen, 1974; Komi and Bosco, 1978; Bosco and Komi, 1979b; Bosco and Komi, 1980; Bosco et al., 1981).

2.2.8 Relationship of Isokinetic Torque to Vertical Jump

Genuario and Dolgener (1980) investigated the relationship between the vertical jump and the peak isokinetic torque. Knee extension and ankle plantar flexion torque were assessed in 29 female athletes at angular speeds of 30 and 180 degrees.s^{-1}. Plantar flexion torque was obtained with the subjects seated and knee in full extension. The vertical jump was expressed both in inches and ft.lb (body mass displaced during jumping provided an indication of the work done).

The highest correlation was found between vertical jump expressed in ft.lb. and peak knee extension torque at 180 degrees.s^{-1} ($r = 0.587$, $p<0.01$). The peak plantar flexion torque exhibited a lower correlation with vertical jump expressed in ft.lb. ($r = 0.502$, $p<0.01$). There was no significant correlation between peak torque generated at 30 degrees.s^{-1} and vertical jump expressed in ft.lb. The correlations determined in this study were low and it was concluded that there was little if any relationship between peak torque at either angular speed and the vertical jump ability for this group of subjects.

Perrine, Gregor, Munroe and Edgerton (1978) compared total-leg thrust isokinetic force and vertical jump height. Ten skilled intercollegiate volleyball players and ten unskilled jumpers, five males and five females in each group, participated in the study. Vertical jump height correlated only moderately (r = 0.66) with peak force.

Oberg (1988) assessed 224 soccer players and 57 nonathletes for isokinetic knee extensor torque and one-legged vertical jump ability. Both legs were assessed for jump height which was calculated from flight time of the vertical force trace. Knee extensor torque exhibited a higher correlation to jump height for the dominant jump leg (r = 0.7 to 0.8) than for the nondominant jump leg (r = 0.5 to 0.7).

Low to moderate correlations have been determined between peak isokinetic torque and vertical jump ability (Perrine et al., 1978; Genuario and Dolgener, 1980; Oberg, 1988). Unlike single joint actions assessed by Cybex II, the vertical jump is a complex action which involves biarticular muscles (Gregoire et al., 1984), contribution of many segments (Hubley and Wells, 1983), and possible utilization of elastic energy (Asmussen and Bonde-Petersen, 1974) and stretch reflex potentiation (Bosco and Komi, 1979a).

2.3 Unilateral and Bilateral Lower Extremity Activity

Investigations comparing unilateral and bilateral lower extremity activity have included isometric leg press (Secher, Rorsgaard and

Secher, 1978; Vandervoort, Sale and Moroz, 1984; Secher, Rube and Elers, 1988; Schantz, Moritani, Karlson, Johansson and Lundh, 1989), isometric knee extension (Schantz et al., 1989), isokinetic leg press (Vandervoort et al., 1984) and CMJs (Soest, Roebroeck, Bobbert, Huijing and Ingen Schenau, 1985).

Many of the studies which assessed maximal isometric leg press force (hip and knee extension) required the subjects to sit in a chair and press the feet against a foot-plate attached to a steel rod mounted in bearings on an iron frame (Secher et al., 1978; Secher et al., 1988; Schantz et al., 1989). A strain gauge dynamometer (Asmussen, Heeboll-Nielsen and Molbech, 1959) was used to measure the force.

Secher et al. (1978) compared maximal isometric unilateral (one-leg) and bilateral (both legs simultaneously) leg press force. Six male subjects, age 23 to 26 years, body mass 80 ± 4.9 kg, participated in the study. The ankle and knee joints were at a predetermined angle of 90 degrees. The maximal force of the bilateral leg press was $75 \pm 3.6\%$ of the summed unilateral force (the force recorded during separate left and right leg contractions).

In a study with a larger sample size, Secher et al. (1988) compared maximal isometric force during bilateral and unilateral leg press with 167 female and male, untrained and trained subjects (eight bicyclists, 38 weight lifters). It was found that the bilateral force was $82 \pm 1.3\%$ of the summed unilateral force with no significant difference between trained and untrained subjects.

Schantz et al. (1989) compared bilateral and unilateral leg press force of six male and eight female students, age 23 ± 2 years with a mean body mass of 64 ± 2 kg. The knee joint angle was 90 degrees. The results demonstrated that the bilateral leg press force was significantly lower than the summed unilateral force ($p < 0.05$).

Modifications made to a Cybex II permitted an alternative method to assess maximal isometric leg press strength. Vandervoort et al., (1984) compared maximal isometric bilateral and unilateral leg press force of nine male physical education students. The subjects were aged 20 to 24, body mass 64 to 74 kg, and the knee joint angle was 100 degrees. Maximal bilateral strength was found to be significantly less than summed unilateral ($p < 0.01$).

Maximal isometric knee extension force was also assessed by Schantz et al. (1989). The subjects were seated with their lower legs attached to the lever arms of two Cybex IIs with the knee joint at a 90 degree angle. Contrary to the findings of isometric leg press, the bilateral isometric knee extension force was significantly greater ($4.2 \pm 1.0\%$) than the summed unilateral force.

It has also been reported that bilateral leg strength significantly differed from summed unilateral during dynamic contractions. Vandervoort et al. (1984) assessed maximal voluntary contractions with a Cybex II modified to evaluate bilateral and unilateral leg press torque.

The subjects commenced extension from a knee angle of 90 degrees. Peak and average torque generated during right leg only, and bilateral leg presses were recorded from ten angular speeds ranging from 0 to 424 degrees.s^{-1}.

Four of the subjects were utilized for an EMG study. EMG activity in vastus medialis, vastus lateralis, and rectus femoris of the right leg were compared between unilateral and bilateral maximal contractions at 15 and 380 degrees.s^{-1}.

Maximal strength of the bilateral leg press was found to be significantly less than the summed unilateral leg press strength for all concentric speeds ($p<0.01$). Significantly less integrated EMG activity was recorded from the knee extensors muscles of the dominant leg during bilateral compared with unilateral maximal contractions ($p<0.006$). The results indicated that the extent of motor unit activation appeared to be reduced in bilateral relative to unilateral maximal contractions.

It has been suggested that force reduction resulted from the incapacity of the nervous system to activate maximally a large number of muscles simultaneously. Secher et al. (1978) proposed that this reduction was due to a decreased recruitment of ST muscle fibres while Vandervoort et al. (1984) indicated a decreased activation of FT muscle fibres. The exact mechanism is unknown.

To investigate whether the differences between unilateral and bilateral isometric and isokinetic actions applied to complex movements, a comparison of one-legged and two-legged CMJs was made by Soest et al. (1985).

Ten well trained male volleyball players, aged 23 ± 4 years and body mass 83.5 ±10.0 kg, performed the one-legged and two-legged CMJs (Table 9). One-legged jumps were performed with the left leg. Anthropometric measures revealed that the circumferences of the left leg were smaller than those of the right leg, thus the left leg was not likely to have been dominant.

Subjects were instructed to keep their arms akimbo and keep the right leg inactive. Ground reaction forces, cinematographic and EMG data were recorded. Jumping height was defined as the vertical distance between the highest position of the greater femoral trochanter landmark and of this landmark when the subject was standing erect. It was found that the the jumping height in one-legged jumps was 58.5% of the jumping height in two-legged jumps.

Table 9. One-legged and two legged countermovement jumps.

	One-legged jump	Two-legged jump
Jumping height (cm)	31 ± 3	54 ± 6

Adapted from Soest et al., 1985.

In summary, the majority of studies comparing unilateral and bilateral lower extremity activity have found the summed unilateral activity to be significantly greater than the bilateral. It has been demonstrated that maximal isometric bilateral leg press force was significantly less than that of the summed unilateral leg press (Secher et al., 1978; Vandervoort et al., 1984; Secher et al., 1988; Schantz et al., 1989).

Maximal bilateral isometric knee extension force was found to be significantly greater than the summed unilateral force. During dynamic and complex movements, the summed unilateral activity was greater than the bilateral. Vandervoort et al. (1984) found the maximal isokinetic leg press strength to be significantly greater for the summed unilateral than for the bilateral press. Comparisons of one-legged and two-legged CMJs illustrated that the jumping height in the one-legged CMJ was significantly more than 50% of that in the two-legged CMJ (Soest et al., 1985).

2.4 Video Analysis of Motion

2.4.1 The Peak System

Advancements in image processing technology have led to the introduction of video systems into the area of motion analysis. The Peak system (Peak Performance Technologies Inc., 1989) has been designed to perform manual digitizing from standard VHS format video tape recordings. The system's "frame grabber" captures single video frames recorded on videotape, where they are split into two fields, enhanced, and presented for digitization. A cross-hair pointer, operated by a "mouse" is superimposed onto the digitally stored image thereby eliminating parallax error.

The system has three main hardware components; the video recorder and monitor, AT compatible computer and monitor, and the Peak 2D Core. Use of a shuttered video camera ensures a crisp, clear image. The Peak 2D Core consists of two circuit boards: a video recorder controller and a frame grabber. Each videotape image is composed of two separate fields. When the video camera operates at 25 frames.s^{-1}, this frame splitting ability results in the actual film speed being 50 frames.s^{-1} (Peak User's Reference Manual, 1989).

2.4.2 Accuracy of the Peak System

The accuracy of the Peak system has been compared with that of 16mm film for point reprediction using the Direct Linear Transformation Method (Kennedy, Wright and Smith, 1989). Survey range poles forming the boundaries of a cube with 20 control points of known spatial coordinates, were filmed and videotaped. A 16mm Locam intermittent camera was used for filming and a Panasonic AG450 was used to videotape. A Summagraphics Micrግrid II tablet connected to an IBM personal computer was utilized to digitize the 16mm film. The video records were digitized using the Peak system. Three investigators digitized three frames per camera view. The nine sets of digitized points for both film and video were compared with the actual coordinate values.

Resultant means errors were found to be statistically different, 4.8mm and 5.8mm for film and video respectively. The investigators stated that 1mm mean difference between the video was of little practical significance. If the calibrated field (2x2x2m cube) was considered, then 5.8mm for video represented an error of only 0.29% of the real space measured and the 4.8mm error for film was 0.24% of the field. It was concluded that video format of the Peak system was comparable in accuracy to 16mm filming method (Kennedy et al., 1989).

2.4.3 Sampling Rate

The accuracy of motion analysis systems is also dependent on the sampling rate and the harmonic content of the signal. The maximum sampling rate is usually the maximum frame rate. The Nyquist sampling theorem states that the sampling rate must be at least twice the value of the highest frequency component present in the pure signal. In actual practice, it has been recommended to choose a sampling rate three to four times the highest frequency to ensure a satisfactory reproduction of the original signal (Dainty and Norman, 1987). The maximum sampling rate for the Peak system is 50Hz. This implies that the system would not be suitable for analysing motion in excess of approximately 12 Hz.

D'Amico, Ferrigno and Rodano (1989) assessed the frequency content of body landmark displacements during several track and field movements including the vertical jump. Two male athletes, one race walker and a hurdler acted as subjects. The Elite system was used to analyze the motion. It comprised of two television cameras allowing for three dimensional measurements. Reflective markers were adhered on the skin over the iliac crest, head of the femur, knee joint, lateral malleolus, and fifth metatarsal head. The subjects were illuminated by infrared strobes, mounted on the camera. The sampling rate was 50 frames.s^{-1}.

Significant differences were found among the frequency content of the five anatomical points during the same movement, and between x and y coordinates of each marker during the same movement. For the vertical jump, the means and standard deviations of the cut off frequencies bounding 99.5% of the signal power for the five markers were 4.84 ± 2.20 and 2.80 ± 1.47 Hz for the x and y coordinates respectively. Based on this data, the Peak system is appropriate for analyzing the vertical jump since the frequency content of the anatomical markers did not exceed 12 Hz.

2.4.4 Data Smoothing

Similar to 16mm film, raw video data usually contains error arising from systematic and random sources. The potential sources of error include: misalignment of the camera, perspective error due to motion out of the photographic plane, movement of the camera, distortion due to the optical system of the camera, movement of anatomical markers in relation to the joint axes of rotation, precision limits in the digitization process, inaccurate temporal and spatial scales, and determining the centre of the anatomical markers (Wood, 1982).

The derivatives of the displacement data are required to ascertain velocity and acceleration data. Numerical differentiation acts as a high pass filter and amplifies the errors which can occur with relatively high frequency (Lanshammar, 1982). This has been demonstrated to significantly affect the accuracy of the results. Data smoothing is required to eliminate the errors that occur in the higher order derivatives. To reduce or smooth out the errors that occur in the higher devivatives a digital filter may be used (Hubley and Wells, 1983; Bobbert et al., 1986; Bobbert and Ingen Schenan, 1988). The Peak system includes a low-pass, fourth order, zero lag Butterworth digital filter with manual cut-off frequency selection. This type of filter is similar to that advocated by Winter, Sidwall and Hobson (1974).

CHAPTER 3

METHODS

3.1 Subjects

The amputee subjects were male, young, and regularly engaged in sporting and/or recreational activities. They responded to requests for research participants placed with several organisations including Amputees Association of Victoria, prosthetics department of hospitals, Department of Sport and Recreation (Disabled), and health and fitness centres. The normal subjects were selected for being comparable ($\bar{x} \pm$ 1SD) in age, body mass, height and participation in sporting and/or recreational activities.

Subjects were screened for medical contra-indications, previous training on isokinetic exercise equipment and vertical jump experience. Voluntary and informed consent in accordance with F.I.T. guidelines on research with humans was secured from all subjects prior to their participation in this study (Appendix 1). Two testing sessions for each subject were required to collect the data. The subjects reported to the Department of Physical Education and Recreation at F.I.T. One session involved the determination of peak isokinetic knee extension and ankle plantar flexion torques. The other session involved the collection of anthropometric data and measurements of CMJ and SJ performance. The sequence of the testing sessions was randomized between subjects.

3.2 Anthropometric Measurements

Anthropometric data were collected to describe the physical characteristics of the subjects and to estimate the segment inertial properties of the residual limb of the amputee subjects. The circumference measurements were taken perpendicular to the long axis of the residual limb in a transverse plane. Equipment used to measure height, circumference and length was accurate to 1mm and the values were read to the nearest mm. For all measurements the mean of the two recorded trials were calculated.

Height: The subject stood barefoot with the heels together (amputees wore prostheses) and back against a wall which was equipped with a stadiometer. The arms were placed in an akimbo position and the subject was instructed to inhale. A sliding wedge plate was placed on the subject's head which formed a right angle with the stadiometer and indicated the height. The subject then flexed at the knee/s and stepped away. The value was read and recorded.

Body mass: A plastic seat with a metal frame was placed on and tared on a Sauter E1200 electronic scale with a sensitivity of 0.005kg. The subject was dressed as for the vertical jump (section 3.4), sat motionless and respirated at their usual rate. Once the digital display stabilized, the body mass was read and recorded.

Knee circumference: The below-knee amputee was seated with the knee in full extension and a Dean fibreglass tape measure was placed at the mid-patellar level.

Thigh circumference: The above-knee amputee stood while the Dean fibreglass tape measure was placed at the inferior edge of the gluteal crease.

Distal residual limb circumference: The amputee was seated with the knee in full extension (for below-knee amputees) while the Dean fibreglass tape measure was placed at the distal section of the residual limb.

Residual limb length: One arm of a Holtain anthropometer was placed at the greater femoral trochanter (for above-knee amputees) or lateral epicondyle (for below-knee amputees) and the other arm was positioned at the most distal point of the residual limb.

3.3 Determination of the Centre of Gravity Location

The location of the CGB was determined by the segmentation method (Braune and Fischer, 1889 as cited by Williams and Lissner, 1962) from single frames of the videotape. The normal subjects were represented by a model composed of 14 rigid segments: head, trunk, upper arms, forearms, hands, thighs, lower legs and feet (Clauser, McConville, and Young, 1969). The model for the above-knee and below knee amputees comprised of 12 and 13 segments respectively.

Adhesive reflective markers were placed on the skin or attire over anatomical landmarks as described in Table 10. These landmarks were located by palpating bony prominances as the body segments underwent various joint motions to facilitate structural recognition. A marker was placed at the end of the residual limb of the amputees.

Table 10. Body segments as identified by the anatomical landmarks

Head (including neck): Apex of the head to the seventh cervical vertebra.

Trunk: Glenohumeral axis to the greater femoral trochanter.

Upper arms: Glenohumeral axis to elbow axis.

Forearm: Elbow axis to wrist (ulnar styloid).

Hand: Wrist axis to knuckle II of the middle finger.

Thigh: Greater femoral trochanter to the lateral femoral epicondyle.

Lower leg: Lateral femoral epicondyle to the lateral malleolus of the fibula.

Foot: Lateral malleolus of the fibula to head metatarsal II.

Adapted from Plagenheof, Evans, and Abdelnour, 1983.

The location of the CGB of the normal subjects was computed using the relative segmental masses and locations of the segment centre of gravity generated by Plagenheof et al. (1983). They used water displacement data obtained on living subjects (35 men and 100 women) and cadaver density data from Dempster (1955) to calculate gender specific segmental masses as percentages of the total body mass (Appendix 2). The location of the segment centre of gravity was expressed as a percentage of the segment length from the proximal end (Appendix 3).

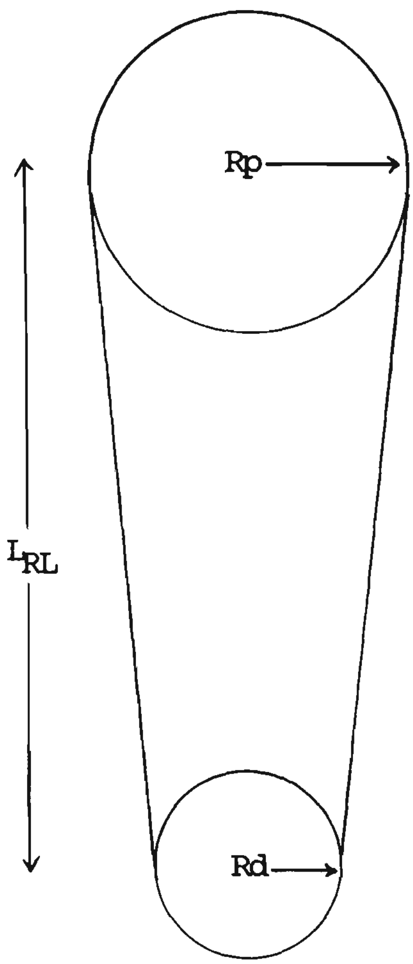
Plagenheof et al. (1983) identified the inherent errors in the use of these anatomical data: soft tissue movement, use of a single point to represent the joint axis, inaccuracy of locating that point from superficial landmarks, omission of motion in the extremities about the long axis, and variability between cadaver and living human data.

For the amputee subjects, the relative segmental masses were calculated as follows:

$$\text{relative segmental mass of amputee} = \frac{\left(\text{relative segmental mass} \quad \text{(Plagenheof et al., 1983)}\right)}{\left(\text{100 - relative mass of missing segments}\right) + \left(\text{relative mass of residual limb}\right)}$$

The geometrical model by Hanavan (1964) was used to calculate the volume and position of the centre of gravity of the residual limb of the amputee subjects. The model assumed the limb to have constant density and be the shape of a truncated cone. Density data from Dempster (1955) (thigh = $1.05kg.l^{-1}$, lower leg = $1.09kg.l^{-1}$) along with the volume calculated from the Hanavan (1964) model were used to calculate the mass of the residual limb. The segmental mass was the product of the volume and segmental density.

Figure 8. Hanavan model used to calculate the volume and location of the centre of gravity of the residual limb of the amputee subjects.



$$V = \left(\frac{\pi}{3}\right)\left(L_{RL}\right)\left(Rp^2+2RpRd+Rd^2\right)$$

$$CGRL = \frac{\left(L_{RL}/4\right)\left(Rp^2+2RpRd+3Rd^2\right)}{\left(Rp^2+RpRd+Rd^2\right)}$$

Where V = volume of the residual limb

CGRL = location of the centre of gravity of the residual limb

L_{RL} = residual limb length

R_p = radius at proximal point

R_d = radius at distal point

Adapted from Hanavan (1964).

The OGRL was relative to the proximal point which was the gluteal fold for above-knee amputees and the centre of the patella for below-knee amputees. The radii were estimated from the circumferences measured assuming a circular cross section at the point at which the circle was measured.

3.4 Countermovement and Static Jumps

Standardized instructions were given to each subject. The subjects warmed up by either cycling at a moderate intensity for five minutes on a stationary Monark bicycle or hopped when cycling was not possible (for some amputee subjects). To stretch the dominant lower extremity, prone knee extensors stretch and standing plantar flexors stretch were performed twice for 20s. Leg dominance of the normal subjects was determined from kicking preference (Wyatt and Edwards, 1981). The normal subjects were requested to kick a ball which was rolled to them from a distance of four metres. The intact leg of the amputee subjects was deemed dominant.

Subjects were dressed in skin tight bicycle shorts and a swimming cap. Adhesive reflective markers ($2.5cm^2$) were placed on: the top of the swimming cap (apex of the head), the bicycle shorts over the greater femoral trochanter, lateral aspect of the fifth phalange of the dominant leg in line with the head of metatarsal II, and on the skin over the other anatomical landmarks. The amputees performed without their prosthesis.

Subjects performed maximal voluntary one-legged CMJs and SJs on a AMTI OR651 force platform interfaced to an IPEX computer which sampled data at a rate of 200Hz. The platform was unmounted but since the subjects performed vertical jumps, shearing forces were held to a minimum and the platform was stabilized in the direction of interest.

The vertical component of the ground reaction force was recorded and used to confirm that no countermovement occurred during the SJ trials. Practice trials were allowed for each jumping condition. The subjects were allowed to choose the starting position in SJs, no constraint was placed on the angle of knee or hip flexion.

The subject was asked to position himself on the centre of the force platform (when necessary, amputee subjects balanced by placing their hand against a nearby wall). A verbal signal of "jump" was given as the experimenter activated the measurement system via the keyboard. This signal informed the subject to immediately initiate the jump.

Jumps were performed in a randomized sequence with a rest period of four minutes between jumps to reduce possible effects of fatigue. Subjects were instructed to attain the highest possible jumping height. The contralateral leg was held inactive and the arms were in an akimbo position. Three trials for each jumping conditions were recorded on videotape. The highest jump for each condition was determined from inspection of the air borne phase of the ground reaction force - time graph.

3.5 Video Taping

Vertical jump performance was calculated from kinematic data captured by the Peak system instead of the kinetic data generated by the force platform. The video taping procedure set out by the manufacturer was followed (Peak User's Reference Manual, 1989). Many of these guidelines were identical to 16mm film analysis as described by Miller and Nelson (1973).

Since each video camera has a unique height-to-width ratio of pixel positioning, the aspect ratio for the camera was computed prior to data analysis. This ensured constant scaling between vertical and horizontal positions on the monitor (Peak User's Reference Manual, 1989).

A Panasonic S-VHS AG450 video camera was secured to a stable tripod and positioned as far from the subject as possible (7.3m) to minimize the effect of perspective error. The centre of the camera lens was 1.00m above the ground. The optical axis of the camera was aligned perpendicularly to the sagittal plane of the motion.

The camera was levelled with a bubble level along the optical axis as well as laterally. The camera was also sighted on the centre of the action. The zoom lens was used to enlarge the image size and reduce the field of view. The background was plain and devoid of any shiny surfaces. Two Ianebeam 800 Watt lamps were placed adjacent to the camera parallel to the optical axis and were used to illuminate the subject.

required the operator to define the centre of mass location for each segment of the model via proximal and distal landmark identification, centre of mass location from the proximal point and percentage of the total body mass characterized by the segment. This permitted the computation of the position of the CGB for each frame. Bilateral symmetry was assumed for the position of the upper extremities (Appendix 4 is an example of a Spatial Model Set Up).

The Project Set Up program was used to define the specific parameters that were unique to each separate video taping session. These files contained the name of a previously defined spatial model, identification of the camera (identifying its aspect ratio), picture rate, number of pictures per field, number of pictures to skip when digitizing, number of reference points to digitize, scaling factor, unit of length, and the event frames.

The scaling factor was determined by the system's software once the scaling rod was digitized from the video tape. An event frame was a special flag that was stored to identify a frame in which an important event occurred such as take-off during the vertical jumps (an example of a Project Set Up is provided in Appendix 5).

The Data Capture program coordinated the Peak system's video control and frame grabbing hardware and facilitated the digitization process. The first frame for analysis was selected by the operator and imported into computer memory. This method permitted image processing techniques to split the imported frame and reconstruct it as two separate pictures thereby doubling the number of pictures to 50Hz.

The video camera was activated three minutes before the first trial. To permit the conversion of video image measurements to real distances a right angle scaling rod of known dimensions (1.00 x 1.00m) with contrasting segments (black and white) of 0.20m was positioned in the plane of motion at the contact point of the subject and the force platform. This was videotaped before the subject trials. The video camera operated at 25 frames.s^{-1} and the shutter was set at 1/1000s. To avoid disturbing the camera, a remote control was used. The motion was captured on Panasonic S-VHS 675 high resolution video cassettes.

3.6 Digitization

The Peak system was used to digitize the vertical jumps and perform the data calculations (Peak User's Reference Manual, 1989). To digitize the previous recorded vertical jumps, the video tape was first "encoded". During the encoding process, the system recorded a unique frame number on the second audio track beside each video frame. This allowed the Peak software to locate the exact frame required to be digitized.

The Peak system's software was menu driven and required the creation of four file types by the operator: Spatial Mode, Project, Trial, and Data files.

The Spatial Model Set Up program created a file containing the Spatial model name, number of body points in the model, label for each point, and the manner in which the points were connected. This program also

After the frame was grabbed, split, and enhanced, a stable clear image was presented to the operator for digitization. A three button mouse was used to position the cross hair on the desired body points and then manually digitized. The computer prompted the operator which point to select next. The coordinates of the digitized points were automatically stored in memory.

Once the motion was digitized, the raw position data were scaled and smoothed (cut-off frequency of 12Hz). The position of the CGB was calculated and stored in the Conditioned Data Acquisition file. A print out of these data were then obtained.

3.7 Isokinetic Peak Torque Determination

Maximal voluntary concentric isokinetic knee extensor and plantar flexor torque of the dominant leg were assessed using a Cybex II at an angular speed of 60 degree.s^{-1}.

3.7.1 Cybex Calibration

The dynamometer was calibrated immediately before each testing session in accordance with instructions provided by the manufacturer (Cybex, 1983). Cybex certified calibration disc weights were placed on a lever arm of known length and allowed to fall from the vertical position through a 180 degree arc of motion at 30 degrees.s^{-1}. This was performed for all three torque range scales.

The peak torque was noted and if necessary, appropriate corrections were made by adjusting the potentiometer. Since the pressure transducer and force measuring load cell inside the dynamometer operated independently of the speed control mechanism, calibration at one speed (30 degrees.s^{-1}) was all that was required to ensure accurate torque readings at all test speeds (Cybex, 1983).

3.7.2 Protocol

Subjects were provided with an explanation of isokinetic exercise and a description of the testing procedures. Instructions were given to each subject in the same manner. The warm up was identical to that for the vertical jumps.

Before testing, the subjects were permitted three submaximal and three maximal nonreciprocal practice trials at 60 degrees.s^{-1} for each joint to allow the muscles to warm up and to familiarize the subjects with the equipment and experimental procedure. This protocol has been found to yield reproducible Cybex II data (Johnson and Siegel, 1978).

Following a rest period of two minutes, each subject performed three nonreciprocal contractions with 30s rest period between trials. Studies that have obtained reliable measurements have used nonreciprocal contractions (Johnson and Siegel, 1978; Mawdsley and Knapik, 1982). Each trial was preceded by a verbal signal to initiate a response. The subjects were instructed to kick (for knee extensors) or press (for plantar flexors) as hard and as fast as possible for the entire ROM. Verbal encouragement was provided to elicit a maximal effort. Knowledge of results was not provided until the subject had completed the entire protocol.

To diminish the variability that may have resulted from learning or fatigue, a randomized testing sequence of joints was employed. Between the testing of different joints, there was a five minute rest. Each effort was recorded on the Cybex II dual-channel recorder at a chart speed of $25 mm.s^{-1}$ and a damp setting of zero. The highest torque value recorded within the ROM was designated the peak torque. The highest of these three peak torque levels was selected as the representative value.

3.7.3 Gravity Correction

Once the test trials were completed several passive drops of the limb-lever system were performed for the knee extensors. The angular speed was set at 30 $degrees.s^{-1}$ and the limb-lever system was initially supported by the experimenter in full extension. The subject was instructed to completely relax the extremity which was then released by the experimenter and it fell passively against the resistance offered by the dynamometer. The minimum passive torques from these curves were used to correct the measured torques for gravity (Nelson and Duncan, 1983).

Pilot work revealed that a passive drop from full plantar flexion in the prone position was not possible. The initial motion was influenced by the elastic recoil of connective tissue of the ankle and the relative light mass of the foot segment was insufficient to carry the limb-lever system to the neutral position. This also implied that the gravitational torque was not substantial. For these reasons, plantar flexion torques were not adjusted for gravity.

3.7.4 Stabilization and Positioning

Subject positioning and stabilization were in accordance with the guidelines set out in the Cybex II handbook (1980). The moving limb segments were aligned parallel to the lever arm of the dynamometer. The axis of rotation of the joint and that of the dynamometer coincided. Limb segments were firmly strapped to the dynamometer, S.H.D. table, or U.B.X.T. as appropriate. Straps were applied to provide stabilization for other body parts, so as to isolate the muscles being tested.

3.7.5 Knee Extension

The subject was dressed in loose fitting clothing removed their shoes and sat on the S.H.D. table with the back supported and a thigh-trunk angle of approximately 100 degrees. Axis of rotation of the dynamometer was aligned with the lateral femoral epicondyle. Stabilization straps were used across proximal and distal thigh, and chest (anchoring the subject to the back rest). The shin pad was positioned with its bottom edge level with the superior border of the medial malleolus. Full extension was designated as the zero degree position. The subjects crossed their arms over their chest and began from approximately 90 degrees of knee flexion and went to full extension. A stabilization weight was positioned onto the base of the dynamometer prior to each test to minimize any movement of this unit during knee extension. The torque range scale was set at either 180 or 360 ft.lb. (244 or 488 Nm) depending on the torque value registered during the warm up trials. The angle range was set at 150 degrees.

3.7.6 Ankle Plantar Flexion

The subject adopted a prone position on the U.B.X.T. and their foot was strapped onto the foot plate. Velcro straps stabilized the thigh and pelvis. The subject was instructed to keep the knee of the test limb in full extension throughout the movement. The contralateral leg remained straight and the hands grasped the sides of the U.B.X.T. The test commenced from maximum dorsiflexion. The torque range scale was set at 180 ft.Ib. (244 Nm) and the angle range at 150 degrees.

3.8 Statistical Analysis of Data

Comparisons were made within and between the data from the amputee subjects and the data from normal subjects. Means and standard deviations of the descriptive data, peak isokinetic torques, and one-legged vertical jump performances were calculated. A one-tailed paired t-test was used to assess the difference between CMJ and SJ performance for the amputee and for normal subjects.

Having satisfied Cochran's test for homogeneity of variance, multivariate ANOVA was used to perform main effect analysis between these two multivariate groups. Pearson Product Moment correlation coefficients and their significance levels were also generated to observe the association between the variables within each group. The Statistical Analysis System (SAS/STAT, 1988) was used to analyse the data.

CHAPTER 4

RESULTS

The descriptive data of the amputee and normal subjects are presented in Tables 11 and 12. Four amputee subjects participated in the study. The dominant (non-amputated) leg for all amputees was the left. Since the normal subjects were selected on the basis that their age, height, and body mass fell in the range of the $\bar{x}\pm 1SD$ of the amputee subjects, these values were comparable. All normal subjects had a right dominant leg.

Table 11. Age, height, body mass, and dominant leg of amputee subjects.

Subject	Age (years)	Height (cm)	Body mass (kg)	Dominant Leg
A1	35.1	179.2	71.075	Left
A2	28.3	182.8	89.020	Left
A3	26.3	179.2	75.320	Left
A4	36.3	177.4	69.830	Left
$\bar{x}\pm SD$	31.5±4.9	179.7±2.3	76.4±8.9	

Table 12. Age, height, body mass, and dominant leg of normal subjects.

Subject	Age (years)	Height (cm)	Body mass (kg)	Dominant leg
N1	27.4	181.6	82.825	Right
N2	32.3	177.6	74.410	Right
N3	28.5	179.7	71.685	Right
N4	36.4	177.9	79.550	Right
$\bar{X} \pm SD$	31.1 ± 4.1	179.2 ± 1.8	77.1 ± 5.0	

Table 13 illustrates the characteristics of the amputee subjects. The amputee group comprised of the two above-knee and two below-knee amputees. The time from amputation to participation in this study ranged from 2.3 to 23.3 years with a mean of 11.0 years. The calculated stump anthropometrics required for the determination of the location of the CGB are depicted in Table 14.

Table 13. Characteristics of amputee subjects.

Subject	A1	A2	A3	A4
Amputation level	Above-knee	Above-knee	Below-knee	Below-knee
Time from amputation to test (years)	16.1	2.3	2.4	23.3
Distal stump circumference (cm)	39.0	40.3	23.6	25.5
Proximal stump circumference (cm)	59.5	57.2	36.1	34.5
Stump length (cm)	19.8	32.3	19.5	7.6

Table 14. Calculated stump anthropometrics.

Subject		A1	A2	A3	A4
Distal stump radius (cm)		6.2	9.1	3.8	4.1
Proximal stump radius (cm)		9.4	6.4	5.8	5.5
Stump volume (m^3)		3.88	6.15	1.41	0.55
Stump centre of mass location	Proximal (cm)	8.6	14.3	8.4	3.4
	% Proximal distance	43.2	44.3	43.1	45.0
Stump mass (kg)		4.07	6.45	1.48	0.60
Relative stump mass (%)		5.73	7.22	1.96	0.86

The highest isokinetic torque value of the three trials at 60 degress.s^{-1} for knee extension and ankle plantar flexion for each subject was recorded. The peak isokinetic knee extensor torque for the amputee subjects ranged from 164 to 207 Nm with a mean of 190 $\pm$ 19 Nm

(Table 15). The peak ankle plantar flexor torque ranged from 73 to 114 Nm with a mean of 84 ± 20 Nm. These values did not significantly ($p<0.05$) differ from those of the normal subjects (Table 16).

For the normal subjects, the mean peak isokinetic knee extensor torque was 199 ± 15 Nm and ranged from 188 to 220 Nm. The peak ankle plantar flexor torque ranged from 103 to 146 Nm with a mean of 115 ± 21 Nm.

Table 15. Peak isokinetic knee extensor and ankle plantar flexor torques of amputee subjects.

Subject	Knee extensor torque (Nm)	Ankle plantar flexor torque (Nm)
A1	201	77
A2	207	114
A3	186	73
A4	164	73
$\bar{X} \pm SD$	190±19	84±20

Table 16. Peak isokinetic knee extensor and ankle plantar flexor torques of normal subjects.

Subject	Knee extensor torque (Nm)	Ankle flexor torque (Nm)
N1	188	108
N2	191	103
N3	195	104
N4	220	146
$\bar{X} \pm SD$	199±15	115±21

Table 17 displays the one-legged CMJ and SJ performance of the amputee subjects. The highest jump of the three trials for each condition was recorded. Vertical jump performance for CMJs ranged from 10.7 to 15.3 cm with a mean of 13.1 $\pm$ 1.9 cm. For the SJs, the range was 10.2 to 12.2 cm with a mean of 10.6 $\pm$ 1.1 cm. There was a significant ($p<0.05$) difference between the two jumps. CMJ performance was on the average 2.5 cm greater than SJ performance.

Table 17. One-legged vertical jump performance of amputee subjects.

Subject	CMJ (cm)	SJ (cm)
A1	15.3	10.5
A2	10.7	9.5
A3	13.4	12.2
A4	12.9	10.2
$\bar{X}\pm SD$	13.1$\pm$1.9	10.6$\pm$1.1

No statistical ($p<0.05$) difference was found between the performance of the two jumps for the normal subjects (Table 18). The height attained in the CMJs ranged from 10.9 to 17.1 cm with a mean of 14.6 $\pm$ 2.6 cm. For the SJ condition, the mean was 11.1 $\pm$ 0.05 cm and ranged from 10.3 to 11.8 cm.

Table 18. One-legged vertical jump performance of normal subjects.

Subject	CMJ (cm)	SJ (cm)
N1	15.5	11.5
N2	10.9	11.8
N3	17.1	10.3
N4	14.9	10.7
$\bar{X}\pm SD$	14.6±2.6	11.1±0.5

Although the normal subjects displayed a greater mean performance in one-legged CMJs and SJs than the amputee subjects, the difference was nonsignificant ($p<0.05$). Table 19 provides a summary of the multivariate ANOVA for the variables.

Table 19. Multivariate ANOVA summary for the variables.

Variable	Group	$\bar{X}$	SD	F-ratio	Pr > F
Knee (Nm)	Amputee	190	19	0.56	0.4833
	Normal	199	15		
Ankle (Nm)	Amputee	84	20	4.68	0.0738
	Normal	115	21		
CMJ (cm)	Amputee	13.1	1.9	0.88	0.3834
	Normal	14.6	2.6		
SJ (cm)	Amputee	10.6	1.1	0.50	0.5050
	Normal	11.1	0.5		

Pr > F = probability of exceeding the F-ratio.

The correlation coefficient between peak isokinetic torques and one-legged jump performances for amputee and normal subjects are presented in Table 20 and 21 respectively. The only significant ($p<0.05$) correlation found was between the peak isokinetic knee extensor torques and peak isokinetic ankle plantar flexor torques for the normal subjects ($r = 0.961$).

Table 20. Correlations between peak isokinetic torques and one-legged jump performance for amputee subjects.

	Ankle	CMJ	SJ
Knee	0.667	0.116	0.240
Ankle		0.783	0.664
CMJ			0.458

Table 21. Correlations between peak isokinetic torques and one-legged jump performance for normal subjects.

	Ankle	CMJ	SJ
Knee	0.961*	0.138	0.501
Ankle		0.122	0.344
CMJ			0.792

* significant at $p<0.05$ level of confidence.

CHAPTER 5

DISCUSSION

Amputee subject recruitment was found to be a difficulty. The impression received by the author was that there were a number of suitable amputees in the general population but they were reluctant to take part in the study. It is possible that these individuals after having experienced trauma and being fitted with prostheses did not welcome any more testing. Some of the organisations contacted also appeared hesitant to assist in recruiting subjects, stating that the amputees had committed their time to other studies. For this investigation, four lower extremity amputees consented to serve as research participants.

The mean peak isokinetic torques for knee extension and ankle plantar flexion of the normal subjects were 9 Nm (5%) and 31 Nm (37%) greater than those of the amputee subjects. The differences were not significant ($p<0.05$). This supports the hypothesis that there would not be a statistically significant difference between the peak isokinetic torques. With a small sample size, a large difference is required to establish statistical difference. Perhaps with larger groups a significant difference may be found for peak isokinetic torques.

The mean peak isokinetic plantar flexor torques for both the amputee (84 ± 20 Nm) and normal (115 ± 21 Nm) subjects at 60 degrees.s^{-1} were lower than the values previously reported for non-amputee individuals. Fugl-Meyer (1981) assessed the dominant limb of 15 male athletes at 30, 60, 120, and 180 degrees.s^{-1}. The mean peak torque at 60 degrees.s^{-1}

was 145 ± 24 Nm. A reason for this may be found in the variation in subject positioning. Fugl-Meyer (1981) assessed the subjects in a supine position. While in the present study, the action was performed in a prone position. Since the knee was in full extension and the ROM was similar (maximum dorsiflexion to maximum plantar flexion) for both studies, the muscle length-tension relationship was unlikely to have contributed to the difference.

The mean peak isokinetic knee extensor torques for the amputee (190 ± 19 Nm) and normal (199 ± 15 Nm) subjects at 60 degrees.s^{-1} were comparable to the value (191 ± 35 Nm) obtained by Poulmedis (1985) for 18 elite male soccer players at 90 degrees.s^{-1}. The soccer players were not assessed at 60 degrees.s^{-1} but it could be argued that they would have generated greater values than the subjects in the present study. This is based on the fact that they generated the highest torque (249 ± 29 Nm) at the lowest test speed of 30 degrees.s^{-1}. This would suggest that they would follow the torque-velocity relationship established by others (Moffroid et al., 1969; Thorstensson et al., 1976; Barnes, 1980; Yates and Kamon, 1983), that is, as the speed of isokinetic testing decreases, peak concentric torque values tend to increase. Due to the nature of the sport, elite soccer players engage in intense sprinting and kicking bouts which are likely to enhance knee extensor strength.

The amputees in this study generated greater mean peak isokinetic knee extensor torques than the amputees in Renstrom's (1981) group. Renstrom measured the torques of 24 male below-knee amputees. At 60 degrees.s^{-1}, the mean value was 140 ± 12 Nm. The subjects had a mean age of 61 ± 18 years and mean time from amputation to testing was 2.3 ± 1.8 years. The subjects in the present study were younger (31.5 ± 4.9 years) and had been amputees for a longer period of time (11 ± 10 years). It is believed that these two points largely account for the superior peak knee extensor torques of the present group.

The amputees in the present study did not demonstrate significant differences in peak knee extensor nor ankle plantar flexor torques when compared to the normal subjects. Peak isokinetic torque may serve as a reflection of strength. Strength is an important factor in many sporting actions.

All of the amputee subjects jumped higher in the CMJ condition than the SJ. The mean difference was 2.5 cm (24%) and significant at $p<0.05$. The mean difference for the normal subjects of 3.5 cm (32%) was not statistically significant. There are some factors which could account for this lack of statistical significance: one of the normal subjects attaining a greater jump performance in the SJ than the CMJ which contradicts previous findings, and the sample size being small.

The greater mean enhancement of jump performance after incorporating a countermovement for the normal subjects suggests a higher net contribution of the mechanisms activated when the muscles are prestretched. One mechanism is the utilization of stored elastic energy (Asmussen and Bonde-Peterson, 1974). When an active muscle is forced to stretch it stores elastic energy which can be partially recovered during the shortening phase. The stretching of active muscles prior to shortening occurs in a vertical jump by incorporating a countermovement. This countermovement with rapid flexion at the lower extremity joints places the extensors on stretch. Greater work done by the contractile component is also believed to occur when the muscles are prestretched. Cavagna et al. (1968) found that a muscle both in vitro and in vivo, which shortened immediately after being stretched performed greater work than the same muscle if it shortened from a state of isometric contraction, with the speed, the length, and extent of shortening being constant. Another mechanism postulated to be activated when the muscles are prestretched is stretch reflex potentiation (Bosco and Komi, 1979a). Prochazka et al. (1977) demonstrated that a fast stretch of an active muscle caused substantial stretch reflex potentiation via afferents from the muscle spindles resulting in an increased frequency of motor unit discharge.

Most of the normal subjects (three out of four) jumped higher in the CMJ than the SJ. This finding is in agreement with those for two-legged vertical jumps reported in the literature. Asmussen and Bonde-Peterson (1974) found a significant ($p<0.02$) mean difference of 2cm (5%) between the SJ (36.6 cm) and CMJ (38.6 cm) performance of 14 male and five female subjects. A greater mean difference of 5.7 cm (16%) was found by Bosco and Komi (1979b). Thirty-four male physical education students attained a mean CMJ performance of 41.6 cm compared with 35.9 cm for the SJ. In a study with a larger sample size, Bosco and Komi (1980) assessed a total of 226 subjects (113 males and 113 females) ranging in age from 4 to 73 years. The subjects were divided into age groups. All groups attained a higher rise of the CGB in the CMJs when compared to the SJs. The improvement in performance ranged from 10 to 20% for the male groups and 12 to 23% for the female groups.

There are other studies (Komi and Bosco, 1978; Bosco et al., 1981) which demonstrated a greater mean performance of CMJs over SJs but the jumping conditions (present knee joint angle) differed from those of the present investigation. The conditions in the three studies quoted above approximated those in the present investigation. To eliminate arm swing in this investigation as well as others, the arms were positioned in an akimbo position. There was no constraint on movement amplitude about the knee joint for SJs or CMJs. One difference between the two studies was that vertical performance was calculated from the flight time measured from the vertical ground reaction force trace. As previously stated, this method of calculation as compared to cinematographic technique has been shown to produce a difference of $\pm$ 2% (Komi and Bosco, 1978).

Some difficulty was experienced during the determination of the stump anthropometrics. The Hanavan (1964) model was used to calculate volume and position of the centre of gravity of the residual limb of the amputee subjects assumed the limb to have constant density and be the shape of a truncated cone. The calculations required a distal stump circumference which was difficult to determine since the stump end was generally dome shaped. Stump volume in future studies may be better measured by water volumetry techniques.

The mean score for one-legged CMJ performance of ten well trained male volleyball players was found to be 31 cm (Soest et al., 1985). This is more than twice the mean CMJ performance of the dominant leg of the amputee (13.1 cm) and normal (14.6 cm) subjects of present investigation. Admittedly, the amputee and normal subjects were not skilled jumpers but the volleyball players performed the one-legged jumps with their left leg. Anthropometric measures suggested that the left leg was not likely to have been dominant. Part of this large difference may be attributed to the definition and calculation of jumping height of the volleyball players. Jumping height was defined as the vertical distance between the highest position of the greater femoral trochanter landmark and of this landmark when the subject was standing erect. It is assumed by this author that "standing erect" signified that the heel was in contact with the ground. In the present investigation, jumping height was defined as the height attained by the CGB from the instant the metatarsal heads of the foot lost contact with the force platform to the apex of the jump. Had the jump height of the volleyball players been measure from take-off and not from standing with heel contact, the recorded jump height would have been considerably less.

In the present study, although the normal subjects achieved a greater height during CMJs and SJs than the amputee subjects, the difference was not found to be significant. This is support for the hypothesis that performance in one-legged vertical jumps would not significantly differ between amputee and normal subjects. This should be encouraging for amputees since one-legged jumps and take-offs are performed in athletic activities in which unilateral lower extremity amputees participate, such as the high jump and swimming starts.

Consistent with previous findings (Perrine et al., 1978; Genuaro and Dolgener, 1980; Oberg 1988), this investigation found low to moderate correlations (r=0.116 to 0.783) between peak isokinetic torques and vertical jump performance for both the amputee and normal subjects. No correlation was found to be significant. This may be explained by a number of factors. The vertical jump is a complex movement involving actions at many joints. The isokinetic torque values are for a single joint motion. The isokinetic speed was set at 60 degrees.s^{-1} while the angular speed of the leg segments during vertical jumping may exceed the maximal Cybex II speed setting of 300 degrees.s^{-1}. Ingen Schenau et al. (1985) found the mean maximal angular velocity of plantar flexion of 12 trained subjects during SJs to be 970 degrees.s^{-1}. Vertical jumping also involves coordination: timing, sequencing and amplitude of the forces of the elastic and contractile components of the muscular system.

CHAPTER 6

6.1 CONCLUSIONS

The following conclusions were reached based on the findings of this investigation:

1. The mean peak isokinetic knee extensor and ankle plantar flexor torques at 60 degrees.s^{-1} for the non-amputated leg of the unilateral lower extremity amputees were less but not significantly different from those of the dominant leg of the normal subjects. Since isokinetic torque is a reflection of strength, the normal subjects did not have superior knee extensor or ankle plantar flexor strength.

2. Consistent with the findings of two-legged vertical jumps (Asmussen and Bonde-Peterson, 1974; Bosco and Komi, 1979b; Bosco and Komi, 1980), the amputee subjects attained a significantly higher mean rise of the centre of gravity of the body during one-legged countermovement jumps compared to static jumps. The normal subjects also attained a higher mean rise of the centre of gravity of the body during one-legged countermovement jumps compared to static jumps but the difference was not significant.

3. The normal subjects attained a higher mean rise of the centre of gravity of the body than the amputee subjects during one-legged countermovement and static jumps but the differences were not significant. Compared to normal subjects, unilateral lower extremity amputee subjects would not be disadvantaged in their ability to perform standing one-legged jumps.

4. No significant correlations were found between peak isokinetic knee extensor and ankle plantar torques at 60 degrees.s^{-1} and height attained by the centre of gravity of the body during countermovement and static jumps of the amputee and normal subjects. This substantiates the belief that many factors contribute to vertical jump performance.

6.2 RECOMMENDATIONS

1. Due to the limited number of subjects tested in this investigation, it is recommended that a study with a larger sample size be conducted.

2. It is recommended that the findings of this investigation be made available so as to encourage unilateral lower extremity amputees and other individuals with disabilities to engaged in sporting and recreational activities.

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APPENDIX 1

APPENDIX 1: Subject Consent Form.

FOOTSCRAY INSTITUTE OF TECHNOLOGY

DEPARTMENT OF PHYSICAL EDUCATION & RECREATION

STANDARD CONSENT FORM FOR SUBJECTS INVOLVED IN EXPERIMENTS

1. CERTIFICATION BY SUBJECT

I, ...

of ....

certify that I have the legal ability to give valid consent and that I am voluntarily giving my consent to participate in the experiment entitled:

" *BIOMECHANICAL CHARACTERISTICS OF THE LOWER*

EXTREMITIES OF AMPUTEE VERSUS NORMAL SUBJECTS

...."

being conducted at Footscray Institute of Technology by: ....

CON HRYSOMALLIS.

I certify that the objectives of the experiment, together with any risks to me associated with the procedures listed hereunder to be carried out in the experiment, have been fully explained to me by:

CON HRYSOMALLIS

....

and that I freely consent to participation involving the use on me of these procedures.

Procedures

(i) PERFORM A SERIES OF MAXIMAL EFFORT ONE-LEGGED VERTICAL JUMPS ON A

FORCE PLATFORM WHILE BEING VIDEO TAPED.

(ii) PERFORM MAXIMAL KNEE EXTENSION AND ANKLE PLANTAR FLEXION ON A

ISOKINETIC DYNAMOMETER.

....

I certify that I have had the opportunity to have my questions answered and that I understand that I can withdraw from this experiment at any time and that this withdrawal will not jeopardise me anyway.

Signed: ....)

Witness other than the experimenter ....) .... Date

CERTIFICATION

I, *CON HRYSOMALLIS* ....have fully explained the objectives, risks and procedures of the abovenamed experiment to the subject named herein.

Signed .... Date ....

NOTES:
1. Those signing this form are reminded that while research workers have a duty to advance knowledge by research, the rights of the individual subject take precedence over expected benefits to knowledge or to the community.
2. The experimenter is reminded of the need to observe confidentiality, when appropriate, to protect the interests of subjects.
3. Subjects who are employees of Footscray Institute of Technology should be advised that participation in the experiment does not affect in any way their entitlement or right to receive workers' compensation.

APPENDIX 2

APPENDIX 2: Segmental Masses as Percentages of the Total Body Mass for Males.

Segment	Percentage of total body mass
Hand	0.65
Forearm	1.87
Upper arm	3.25
Foot	1.43
Lower leg	4.75
Thigh	10.50
Trunk	46.48
Head and neck	8.26

Plagenhoef et al.(1983).

APPENDIX 3

APPENDIX 3: Segment Centre of Gravity Location as a Percentage of the Segment Length from the Proximal End for Males.

Segment	Percentage of segment length
Hand	46.8
Forearm	43.0
Upper arm	43.6
Foot	50.0
Lower leg	43.4
Thigh	43.3
Trunk	63.0
Head and neck	55.0

Plagenhoef et al.(1983).

APPENDIX 4

APPENDIX 4: An Example of a Spatial Model Set Up.

Name:	AMPAK
# of Points:	12
1	HEAD
2	NECK
3	SHOULDER D
4	ELBOW D
5	WRIST D
6	KNUCKLE D
7	HIP D
8	KNEE D
9	ANKLE D
10	TOE D
11	HEEL D
12	STUMP

SEGMENTS	P	D	%Dist	%Mass
HEAD+NECK	2	1	55.0	9.28
TRUNK	7	3	63.0	52.60
THIGH D	7	8	43.3	11.79
STUMP	7	12	44.3	5.73
LOWER LEG D	8	9	43.4	5.33
FOOT D	9	10	50.0	1.61
UPPER ARMS	3	4	43.6	7.30
FOREARMS	4	5	43.0	4.20
HANDS	5	6	46.8	2.1

APPENDIX 5

APPENDIX 5: An Example of a Project Set Up.

1	Project Name:	AMPAK1	
2	Spatial Model Name:	AMPAK	
3	Camera Used:	4	SUPER VHS
4	Picture Rate:	50	
5	# of Pictures per Field	1	
6	Pictures skipped,(U)ser select:	0	
7	Number of Reference Points:	1	
8	Scaling Factor:	138.0018	
9	Units of Length:	METRE	
10	Number of Event Frames:	1	