ANALYSIS OF DYNAMIC LIFTING EXERTIONS PERFORMED BY MALES AND FEMALES ON A HYDRODYNAMOMETER

ANDREW DALETH JEREMY PINDER

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Department of Anatomy and Developmental Biology
Royal Free and University College Medical School
University College London
Royal Free Campus
Rowland Hill Street
London NW3 2PF

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Do you not know?
Have you not heard?
The LORD is the everlasting God,
the Creator of the ends of the earth.
He will not grow tired or weary,
and his understanding no-one can fathom.
He gives strength to the weary
and increases the power of the weak.
Even youths grow tired and weary,
and young men stumble and fall;
but those who hope in the LORD
will renew their strength.
They will soar on wings like eagles;
they will run and not grow weary,
they will walk and not be faint.

Isaiah 40:28-31 (NIV)

This is what the LORD says:
"Let not the wise man boast of his wisdom
or the strong man boast of his strength
or the rich man boast of his riches,
but let him who boasts boast about this:
that he understands and knows me,
that I am the LORD, who exercises kindness,
justice and righteousness on earth,
for in these I delight,"
declares the LORD.

Jeremiah 9:23-24 (NIV)

Frontispiece 1

Frontispiece 2

Frontispiece 3

ABSTRACT

Gender differences in physical capability have implications for worker selection policies. Ability to perform maximal dynamic lifts under controlled conditions is known to be related to ability to carry out physically heavy employment.

The mechanics of muscular contraction are reviewed in the context of the measurement of dynamic strength. Gender differences in dynamic strength are reviewed in the context of the performance of military tasks.

The principles of fluid mechanics governing the operation of a hydro-resistive dynamometer and its instrumentation and calibration are described, with experimental protocols and methods of data collection. The relationship between force and velocity can be controlled and measurements are repeatable.

Subjects performed maximal dynamic lifts from 0.4 m from the ground to above 1.8 m. Force, position and time were measured, and related measures derived. Usable data from 201 male and 69 female serving soldiers are reported. Relationships between the different parts of the lift are modelled using linear regression. Differences in performance between subjects from different military employment groups are explored, as are differences in lifting technique.

Gender differences are identified using analysis of covariance. Relative to stature, males and females lift in the same manner. The gender differences almost completely disappear when differences in fat-free mass are taken into account across the range of the lift.

Principal Components Analysis is used to study the underlying features which affect the variability of the lift. The most important factors are the strength of the initial pulling phase and the need to change grip at chest height. The factors obtained are device dependent.

Absolute gender differences in strength limit the entry of women into physically demanding jobs. Therefore, if selection on the basis of gender is to be avoided, actual ability to perform the job should be the paramount selection criterion.

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CHAPTER 1

INTRODUCTION

1.1 Background

The data reported in this thesis were collected as part of a much larger study being carried out by the Centre for Human Sciences (CHS) of the Defence Research Agency (DRA) into physical selection standards for the British Army (Rayson and Holliman, 1995, Rayson *et al.*, 1996, Rayson, 1997, 1998, Rayson *et al.*, in press). Many job specialisms within the Army are physically, or even maximally demanding, and many specialisms, particularly front-line or 'teeth-arms' have historically been closed to women for social reasons. The physical requirements of these specialisms have therefore been based upon the capabilities of fit and trained young males.

Attitudes to the roles that women play in society have changed dramatically in the last 100 years. Reflecting this, the Army wished to comply with Equal Opportunities legislation, in the expectation that political decisions would be made to increase the number of units which women would be allowed to enter. Given that the physical demands of the jobs were unlikely to change in the short term, it wished to have legally and scientifically defensible methods of better matching the capabilities of soldiers with the demands of the specialisms irrespective of gender. Therefore the CHS project was set up to identify the physical requirements of the different specialisms within the Army, to identify screening tests which could be used to predict which recruits would be capable, after basic and trade training, of performing the tasks, and to identify 'gender-free' physical selection standards which could be used to allocate recruits to units.

It is worth noting that it is inherent in the role of the military that they will be called upon to perform physically extreme tasks, because the unit that can perform harder tasks for longer periods of time will have more options open to it in the extreme conditions of battle and is more likely to be victorious. While it is clearly sensible to reduce the physical demands of military tasks, particularly in peace-time conditions, training must simulate battle-field conditions. The role of the infantry soldier will always be demanding, and changing terrain and weather conditions, the effects of enemy action, and equipment failures will make tasks that are straightforward in a military base difficult, if not impossible, in the field. In fact the aim of warfare is to overwhelm the enemy physically so that he is rendered incapable of resisting. This means that the demands can be expected to increase as a battle progresses and losses of men and equipment are sustained. As this happens, tasks and equipment will be abandoned as they become impossible or unusable. If use or movement of a piece of equipment demands the physical exertion of four soldiers and only three are left then it will be abandoned.

1.2 Manual handling as a classic ergonomics problem

Manual materials handling is an activity of major economic importance worldwide, but especially so in less developed countries where it is still more economic to use human labour instead of mechanisation. It has been widely acknowledged to be a major cause of injury to industrial workers (Ayoub and Mital, 1989). In 1990/91 in the UK, 34% of reported accidents that caused more than 3 days absence from work were associated with manual handling. 65% of these handling injuries were sprains or strains. The back was injured in 45% of handling accidents (HSE, 1992). As a result there are recent attempts to regulate manual handling operations (HSE, 1992) and to provide methods which will allow the safe design of manual handling tasks (Waters *et al.,* 1993, 1994).

Ayoub *et al.* (1979) described two opposing philosophies which may be adopted for dealing with the problems caused by manual materials handling, saying that carrying either to the extreme would be unsatisfactory.

1 "Setting lifting standards so low that literally everyone would be able to perform the lifting task repetitively for extended time periods without incurring either fatigue or bodily injury".

2 "Relaxing the lifting standards in an attempt to optimise the working efficiency at the expense of worker safety".

A third philosophy, propounded by NIOSH (1981) and Liles *et al.* (1984), can be added:

3 Selection of workers so that heavy lifting tasks are only performed by workers who are capable of performing them without risk to themselves.

The descriptions of these three philosophies can be summarised, or even caricatured as:

1 Ergonomic job redesign / fitting the job to the man / giving the worker an easy ride

2 Economic deregulation / creating a free-market / creating unsafe systems of work

3 Selection and training of workers / fitting the man to the job / expecting the worker to pull his weight

Thus the design of manual handling tasks is a classic example of the concerns of ergonomist, and the volume of scientific publications on the topic reflect this.

1.3 Manual handling as a military problem

Rayson (1998) reported a survey of the most physically demanding tasks carried out by soldiers in the British Army. The survey was limited to tasks that would, in theory, be carried out by all soldiers within a particular unit. Of 64 tasks measured, 88% involved lifting and 48% involved carrying. 55% involved a combination of actions, with lifting and carrying comprising 89% of these. 76% of lifts started below 0.3 m; 61% of lifts finished in the region between 1.0 m and 1.7 m. 37% of tasks were single person, and 63% were multi-person. Team size ranged up to eight people. Loads ranged from 10 kg to 111 kg per person. The characteristics of objects that were handled often required the employment of unusual methods of handling. Objects could be large, of variable shape, asymmetrical in load distribution, unstable or lacking handles.

It is clear from this work that physically demanding manual handling operations are a feature of military activities and that some of them are very extreme. Therefore manual handling is a problem within the military context which needs to be addressed from an ergonomics perspective.

1.4 Gender differences and sex discrimination

As noted above, social attitudes to the roles that women play in society have changed dramatically in the last 100 years. This improvement in the status of women has been partly a result of technological progress, particularly in the fields of reproductive medicine and birth control, allowing the roles that men and women adopt in society to change. These changes in role have been facilitated by the passing of legislation outlawing discrimination on the basis of the sex of a worker and the more recent development of a culture of 'Political Correctness' where attempts have been made to alter the way in which language is used to describe differences such as gender differences in order to alter the underlying perceptions within society of the nature and importance of these differences. In other words, a deliberate attempt is being made to blur the distinctions between men and women in the pursuit of equality between the sexes.

That there are genuine differences between men and women is biologically undeniable. However, the issue of the relations between and the appropriate roles of the two sexes has been a matter of debate throughout history. For example, John Knox in his polemic against Mary Tudor, the *First Blast of the Trumpet against the Monstrous Regiment of Women* (1558) wrote [regiment in this context means government]:

> *"I exempt such as God, by singular privilege and for certain causes known only to Himself, hath exempted from the common rank of women, and do speak of women as nature and experience do this day declare them. Nature, I say, doth paint them forth to be weak, frail, impatient, feeble and foolish; and experience hath declared them to be inconstant, variable, cruel and lacking the spirit of counsel and regiment."*

Knox also quoted the theologian Tertullian who wrote *Against Marcion* (circa AD 200):

> *"he [Tertullian] reciteth this as a great monster in nature: 'That women in those parts were not tamed nor embased by consideration of their own sex and kind, but that all shame laid apart they made expenses upon weapons and learned the feats of war, having more pleasure to fight than to marry and be subject to men'."*

It is therefore clear that women have long been portrayed as 'the weaker sex' and that women adopting male roles such as government or learning 'the feats of war' have often been regarded with horror.

Far more recently, Hayne (1981), in a discussion of the subject of the manual transport of loads by women in which he attempted "to identify practical solutions to the problems which may arise when the concept of sex equality is applied in industry", stated that:

> *"Though men and women have many similarities, it is essential to recognise the differences that exist between the sexes, especially when considering manual tasks in order that true health, safety and welfare at work can be a reality for all."*

He also made some fascinating comments regarding the legal situation regarding sex discrimination and health and safety in the UK. Thus,

> *"The physiological factors of strength and stamina are not generally acceptable as genuine occupational qualifications. This is because employers are expected to organise their work patterns in such a way that women are not exposed to excessive stress."*

He also noted that:

> *"as the principles of equality were introduced, many of the women who sought work in previously all-male areas had no real concept of what was involved."*

and that:

> *"Before the Equal Pay Act, male workers were quite often willing to help their female colleagues with heavy tasks. Predictably their attitudes changed and 'you say you are equal, you get the pay, you do the work', was not an uncommon reaction. Such a view seems excusable from those who saw one man being replaced by two women on a loading task, especially when it was costing nearly three times as much in wages, due to seniority pay differentials."*

Redgrove (1984), in a paper with the challenging title of "Women are not from Lilliput or Bedlam", argued that women tend to be seen as small simple-minded men who are too delicate for some jobs and too stupid to be employed in anything but the most menial tasks. She noted that most jobs in modern industry make very modest physical demands, with very few being beyond the physical capacity of most women, but women have been condemned to the most menial, heavy and dirty jobs and are still treated as beasts of burden in many parts of the world. She also mentioned the differences in motivation between males and females, with women wishing to not appear physically strong in mixed groups in order to conform to feminine stereotypes, and the conflicting demands on women of home and career.

She concluded that:

> *"The implications of sex differences for women's work depend on beliefs about women's roles and women's particular needs and attributes. All these have to be taken into account when designing work in order to avoid unfair discrimination deriving from social prejudice and in order to achieve more ergonomically designed jobs for men and women."*

Unfortunately Redgrove failed to substantiate her thesis either logically or empirically. If women really were seen as small simple-minded men they would not be called women, they would be called men! She also failed to state an alternative way in which women could be seen. Perhaps we should see men as large clever women who are too strong and clumsy for some jobs and too intelligent to be wasted on menial tasks!

This raises the broader issue of the relative treatment and expectations made of men and women. If women are merely smaller versions of men then there is no need or justification for sex discrimination and they must be seen as equal except in body size, (and possibly intellect, in the unlikely event of women being demonstrated to be more simple-minded than men!) The contradictory demands of feminism must also be taken into account: on the one hand women demand equal treatment with men, because they are as good as men; on the other, they demand special treatment because they are different to men. It is a logical truism to say that if two things are different then they cannot be equal. Men and women differ from their chromosomes, through their hormones to their morphology. The question must be not "Is it wrong to discriminate between men and women?", but "In what circumstances should men and women be treated the same, and in what circumstances should they be treated differently?"

1.5 Gender differences and the military

Because size and strength differences between males and females were particularly apparent in physically demanding occupations, Celentano *et al.* (1984) studied the relationships between size, strength and task demands in three physically demanding military tasks . High attrition rates of female trainees were being attributed by instructors to a lack of physical size or capability. Using data from 23 male and 18 female military recruits, they found that it was possible to predict performance on representative trade tasks from anthropometry, strength and gender. They stated that selection standards for entry to such trades should be developed based on performance criteria that must be met equally by both males and females. The implication of their argument is that the two genders would have the same cut-off in terms of absolute performance on the military tasks and it would not permit lower entry standards for females, or other forms of positive discrimination.

They also pointed out that when gender appears as a significant predictor, the predictive power of other variables might vary, implying that the selection standards for any given task performance criterion could be different for males and females. They ended by arguing that the strength demands on some of the tasks they studied were so high that females might not be able to cope with the physical demands as proficiently as their male counterparts, and while selection and training of females could be a short-term solution, the long-term solution would require effective job and equipment design to bring the physical content of the work to within women's capabilities.

Sharp (1994) reviewed the factors relevant to the performance by women of the physically demanding tasks required in military occupations. Noting that military tasks have historically been designed for the average man, she concluded that the average woman does not have the same physical capacity, nor can she be trained to have the same physical capacity as the average man. She therefore suggested a range of solutions, including physical training to improve performance, task redesign to reduce job demands, the use of mechanical aids, self-pacing and the use of teams to perform tasks. If all these are insufficient, she admitted that the remaining solution is to select the soldiers who can meet the physical demands and job requirements of occupational specialties.

1.6 Conclusions

It is clear that the issues of gender differences in strength and hence in ability to perform physically demanding tasks have been important throughout history and have had important implications for the roles that women have been permitted to perform. In particular women have usually been excluded from the military.

The purpose of this thesis, therefore, is to examine and compare the performance of male and female soldiers on a device measuring maximal dynamic lifting strength in the context of selection policies for jobs which are physically demanding.

CHAPTER 2

LITERATURE REVIEW

2.1 Basic concepts of muscle function

There are three basic concepts related to the mechanics of muscle function (Grieve and Pheasant, 1982; Astrand and Rodahl, 1986): 1) the length-tension relationship; 2) the force-velocity relationship; and 3) the power-velocity relationship.

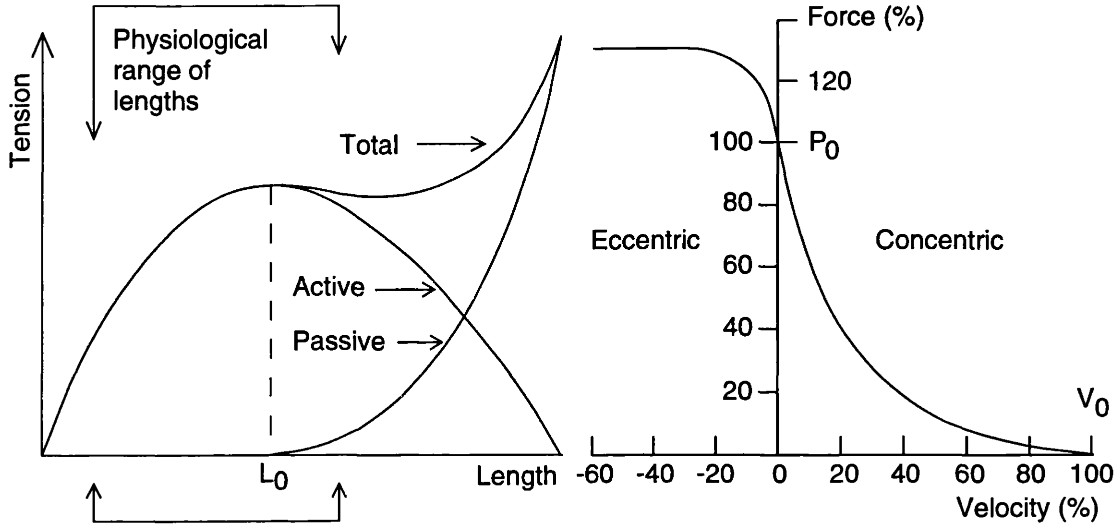


Figure 2.1: The length-tension and force-velocity curves. Redrawn from Figs 3.5 and 3.8 of Grieve and Pheasant (1982) respectively

The length-tension curve of isolated muscle shows that the force a muscle exerts depends upon its length. The torques that can be developed about an articulation depend on the lever arms, orientations and neuromuscular activations of the various muscles acting about that articulation. According to Grieve and Pheasant (1982):

> *"muscles in situ are capable of exerting their greatest tensions in those postures in which they are at their greatest length".*

The force-velocity curve describes the ability of muscle to exert tension while changing length. While it was initially described for isolated muscle fibres, Wilkie (1950) showed that if corrections are made for the mass and moments of inertia of body segments involved, it can also be applied to complete muscle groups acting about a joint. It can be seen, for concentric actions, that as the velocity increases the force decreases. The equation of Hill (1938) describes the concentric part of the curve:

$$(P + a)\cdot(V + b) = (P_0 + a)\cdot b = (V_0 + b)\cdot a = \text{constant}$$

Where P = muscle tension, V = velocity of shortening, P_0 = isometric tension, V_0 = maximum velocity of unloaded muscle, a,b = constants. Gordon *et al.* (1966) reported that V_0 is length dependent, but that at a given length, maximum velocity, V_0, may be regarded as constant. Grieve and Pheasant (1982) interpreted this to mean that for lengths less than the resting length, i.e. most of the normal physiological range, V_0

decreases with P_0, i.e the longer the muscle is to start with, the higher the velocity of shortening that can be obtained. However, Edman (1979) showed for isolated fibres that V_0 is constant over approximately the middle 60% of the range of lengths.

Grieve and Pheasant (1982) also comment that muscle action is history-dependent in ways that cannot be predicted from length-tension and force-velocity characteristics alone. Parnianpour *et al.* (1992) conclude that strength depends upon the measurement technique, i.e. the effect of muscle action will depend on the nature of the resistance.

Asmussen *et al.* (1965) measured force-velocity curves of horizontal pulling actions performed concentrically against an oil-filled hydraulic dynamometer and eccentrically under iso-velocity conditions against a powerful electrical motor. They also measured isometric strengths over the range of the pulling action. Isometric strength decreased linearly as the distance of the hand from the shoulder decreased and the concentric strength, at a velocity of 15% armlength$\cdot$s^{-1}, decreased in parallel with the isometric strength, except at the very beginning of the exertion. They attribute this to the inability of subjects to mobilise full strength immediately, particularly in the light of the more pronounced effect at higher velocities.

Dynamic strength during concentric actions was less than isometric strength in the same position and decreased as velocity increased. They plotted a force-velocity curve which conformed with the curve Hill (1938) obtained for isolated muscle. There were high correlations (of the order of 0.8) between isometric and dynamic strengths, which were independent of the degree of training. They concluded that if results from isometric tests are to be applied to every-day tasks, allowance must be made for the reduction of maximum strength in concentric actions. On the other hand, additional force is available when the muscles are active while being lengthened, as in lowering tasks.

Perrine and Edgerton (1978) measured isokinetic strength of the quadriceps group using a Cybex dynamometer to re-examine the *in-vivo* force-velocity relationship obtained by Wilkie (1950) for isotonic loading of the forearm flexors. Wilkie had corrected his values to take account of the inertia of the forearm, but had not measured acceleration or force directly. They avoided this problem by using isokinetic measurements where the muscle had already achieved the desired velocity.

The force-velocity curve they obtained matched the isolated muscle hyperbola of Hill (1938) at velocities of 192°$\cdot$s^{-1} or greater, but departed from it at slower speeds, with a sharply diminishing rate of rise in force as velocity decreased (Figure 2.2). They claim that the data of Wilkie (1950) and Komi (1973) were not inconsistent with their own findings. They suggest that the differences between the two curves in the high-tension region may reflect the action of some neural regulatory mechanism, which is a suggestion previously discounted by Gasser and Hill (1924).

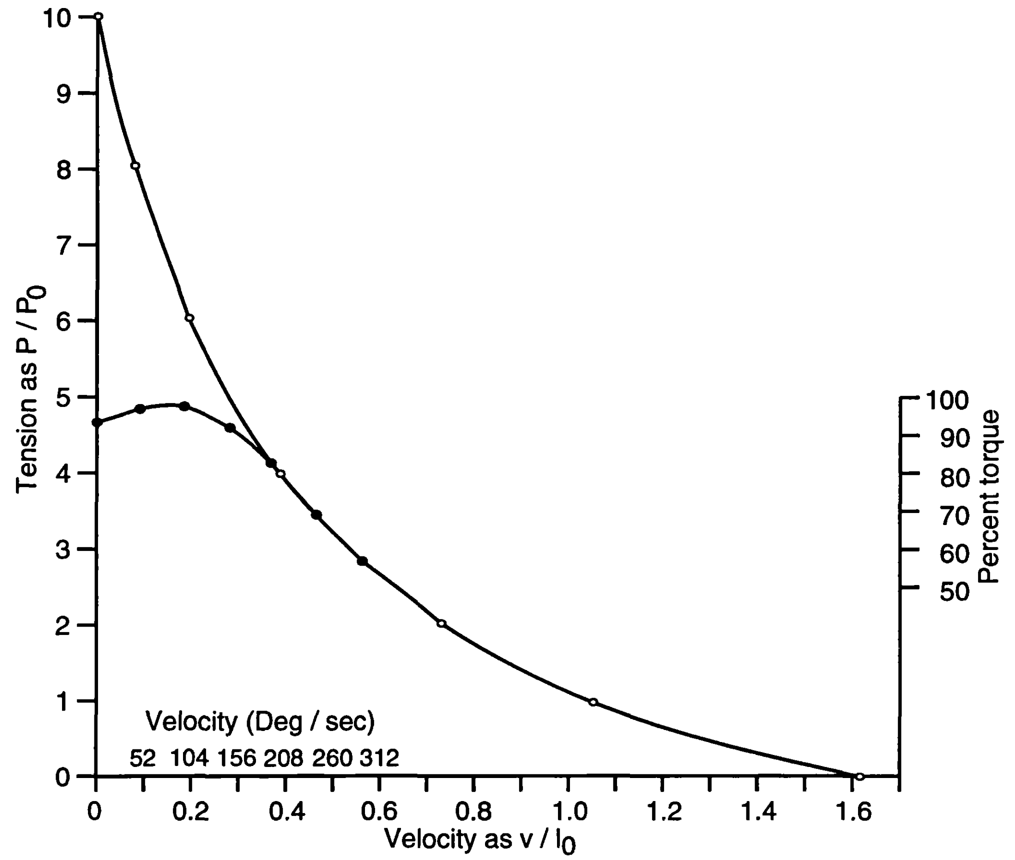


Figure 2.2: Figure 7 from Perrine and Edgerton (1978) (redrawn) showing force-velocity relationships of isolated animal and *in-vivo* human muscles determined under similar loading conditions. Open circles are data obtained from isolated animal muscles by Hill (1970). Closed circles are data obtained by Perrine and Edgerton (1978) from *in-vivo* human muscle scaled to yield the best-fit with the isolated muscle curve.

The power-velocity curve (Figure 2.3) describes the relationship between rate of work (power) and velocity. (Power = force x velocity). No work is done by an isometric action because no motion occurs, and no work is done at peak velocity, V_0, because no force is exerted. Peak power occurs at some intermediate velocity. The precise position at which it occurs will depend on the muscle(s) involved, neural control, fibre orientations, the manner in which the length changes during the movement, and if the argument of Grieve and Pheasant (1982) about the effect of muscle length on V_0 is correct, their initial lengths. Eccentric actions result in the muscle absorbing energy, i.e. negative work is performed.

Perrine and Edgerton (1978) found that power in isokinetic knee extensions rose linearly as velocity increased to $192°\cdot s^{-1}$, then levelled off, peaking at $240°\cdot s^{-1}$, though it was nearly constant in the region of the apparently hyperbolic force-velocity relationship (Figure 2.4).

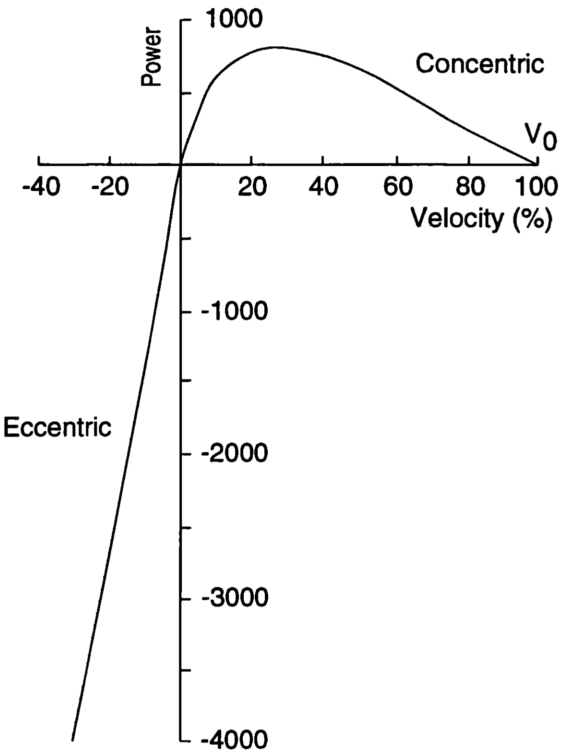


Figure 2.3: The power-velocity curve, redrawn from Fig 3.9 of Grieve and Pheasant (1982)

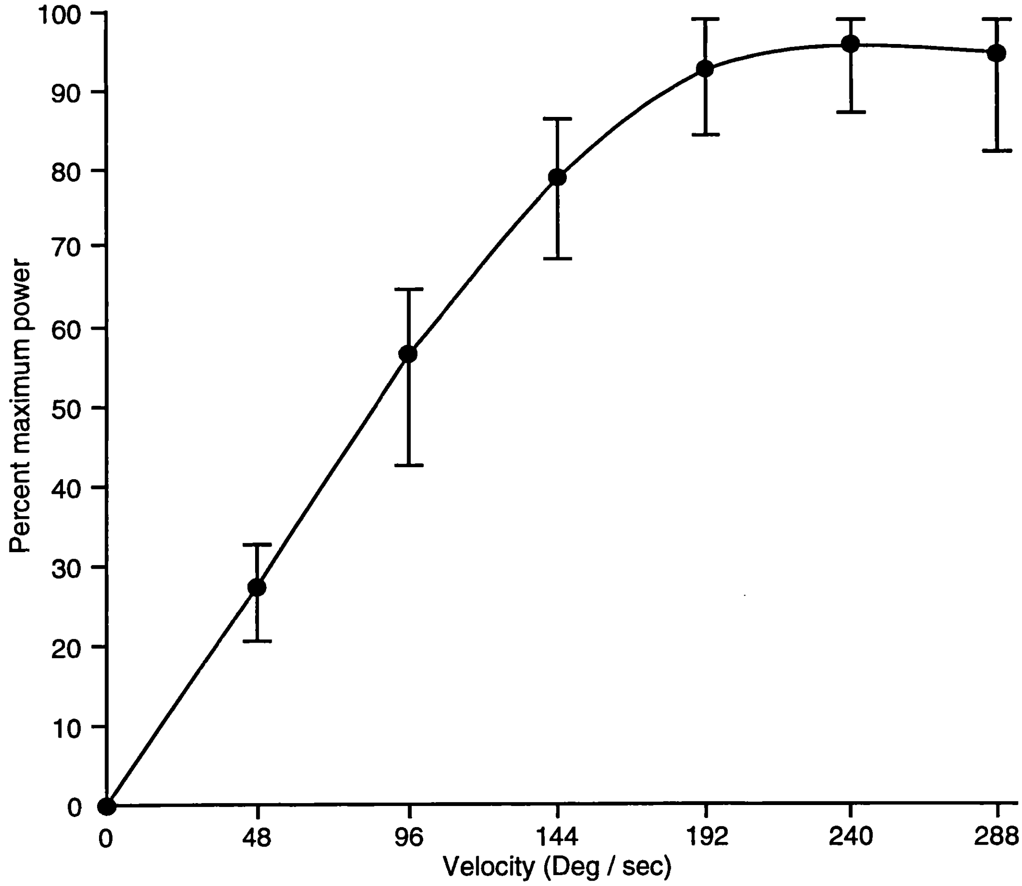


Figure 2.4: Figure 6 from Perrine and Edgerton (redrawn). Power-velocity curve obtained from 15 subjects, showing means and ranges of power normalised to maximum power.

2.2 Measurement of strength

2.2.1 Terminology

Static (isometric) strength is the maximum voluntary force exerted in a fixed posture. *Dynamic* strength is the maximum voluntary force exerted in a movement and may result from both concentric and eccentric actions depending on the muscle groups involved and the presence or absence of co-contractions. In general, motions with a positive velocity (muscular force greater than the external force) are likely to be caused by concentric muscle actions, while motions with a negative velocity (muscular force less than the external force) are likely to be associated with eccentric muscle actions.

Isoinertial tests (Kroemer, 1983) involve the measurement of the maximum weight that a person can move through a defined distance. The inertia of the load remains constant throughout any particular lift, i.e. the load is gravitational (Bosco *et al.,* 1995). The usual protocol is incremental, with a series of lifts of increasing weight being carried out until the subject fails to lift the weight in the prescribed manner. The values obtained are therefore crucially dependent upon the protocol and how rigidly it is enforced.

Accommodating resistance devices provide resistance proportional to the applied force. They are thus not isoinertial and are inherently fail-safe because if the subject stops applying force the reactive force produced by the device disappears. *Isokinetic* devices allow the maximum speed to be pre-set, and in theory offer infinite resistance to prevent acceleration above this speed. The resistance of such a machine matches the applied force, making it a special case of an accommodating resistance device.

2.2.2 Safety of dynamic and static tests of strength

There is no universally accepted single measure of dynamic strength. Early studies of strength concentrated on static tests because "dynamic strength is more complicated and hence subject to many additional influences and potential errors" (Chaffin, 1975). Thus Chaffin *et al.* (1978) chose static tests to eliminate the hazards of objects being dropped and of the dynamic stresses imposed by motion. However, dynamic tests of lifting are "meritorious" because they "involve a total body coordinated action which appears to incorporate strategies or techniques of actual lifting tasks" (Stevenson *et al.*, 1989). Aghazadeh and Ayoub (1985) found dynamic testing faster to administer and safer than isometric testing. Also, Mayer *et al.* (1985) report a total of four testing-related minor muscle strains occurring during isometric testing of 286 chronic low-back pain patients. As a result they eliminated isometric testing from their protocol. Similarly, due to 30 reports of discomfort and three of back injury from 495 subjects citing strength testing as the cause, Batti'e *et al.* (1989) discontinued measuring isometric torso strength.

2.2.3 *Variables available when studying motor performance*

Kroemer *et al.* (1990) have presented a classification of generic variables in motor performance (Table 2.1) and a taxonomy for static and dynamic measurement techniques (Table 2.2):

Table 2.1: Table 2 from Kroemer *et al.* (1990). Original legend: "Generic variables in motor performance measurements"

Independent variables	**Dependent variables**	**Controlled variables**	**Confounding variables**
Muscle motions	Muscle motions	Individual	Motivation
displacement	displacement	age	Fatigue
velocity	velocity	gender	Health
acceleration	acceleration	anthropometry	Fitness
jerk	jerk	Environment	Skill
Mass	Mass	temperature	etc.
Repetition	Repetition	humidity	
Resistance	Output	air velocity	
Body posture	force	radiation	
etc.	torque	noise	
	work	vibration	
	power	Clothing	
	etc.	etc.	

Table 2.2: Independent and dependent variables available for measuring motor performance. Based on Table 3 of Kroemer *et al.* (1990).

Variables			**Measurement techniques**				
	Isometric (static)	**Isokinetic**	**Isoaccel-eration**	**Iso jerk**	**Isoforce**	**Isoinertial**	**Free dynamic**
Displacement (linear / angular)	O	*C*, ×	*C*, ×	*C*, ×	*C*, ×	*C*, ×	×
Velocity (linear / angular)	O	*Constant*	*C*, ×	*C*, ×	*C*, ×	*C*, ×	×
Acceleration (linear / angular)	O	O	*Constant*	*C*, ×	*C*, ×	*C*, ×	×
Jerk (linear / angular)	O	O	O	*Constant*	*C*, ×	*C*, ×	×
Force, torque	*C*, ×	*C*, ×	*C*, ×	*C*, ×	*Constant*	*C*, ×	×
Mass, moment of inertia	*C*	*C*	*C*	*C*	*C*	*Constant*	*C*, ×
Repetition	*C*, ×	*C*, ×	*C*, ×	*C*, ×	*C*, ×	*C*, ×	*C*, ×

C = variable can be controlled, i.e. can be independent variable; O = variable not present, i.e. zero; × = can be dependent variable. The *Constant* variable provides the descriptive name

Table 2.3: Summary of devices which have been used for measuring dynamic lifting strength

	ILM	**Cybex / Liftask**	**Mini-Gym**
Resistance type	Isoinertial	Isokinetic	Accommodating
Mechanism	Weight stack	Hydraulic	Mechanical
Experimental protocol	Incremental	Maximal	Maximal
Controlled variable	Mass	Velocity	Velocity
Accuracy of control	1 -5 kg		$0.1 m\cdot s^{-1}$
Measured variables	Mass	Torque	Force
	Displacement	Force	Velocity
Measurement range	0 - 3 m	0 m to overhead	Flexible
Sampling rate	100 Hz		
Citations	McDaniel *et al.* (1983)	Kishino *et al.* (1985)	Pytel and Kamon (1981)
	Kroemer (1983, 1985)	Timm (1988)	Kamon *et al.* (1982)
	Dales *et al.* (1986)	Weisman *et al.* (1992)	Mital *et al.* (various)
	Stevenson *et al.* (various)		Duggan and Legg (1993)
	Sharp and Vogel (1992)		

	SDST	**ACE**	**Biokinetic ergometer**
Resistance type	Isokinetic	Isokinetic	Accommodating
Mechanism	Electromechanical	Hydraulic	Electromechanical
Experimental protocol	Maximal	Maximal	Maximal
Controlled variable	Velocity	Velocity	Resistance
Accuracy of control	98%	CV 4.5% on one day	
Measured variables	Force	Force	Force
	Displacement		Displacement
Measurement range			1.1 m
Sampling rate	50 Hz	16000 Hz	1000 Hz
Citations	Kumar *et al.* (1988)	Jacobs and Pope (1986)	Garg *et al.* (1988)
	Kumar (1995a,b)	Jacobs *et al.* (1988)	Garg and Beller (1990)
			Garg and Beller (1994)

	Hydrodynamometer	**Omnitron**
Resistance type	Accommodating	Accommodating
Mechanism	Hydraulic	Hydraulic
Experimental protocol	Maximal	Maximal
Controlled variable	Piston area	Orifice size
Accuracy of control	0.73% of area	Up to 12 preset sizes
Measured variables	Force	Force
	Displacement	Displacement
	Velocity	Velocity
	Duration	Power
	Power	Work
	Work	
	Impulse	
Measurement range	0.4 - 2.2 m	
Sampling rate	12.5 kHz	
Citations	Fothergill (1992)	Hortobagyi *et al.* (1989)
	Grieve (1993)	Russell *et al.* (1992)
	Duggan and Legg (1993)	O'Hagan *et al.* (1995)
	Fothergill *et al.* (1996)	

2.3 Dynamic strength measurement using isoinertial techniques

2.3.1 The Incremental Lift Machine (ILM)

From 1976 the USAF used the 'Factor X' Test to classify the weight lifting capabilities of recruits undergoing basic training (Table 2.4). Almost all recruits fell into the first two categories, and the criteria did not reflect the wide variety of physical demands in USAF jobs, with some demanding considerably more than a lift of 70 lb to 6 feet. Also, the classification did not discriminate adequately between individuals of high and low strength (McDaniel *et al.*, 1983).

Table 2.4: Weight lifting categories for the 'Factor X' test (McDaniel *et al.*, 1983)

1)	Able to lift 70 lb to 6 feet
2)	Able to lift 40 lb to elbow height
3)	Able to lift 20 lb to elbow height
4)	Unacceptable, i.e. unable to lift 20 lb to elbow height.

As a result, a Strength Aptitude Test Battery (SATB) which included an Incremental Weight Lift Test was developed (McDaniel *et al.*, 1983), and a series of factors which minimise risk in weight lift testing were described (Table 2.5).

Table 2.5: Factors which minimise risk in weight lift testing (McDaniel *et al.*, 1983)

1	Absolute test criteria, not relative. They claim *(without apparent justification)* that relative criteria may encourage the subject to stoop while lifting.
2	Low initial weight (20 - 40 lb) with increments of about 10 lb, to avoid over-exertion caused by large increments and fatigue caused by a lengthy test with many small increments.
3	Starting handle height between 1 to 2 feet above the floor in order to clear the knees, but not higher to prevent subjects trying to squat under it.
4	Body orientation of straight arms, bent knees, upright back and head.
5	Termination of the test if a subject pauses during a lift.
6	Voluntary participation, medical screening, private testing, prevention of over-motivation, and lack of feedback of performance.
7	Voluntary termination by the subject at any point, without knowledge of other termination criteria.
8	Prevention of multiple attempts at any weight.

An Incremental Lift Machine (ILM) (Figure 2.5) was used to measure the maximum safe weight lift capability of an individual. The device consisted of a weight stack constrained to move vertically, with a maximum weight of 90.7 kg. The subjects stood between and grasped a pair of co-axial handles 400 mm apart which they lifted from the starting position to the specified finish position. The weight was incremented and the procedure repeated until the subject chose to stop, was unable to lift the handles to the finishing point, or reached the 200 lb finishing point. They found poor correlations with stature (males: r = 0.21; females: r = 0.20), but higher for body weight (r = 0.49 and r = 0.36). They describe these as of little value for predictive purposes because the positive relationship between body weight and strength was not strong enough to permit individuals to be assigned to heavy work jobs on the basis of body weight.

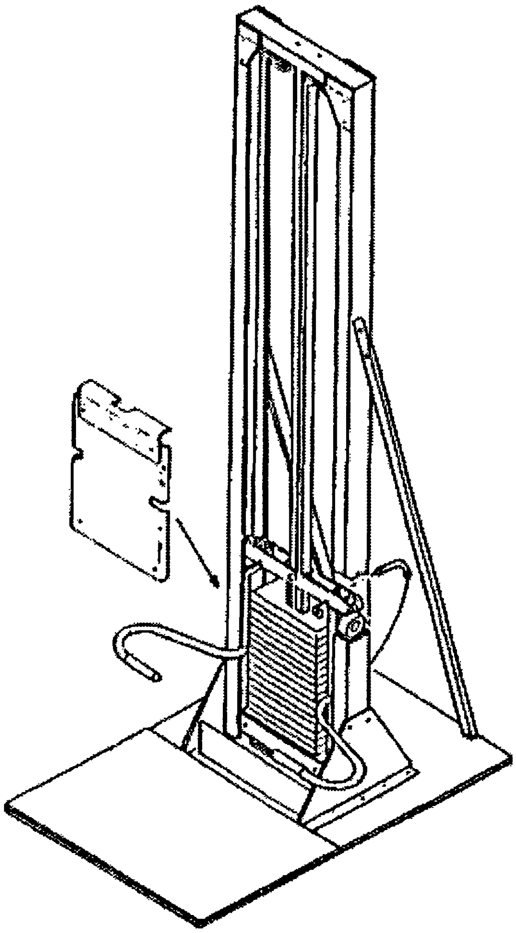


Figure 2.5: Figure 1 from Stevenson *et al.* (1996a). Original legend: "A schematic diagram of the incremental lifting machine (ILM). The cutaway shows the ball bearing rollers. Also, the barrier has been removed to expose the stack of weights."

Numerous studies have subsequently been carried out with the ILM with only slight modifications of the basic design. These are summarised in Tables 2.6 and 2.7. In one of these studies Kroemer (1983, 1985) used two forward pointing horizontal handles attached 460 mm apart. To 'avoid over-exertion risks', they limited maximum loads to 77.3 kg for lifting to knuckle height, and 45.5 kg for overhead lifting. This was contrary to the recommendation of McDaniel *et al.* (1983). Of 25 males tested six reached the 45.5 kg overhead lifting limit and 17 reached the 77.3 kg knuckle height lifting limit. This showed that artificial limits prevent subjects performing maximal exertions. The consistency of the measurements was very good with 31 of 33 subjects repeating their performances in the overhead test to within 2.3 kg. The other two were within 4.5 kg.

Dales *et al.* (1986) tested Kroemer's claims of ILM reliability. They found good subject compliance, no reports of ill-effects and relative speed and ease of testing. The 'technical error', (a measure of test-retest accuracy), was 1.40 kg and 1.07 kg for the comparisons between the first and second and second and third tests respectively. They concluded that assessing maximum overhead lift is an accurate method for quantifying individual dynamic lifting capacity.

Table 2.6: Summary of published studies using the ILM

	Kroemer (1983, 1985)	**Dales *et al.* (1986)**	**McDaniel *et al.* (1983)**
Range of lift	0.05 m - overhead reach	0.24 m - overhead reach	0.305 m - 1.83 m
Starting weight	11.4 kg	18 kg	18 kg
Minimum increment	2.3 kg	1 kg	4.5 kg
Males N	19 / 25	19	1066
Mean ± SD	34.8 ± 5.2 kg	48.1 ± 8.0 kg	51.8 ± 10.5 kg
Females N	14	0	605
Mean ± SD	16.3 ± 3.7 kg	n/a	25.8 ± 5.3 kg
Female:male ratio	n/a	n/a	49.8%

	Ayoub *et al.* (1987)	**Nottrodt and Celentano (1987)**	**Stevenson *et al.* (1989)**
Range of lift	0.305 m - 1.83 m	0.305 m - 1.83 m	0.30 m - 1.86 m
Starting weight	18 kg	18 kg	18.2 kg
Minimum increment	4.5 kg	4.5 kg	4.5 kg
Males N	527	31	16
Mean ± SD	50.0 ± 13.8 kg	43.9 ± 7.3 kg	54.7 ± 10.8 kg
Females N	0	25	0
Mean ± SD	n/a	22.9 ± 4.6 kg	n/a
Female:male ratio	n/a	52.2%	n/a

	Stevenson *et al.* (1990a)	**Ostrom *et al.* (1990) pre-training**	**Ostrom *et al.* (1990) post-training**
Range of lift	0.34 m - 1.83 m	n/k - 1.83 m	n/k - 1.83 m
Starting weight	Gender / weight specific	31.8 kg (m) 18.2 kg (f)	31.8 kg (m) 18.2 kg (f)
Minimum increment	5.0 kg (m) 2.5 kg (f)	4.5 kg	4.5 kg
Males N	99	5	5
Mean ± SD	49.6 ± 8.8 kg	56.4 ± 8.3 kg	64.5 ± 7.5 kg
Females N	33	5	5
Mean ± SD	26.4 ± 5.8 kg	22.7 ± 4.5 kg	28.2 ± 3.8 kg
Female:male ratio	53.2%	40.2%	43.7%

	Ayoub 1 (cited by Ostrom *et al.*, 1990)	**Ayoub 2 (cited by Ostrom *et al.*, 1990)**	**Ayoub 3 (cited by Ostrom *et al.*, 1990)**
Range of lift	n/k - 1.83 m	n/k - 1.83 m	n/k - 1.83 m
Starting weight	n/k	n/k	n/k
Minimum increment	n/k	n/k	n/k
Males N	50	50	20
Mean ± SD	53.4 ± 11.2 kg	52.7 ± 9.2 kg	64.1 ± 11.4 kg
Females N	50	50	19
Mean ± SD	21.6 ± 6.0 kg	22.5 ± 6.1 kg	24.6 ± 4.6 kg
Female:male ratio	40.4%	42.7%	38.4%

	Ayoub 4 (cited by Ostrom *et al.*, 1990)	**Dempsey *et al.* (1998)**	**Stevenson *et al.* (1990b) Sample S**
Range of lift	n/k - 1.83 m	n/k - 1.83 m	0.39 - 1.80 m
Starting weight	n/k	25 kg	Gender / weight specific
Minimum increment	n/k	4.5 kg	5 kg (m) 2.5 kg (f)
Males N	20	25	110
Mean ± SD	52.9 ± 10.7 kg	55.8 ± 12.1 kg	46.1 ± 9.2 kg
Females N	20	0	91
Mean ± SD	22.5 ± 4.3 kg	n/a	23.7 ± 5.0 kg
Female:male ratio	42.5%	n/a	51.4%

n/a = not applicable
n/k = not known

Table 2.7: Summary of published studies using the ILM (continued)

	Stevenson *et al.* (1990b) Sample F	**Stevenson *et al.* (1990b) Sample E**	**Brock and Legg (1997) Pre training**
Range of lift	0.24 m - 1.80 m	0.24 m - 1.80 m	0.25 m - 1.52 m
Starting weight	Gender / weight specific	Gender / weight specific	18.1 kg
Minimum increment	5 kg (m) 2.5 kg (f)	5 kg (m) 2.5 kg (f)	2.3 kg
Males N	23	10	0
Mean ± SD	52.4 ± 10.0 kg	57.3 ± 13.2 kg	n/a
Females N	25	10	63
Mean ± SD	26.3 ± 4.1 kg	27.0 ± 5.9 kg	33.4 ± 8.0 kg
Female:male ratio	50.2%	47.1%	n/a

	Brock and Legg (1997) Post training	**Duggan and Legg (1993)**	**Jacobs *et al.* (1988)**
Range of lift	0.25 m - 1.52 m	0.25 m - 1.52 m	0.305 m - 1.52 m
Starting weight	18.1 kg	18.2 kg	27.3 kg (m) 13.6 kg (f)
Minimum increment	2.3 kg	2.3 kg	4.5 kg (m) 2.3 kg (f)
Males N	0	384	22
Mean ± SD	n/a	54.1 ± 9.7 kg	61.8 ± 11.2 kg
Females N	63	0	28
Mean ± SD	36.9 ± 7.6 kg	n/a	31.3 ± 4.9 kg
Female:male ratio	n/a	n/a	50.6%

	Sharp and Vogel (1992)	**Stevenson *et al.* (1989)**	**Stevenson *et al.* (1990b) Sample S**
Range of lift	0.30 m - 1.52 m	0.30 m - 1.52 m	0.39 m - 1.50 m
Starting weight	18.2 kg	Performance to 1.83 m	Performance to 1.83 m
Minimum increment	4.5 kg	4.5 kg	5 kg (m) 2.5 kg (f)
Males N	2067	16	110
Mean ± SD	61.0 ± 12.4 kg	60.1 ± 13.3 kg	52.1 ± 8.9 kg
Females N	1301	0	91
Mean ± SD	30.2 ± 5.9 kg	n/a	27.2 ± 5.5 kg
Female:male ratio	49.5%	n/a	52.2%

	Stevenson *et al.* (1990b) Sample F	**Stevenson *et al.* (1990b) Sample E**	**McDaniel *et al.* (1983)**
Range of lift	0.24 m - 1.50 m	0.24 m - 1.50 m	0.305 m - elbow height
Starting weight	Performance to 1.83 m	Performance to 1.83 m	Performance to 1.83 m
Minimum increment	5 kg (m) 2.5 kg (f)	5 kg (m) 2.5 kg (f)	4.5 kg
Males N	23	10	1066
Mean ± SD	55.0 ± 9.8 kg	60.5 ± 11.8 kg	58.6 ± 11.2 kg
Females N	25	10	605
Mean ± SD	29.7 ± 5.0 kg	31.8 ± 7.1 kg	30.7 ± 6.3 kg
Female:male ratio	54.0%	52.6%	52.4%

	Ayoub *et al.* (1987)	**Kroemer (1983, 1985)**	**Ayoub *et al.* (1987)**
Range of lift	0.305 m - elbow height	0.05 m - knuckle height	0.305 m - knuckle height
Starting weight	18 kg	11.4 kg	18 kg
Minimum increment	4.5 kg	2.3 kg	4.5 kg
Males N	527	8 / 25	527
Mean ± SD	64.8 ± 17.2 kg	62.2 ± 7.8 kg	80.4 ± 15.8 kg
Females N	0	14	0
Mean ± SD	n/a	49.1 ± 13.7 kg	n/a
Female:male ratio	n/a	n/a	n/a

n/a = not applicable

n/k = not known

Ostrom *et al.* (1990) examined the effect of a two-week 6 Repetition Maximum (6 RM) Progressive Resistance Exercise (PRE) strength training programme on performance on an ILM lift to 6 feet (1.83 m). Male strength increased by 14% over two weeks ($p < 0.05$), while female strength increased by 23% ($p < 0.05$).

Sharp and Vogel (1992) found very little overlap between men and women in ILM performance. In males, performance decreased with age, but increased with stature. Males who failed the US Army body fat standard lifted significantly more than those who passed. Performance increased with lean body weight in both males and females and increased during basic and occupational training. Post-training soldiers were significantly stronger than permanent staff soldiers, who were significantly heavier and fatter. They conclude that there is a need for a continued emphasis on strength training for permanent staff soldiers.

Dempsey *et al.* (1998) measured power when 25 males maximally lifted a 25 kg load to 1.83 m on an ILM. Peak power ranged from 860 W to 1960 W with a mean of 1210 W (SD 260 W).

2.3.2 The Canadian Forces studies of the ILM

A series of papers have presented the results of experiments, sponsored by DCIEM in Canada in the early 1980s, which used the ILM as a tool for measurement and prediction of dynamic lifting capacity (Stevenson 1989, 1990a, 1990b, 1995, 1996a, Bryant *et al.,* 1990). These experiments were originally published in reports which are not widely available (Stevenson *et al.,* 1983, 1985, 1987). A rebuttal of some of the work has been published by McDaniel (1996) to which there was a reply (Stevenson *et al.,* 1996b). Starting from the work of McDaniel *et al.* (1983) they developed their own protocol for predicting task performance using the ILM (Table 2.8).

Table 2.8: Recommended ILM protocol for predicting task performance in the Canadian Forces. (Stevenson *et al.*, 1987)

1 A 240 mm start height, due to it producing lower spinal compressive loads than the previously used 390 mm height;
2 Starting weight determined from the mass and gender of the subject;
3 5 kg and 2.5 kg increments for males and females respectively to make the number of lifts that a subject performed approximately the same for males and females;
4 A target height of 1.8 m, or full extension height, whichever was the smaller, to remove bias due to differences in stature;
5 Free-style lifts, without restrictions such as forbidding back hyper-extension or maintaining upward movement, since, when compared to constrained lift protocols, free-style lifts place less emphasis on technique and more on strength;
6 Safety features, including an inertia reel to prevent the armature falling if released by the subject, wearing of a lifting belt to prevent hyper-extension, 30 second rests between lifts and a three lift warm up immediately prior to testing.

That there are problems with these studies is clear from comparison of the papers. Stevenson *et al.* (1990a) and Bryant *et al.* (1990) appeared as a pair, addressing different issues from the same studies, with the same subjects. Both report in their abstracts that a force transducer was attached to the back of an ILM armature. Stevenson *et al.* (1990a) state that it "provided continuous velocity and displacement data from which the displacement, velocity, acceleration/force and power profiles were determined". Bryant *et al.* (1990) merely claim that it provided displacement data. The claim that a force transducer provided either velocity or displacement data is bizarre. Close examination of the text of both papers reveals that the transducer was an "Intertechnology Displacement / Velocity gauge (DV 301-80A)". Bryant *et al.* (1990) claim the signal was fed to a Techmar Labmaster A/D board, that the voltages collected represented displacement, and were transferred to a Zenith micro, whereas Stevenson *et al.* (1990a) claim that voltages representing both displacement and velocity were sampled by a digital oscilloscope and then transferred to an IBM-PC micro for processing. Stevenson *et al.* (1989) say that the DV 301-80A interfaced with the Techmar A/D board to the Zenith micro was used to measure the positive velocity criterion of McDaniel *et al.* (1983). Stevenson *et al.* (1990b) refer only to the positive velocity criterion and cite Stevenson *et al.* (1990a) for the hardware details. Stevenson *et al.* (1995) reproduce almost word for word the equipment and data processing description of Bryant *et al.* (1990), including a citation of Stevenson *et al.* (1990a), whereas Stevenson *et al.* (1996a) follow Stevenson *et al.* (1990a), but omit references to collection of voltages representing velocity.

Despite the evident confusion of the authors, it can be deduced from the description provided by Stevenson *et al.* (1990a) that displacement alone was measured at a rate of 100 Hz for the 2 s after the lift began. This means that a maximum of 200 data points were collected over a range from 0.34 m to 1.83 m, giving a mean resolution of 7.5 mm per point.

In these studies the starting weights were determined from gender specific regression equations which used body weight as an input. Unfortunately, reference is repeatedly made back to a report by Stevenson *et al.* (1983), which is not widely available, without any indication of the equations, nor even of typical starting weights.

In order to summarise a dynamic lift, a series of 8 Events was identified (Figure 2.6) relating to clearly identifiable points (maxima and minima) in the displacement, velocity, force/acceleration, and power curves (Stevenson *et al.* 1990a). For each of the Events simultaneous values of velocity, displacement, force/acceleration and power were derived, as were average velocity, acceleration, force and power. Bryant *et al.* (1990) used Principal Components Analysis to examine the relationships between the majority of these variables. This is discussed further in Chapter 7 where the same approach is used on data collected on a hydrodynamometer.

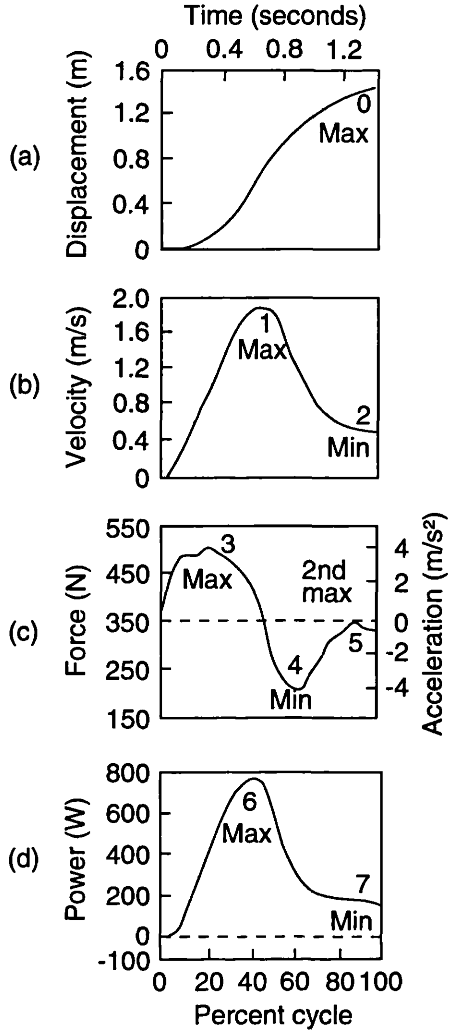


Figure 2.6: Figure 2 from Stevenson *et al.* (1996a) (redrawn) with event numbers added from Stevenson *et al.* (1990a). Original legend: "Dynamic measures of an ILM lift for one subject. All four curves have the same abcissa with scales in seconds and in percentage of lift cycle. Maximum and minimum values have been identified on the curves representing displacement, velocity, force/acceleration and power."

2.3.3 Other free weight tests / devices

Bosco *et al.* (1995) developed an instrumented dynamometer based upon the precise measurement of displacement of gravitational loads. Vertical displacement of the load was monitored with simple mechanics and a sensor where a pair of infrared photo interrupters, phase shifted by 90°, were fixed to a shuttle mounted on the load and travelled along an optical code track strip. This arrangement detected movement in either direction with a resolution of 3 mm or 10 μs, which implies a sampling rate of 100 kHz. They examined the accuracy of the system by calculating maximum errors which were 0.857% for displacement, 0.005% for time, 0.863% for velocity, 0.867% for velocity, 0.291% for velocity and 1.158% for power. They describe these as equivalent or lower than errors generally encountered in kinetic measurements.

No significant differences were found between trials on the same day or between trials on separate days, i.e the magnitude of the results did not change. Test-retest correlations ranged between 0.57 and 0.94. They describe the reproducibility of two consecutive half-squat trials performed on the same day as good but not very high. They interpreted this and the high reproducibility found between day to day measurements as suggesting that at least two or three trials are needed, after reaching a plateau in performance, for consistent evaluation.

2.4 Dynamic lifting strength measurement using isokinetic devices

2.4.1 Modified Cybex II / Liftask devices

In order to measure vertical lifts Aghazadeh and Ayoub (1985) converted the rotary motion of a Cybex II isokinetic dynamometer into linear motion using a 480 mm radius wheel. The Cybex was set to give a vertical speed of 0.75 $m{\cdot}s^{-1}$. They measured dynamic strength from floor to shoulder height (0 - 1270 mm), and from knuckle height to shoulder height (760 - 1270 mm). They describe their measurements as 'dynamic strength', quoting it in units of torque (N·m), but did not convert it into lifting strength by dividing by the radius of the wheel. Also, it is not clear whether peak or mean torque, or torque at any specific point is being quoted.

Kishino *et al.* (1985) used a prototype Cybex device to measure isokinetic lifting strength of normal subjects (23 male, 42 female) and chronic low-back pain patients (43 male, 25 female) at three speeds of lift (0.46 $m{\cdot}s^{-1}$, 0.76 $m{\cdot}s^{-1}$ and 0.91 $m{\cdot}s^{-1}$). It appears that each exertion was from floor to overhead reach height, or possibly to a height of 1.12 m. Peak isokinetic strength decreased slightly with speed for all subjects, and patients were significantly weaker than controls at all speeds. For both patients and controls females produced 50-60% of the strength of males. Normalising by body weight diminished both the female : male and the patient / normal difference, but they were still statistically significant. Patients were weaker than controls, with more pronounced drop-off at high speeds. Patients often lifted gingerly using a bent knee/ straight back technique taught them by lifting training programs, but if permitted to lift in the way that "felt right", selected any of several lifting techniques.

Timm (1988) reports normative isokinetic data collected using the Cybex Liftask, the commercial version of the prototype used by Kishino *et al.* (1985). 1236 females and 1452 males of ages from 10 to 79 years, and from a variety of occupational groups were measured. They performed maximal two-handed lifts, from a flexed-knee, flexed-back posture, with the hands on the deck of the Liftask, to a maximal overhead position. Speeds of 0.15 $m{\cdot}s^{-1}$, 0.30 $m{\cdot}s^{-1}$, 0.46 $m{\cdot}s^{-1}$, 0.61 $m{\cdot}s^{-1}$, 0.76 $m{\cdot}s^{-1}$ and 0.91 $m{\cdot}s^{-1}$ were used. Peak force, peak force as percent body weight, height at which peak force occurred, average force, average force as percent body weight, average power, and total work were recorded. Timm (1988) issued a caution about the use of isokinetic assessment of lifting saying that its relative importance has not been fully established.

He attributes this to the traditional use of isokinetics being the assessment of consistent maximal efforts involving single joints, whereas lifting is a multijoint, multisegment and multimuscle activity involving various force processes including isometric, isotonic, acceleration/deceleration as well as isokinetic efforts.

Weisman *et al.* (1990a) modified a Cybex II to allow measurement of vertical lifts at velocities up to $1.524\ \text{m}\cdot\text{s}^{-1}$. A load cell immediately below the handle on which the subject pulled allowed direct measurement of the exerted forces. A potentiometer measured displacement of the cable. The device was interfaced to an IBM PC via an A/D converter but no sampling rate is reported. To determine the repeatability of their results they measured five males performing maximal isokinetic lifts from floor to head height at a speed of $305\ \text{mm}\cdot\text{s}^{-1}$. Horizontal distances of 90% and 30% arm length were used. Each subject performed five lifts at each horizontal distance on each of three test occasions. Maximum isometric strength was measured at the point of greatest isokinetic strength. Strength was dependent upon height, but was not affected by repeatability considerations of the day of testing, the bout or the repetition within the bout. There were high correlations between the results on separate days of testing ($r > 0.83$), suggesting high test-retest reliability.

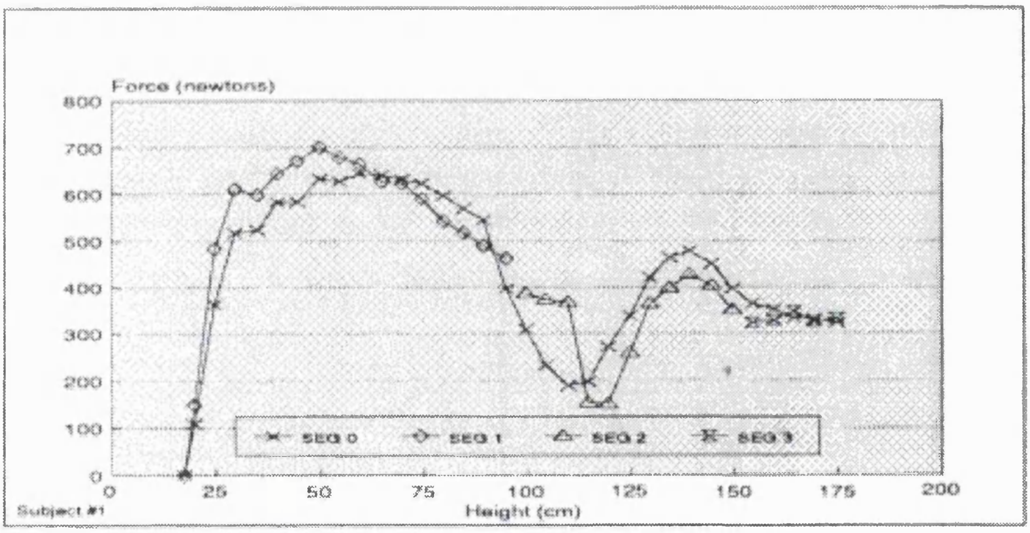


Figure 2.7: Figure 2 from Weisman *et al.* (1990b). Original legend: "Typical plot of force vs. height data for full lift and segmented lift at HD1" (HD1 = 30% of arm length)

Weisman *et al.* (1990b) examined whether a single full isokinetic lift provided the same information as a series of segmented lifts representing the same range of motion (Figures 2.7 and 2.8). Ten male subjects each carried out three vertical lifts in the mid-sagittal plane at each of four horizontal distances (30%, 50%, 70% and 90% arm length) 1) from floor to head height; 2) from floor to waist; 3) from waist to shoulders; 4) from shoulders to head. Force generated during segmented lifts followed closely force during full lifts. Force during a full lift was significantly different at different heights of the lift. In only two of twelve segments were there significant differences between force during segmented lifts and force during a full lift, with a maximum difference of only 31.8 N. Force decreased with horizontal distance. They conclude that because force generated varies throughout a person's range of motion, it is impossible to describe strength with a single value.

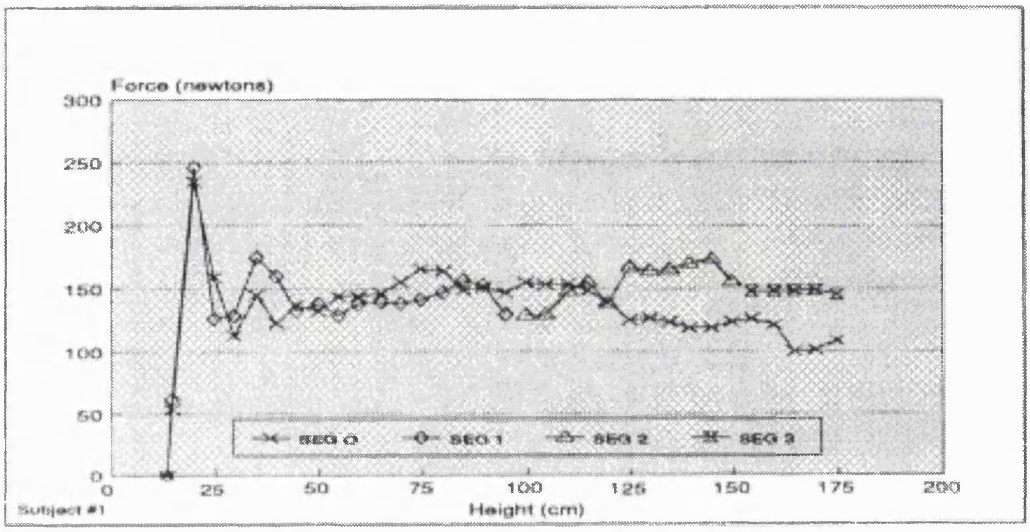


Figure 2.8: Figure 3 from Weisman *et al.* (1990b). Original legend: "Typical plot of force vs height data for full lift and segmented lift at HD4." (HD4 = 90% of arm length)

They then examined variability in strength measurements due to differences in height and horizontal distance of lift (Weisman *et al.,* 1992). Five males and five females each performed three lifts from floor to overhead at horizontal distances of 30%, 50%, 70% and 90% arm length and at speeds of 0.3 and 0.6 $m{\cdot}s^{-1}$. The same 12 regions as in the previous studies were used. In each region maximum and average forces were calculated from "the continuous record sampled every 50 mm ± 6.3 mm", which implies a sampling rate of 6 Hz at 0.3 $m{\cdot}s^{-1}$.

Patterns of strength (Figures 2.9 and 2.10) were stable and nearly identical regardless of lift speed and gender, but absolute strength (Figure 2.11) varied considerably with lift speed and with gender. The mean force generated by females was 23% less than that produced by males at either speed, and there was no interaction of region with gender. Significantly less force was generated at the higher speed, but there was no interaction between speed and region. They deduced that people are able to generate more lifting force in some areas than others, that these patterns are independent of gender and speed of lift, and that the resulting plots of iso-strength lines are consistent with those predicted by the biomechanical model of Chaffin (1974) (Figure 2.12).

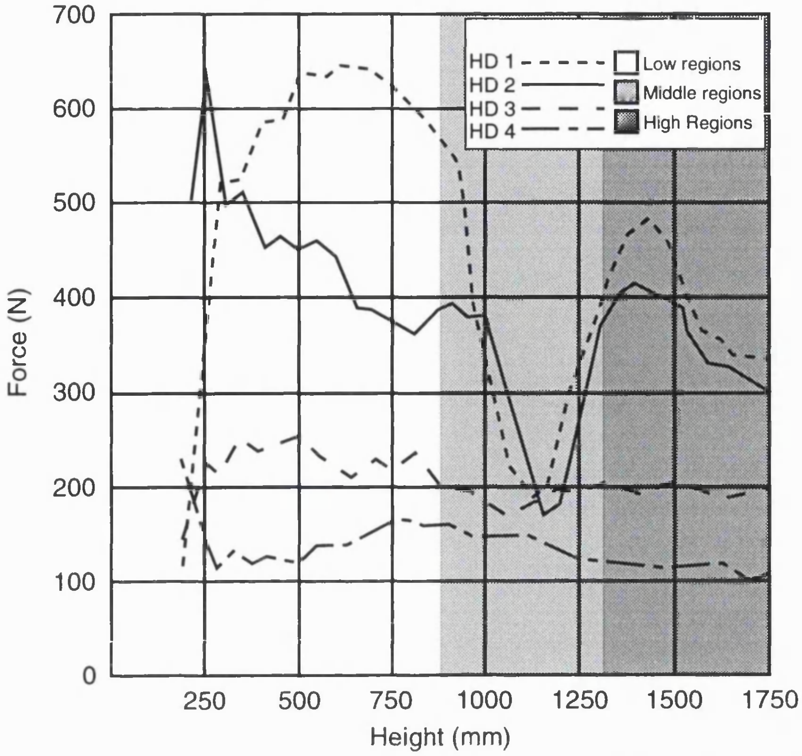


Figure 2.9: Fig. 1 from Weisman *et al.* (1992) (redrawn). Original legend: "Plotted data from a single subject, lifting at one speed. Horizontal distances (HD) 1 through 4 represent 30%, 50%, 70%, and 90% of arm length respectively."

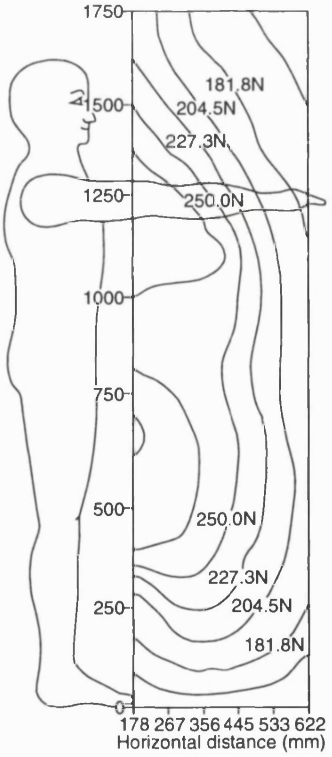


Figure 2.10: Fig. 2 from Weisman *et al.* (1992) (redrawn). Original legend: "Strength, throughout a range of motion and at different horizontal distances (reach), is depicted with contour lines for a single subject. The resulting pattern of iso-strength lines varied little from subject to subject, regardless of gender or speed of lift."

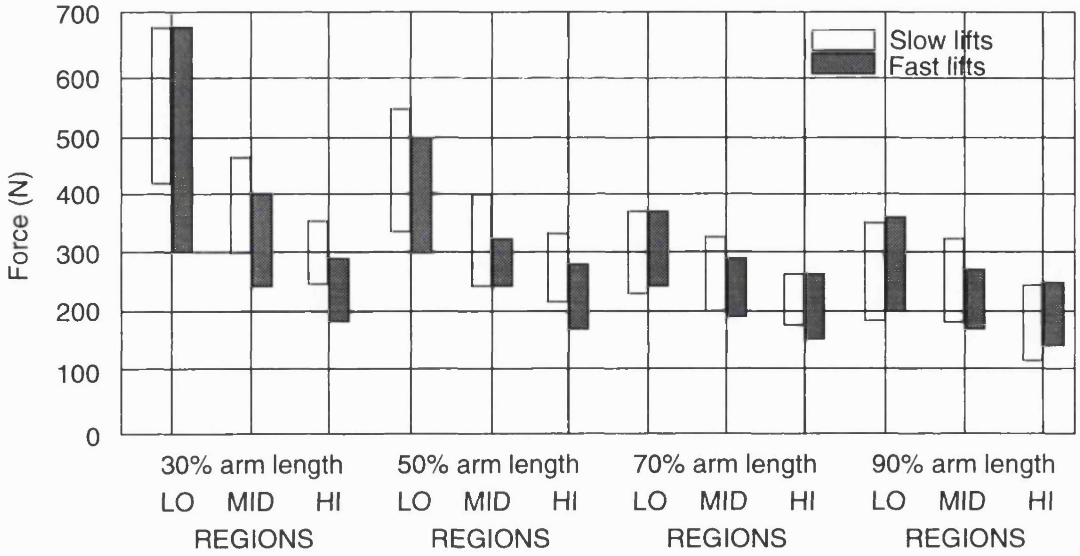


Figure 2.11: Fig. 4 from Weisman *et al.* (1992) (redrawn). Original legend: "The bars show the area from plus one to minus one standard deviations in lifting force generated at each of four horizontal distances from the body. The data for both slow lifts and fast lifts are illustrated. In general, there is little effect of horizontal distance (determined as percent of arm length) on force at either middle level or high lifts, regardless of whether the lifts are fast or slow. However, at low heights, there is a more dramatic decrease in generated force, as horizontal distance increases."

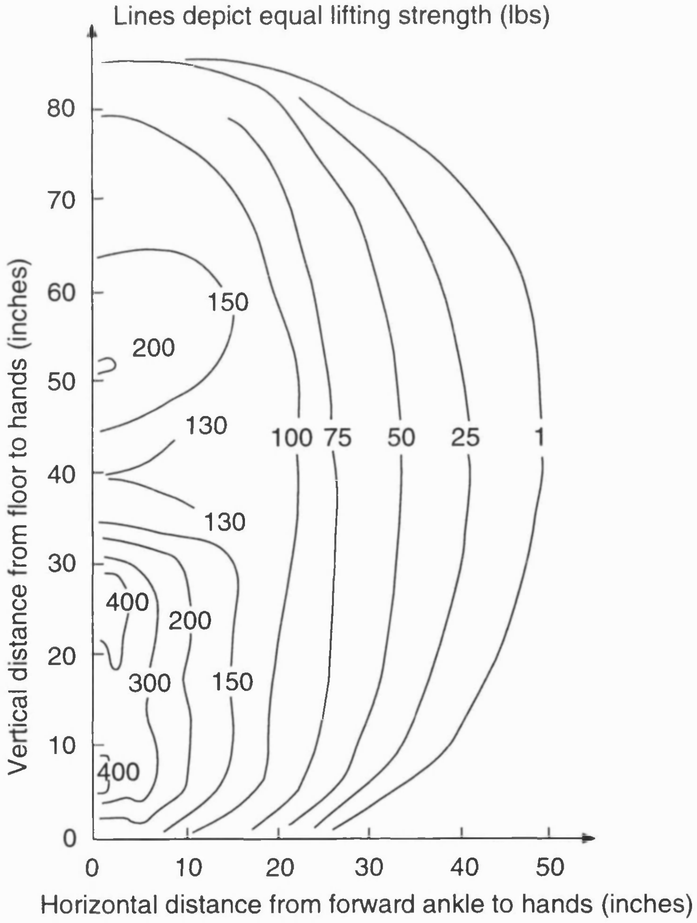


Figure 2.12: Fig. 1 from Chaffin (1974) (redrawn)

Newton *et al.* (1993) standardised and evaluated the Cybex II Back Testing System in normal subjects and low-back pain patients. They used the Cybex Trunk Extension/ Flexion and Trunk Rotation devices at speeds of 60°$\cdot$s^{-1} to 150°$\cdot$s^{-1} and the Liftask device at speeds of 0.46 m$\cdot$s^{-1} and 0.91 m$\cdot$s^{-1}. They found the devices to be safe with no injuries occurring during their testing process, but many patients reported low-back pain as the limiting factor during testing, but not so as to cause them to withdraw. Some normals and patients reported muscular stiffness for 24-48 hours after testing. The devices were mechanically reliable, giving stable readings. The main isokinetic measures were highly reliable on test-retest in normals and patients with good inter and intra-observer reliability. They did not find significant learning effects.

2.4.2 The Mini-Gym

Pytel and Kamon (1981) adapted a 'Mini-Gym' Model 101 to measure dynamic strength by adding a load cell and a speed sensor. They describe the device as having "limited speed control that provided for relatively isokinetic muscle action". This control was labelled a 'clutch' (Figure 2.13). The variation in speed during the period of maximum force application was less than 0.1 m$\cdot$s^{-1} (for a mean speed of 0.73 m$\cdot$s^{-1}). Therefore "during the time of peak force application the motion was ... termed 'isokinetic'".

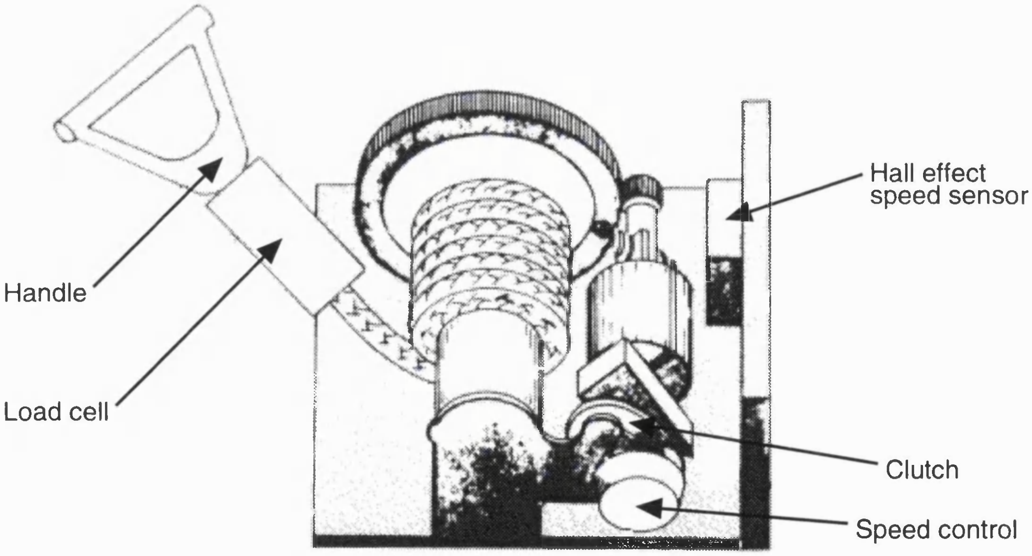


Figure 2.13: Schematic diagram of the Super Mini-Gym device. Derived from Figure 1 of Pytel and Kamon (1981) / Kamon *et al.* (1982)

Mital and Vinayagamoorthy (1984) briefly describe how they modified a Super-2 Mini-Gym to allow measurement of dynamic strength at any height, angle or position and in any plane. They give no details on how measurements were made, accuracy, and most importantly, how speed was controlled. This is unfortunate because later publications (e.g. Mital *et al.,* 1986b, Mital *et al.* 1986c) refer to this paper as if it did contain adequate technical details, though Karwowski and Mital (1986) refer to an electronic tachometer being used for speed calibration, and Ayoub and Mital (1989) refer to the device having "easy speed control". Mital *et al.* (1986a) state that the device is capable of recording forces up to 250 kg. Mital *et al.* (1986a) combined data previously published by Mital and Karwowski (1985), Mital *et al.* (1986c) and Aghazadeh and Ayoub (1985). They concluded that the results of the studies favour the use of the much cheaper Mini-Gym over the Cybex II and state that they did not expect the different operating characteristics (hydraulic and mechanical) of the Cybex and Mini-Gym to influence the magnitude of the strength measurements.

Freivalds and Fotouhi (1987) compared the Cybex II and a Model 500X Mini-Gym, fitted with "a centrifugal brake to provide limited speed control". They describe the Mini-Gym as having three nominal speed settings (corresponding to 0.7, 1.4 and 2.0 $m \cdot s^{-1}$), with a typical variation in speed of less than 0.1 $m \cdot s^{-1}$. The slowest setting was fairly repeatable. They describe the Cybex as accurate, very expensive and cumbersome, and the Mini-Gym as portable, cheap and possibly lacking preciseness. For similar motions there were significant differences between the two devices, with peak forces always lower on the Mini-Gym than on the Cybex. They also found sudden decreases in measured force on the Cybex, particularly at high angular velocities. They suggest this might be due to the effect of delays in fluid pressure build-up and / or mechanical oscillations within the device. They point out that data on both concentric and eccentric muscle actions can be collected with the Cybex, but only concentric actions can be performed on the Mini-Gym, and true angular data for specific joint movements cannot be collected.

Mital and Genaidy (1989) used the Mini-Gym to measure peak isokinetic lifting strengths at 0.75 $m \cdot s^{-1}$ in fifteen different postures. They claim, as others had earlier, that this is the speed at which individuals typically lift loads, but their data contradict it. In two postures no female succeeded in recording a strength value, and some females failed to record forces in six postures, and some males failed to record force in two. This implies that these individuals could not perform these lifts at this speed and therefore could not register a force. Their figures show tremendous variability in sex differences across the different postures, with the female : male strength ratio ranging from 0% where no females recorded a score, to 29% - 66% where all subjects recorded a score. Standing postures were generally stronger than kneeling or sitting postures.

Duggan and Legg (1993) used a "Quasi-isokinetic lift test" similar to that used by Pytel and Kamon (1981). A centrifugal clutch restricted the rate at which a rope could be uncoiled from a drum. The device was not truly isokinetic since the speed of uncoiling increased with the force on the rope, giving speeds of approx 0.75 $m \cdot s^{-1}$ at a load of 15 kg and 1.0 $m \cdot s^{-1}$ at a load of 50 kg.

Mital *et al.* (1995) investigated the influence of pulling speed and arm orientation on one-handed isokinetic pull strength in the vertical plane using the Mini-Gym. They quote a range of five speeds ranging between 0.30 and 0.75 $m \cdot s^{-1}$. It therefore appears that they have succeeded in fitting a more accurate speed control than previously. They took measurements from each of 15 males and five females in 100 experimental conditions (5 speeds, 10 arm orientations, sitting and standing postures), but the starting and finishing positions are not reported). They analysed male and female data separately due to very large differences in absolute values, but found similar trends for both males and females. No differences were found between sitting and standing postures, but posture had highly significant effects on strength, with the strongest exertions occurring in the vertical pull-up, followed by the vertical pull-down. The peak strength was exerted at the slowest speed and declined almost linearly by 30% for males and 21% for females as the speed increased to 0.75 $m \cdot s^{-1}$. Exertions were weakest when the arm was 'hyper-extended'. The pattern of their observations was consistent with the pattern of isometric strength, but values were significantly smaller.

2.4.3 Static and Dynamic Strength Tester

Kumar *et al.* (1988) constructed an isokinetic strength testing device with linear velocity control. It was designed for vertical two-handed sagitally symmetric lifts at a constant speed along a fixed path regardless of the force applied to the handles. Later modifications allowed other directions of exertion to be measured (Kumar, 1995a).

The constant velocity was provided by linking the handle through a cable and one-way clutch to a shaft rotating at a pre-set speed. Resistance free movement of the handle occurred until the threshold speed was reached, when the clutch engaged the shaft and controlled the speed with a very high resistance. A tachometer coupled by a belt to the gearbox of the device was used to measure velocity, and provided velocity feedback for the electronic speed control. A load cell just below the handle measured the applied force and a potentiometer measured displacement of the cable. The device sampled "from all channels at 50Hz", giving a resolution of 20 mm at a speed of 1.0 $m \cdot s^{-1}$. The motor speed was manually calibrated by applying a force of 2000 N to the handle and measuring the time taken for it to move over "measured and marked distances". The displacement transducer was calibrated by moving the handle to known distances and taking readings from the potentiometer. Static loads were applied to the load cell and readings taken. Errors of less than 2%, 1% and 1% were obtained at the three test speeds. Their description does not make clear whether they had succeeded in their aim of providing linear speed control, what size velocity increments were available, or how accurate the velocity control was, particularly at forces lower than 2000 N.

They compared static and dynamic arm and back lifting strengths measured at a range of velocities. Ten males and ten females performed arm and back lifts isometrically and at speeds of 0.2, 0.6 and 1.0 $m \cdot s^{-1}$. Back lifts were performed from 50 mm above the floor to knuckle height; arm lifts were performed from knuckle height to shoulder height. Static lifts were performed at the start positions of the dynamic lifts. Subjects chose their own foot position, but had to use the same position for all eight conditions.

Dynamic strengths declined significantly towards the end of the the range of motion of the lift. Significant differences were found due to speed of motion, gender and the speed × gender interaction. Maximum strength values tended to cluster in the central motion region. For back lifts, linear regressions between peak dynamic strength and peak static strength gave correlations between 0.59 and 0.91, with r decreasing with speed for males, but being lower and staying approximately constant for females. All except one of these correlations for arm lifts were insignificant. They note that because dynamic strength varies as postures changes, the range of motion involved in a given exertion must be considered in specifying the difficulty of a manual lifting task.

2.4.4 Ariel Computer Exercise system

Jacobs and Pope (1986) studied the reproducibility and validity of the Ariel Computer Exercise (ACE) system, a hydraulic device used to measure isotonic, isometric or isokinetic concentric actions. Fluid was forced through valve openings by movement of lever arms fitted to the device. The valve opening could be set to a fixed size or controlled via a rapidly responding stepper motor. Transducers registered changes in fluid pressure, lever arm position and time. They found it to be a valid device for force measurement, but that it required to be validated daily to ensure reproducible and valid force measurements. The desired isokinetic velocities were produced with a high degree of precision and reliability.

Jacobs *et al.* (1988) measured the maximum mass that could be lifted to a height of 1.34m (truck bed height) in a 0.61 × 0.4 × 0.25 m box with handles; ILM performance to a height of 1.52 m; and the peak and mean forces exerted during isokinetic lifts to 1.52 m using the ACE system. They quote test velocities of 0.024, 0.073 and 0.110 $m \cdot s^{-1}$, but there appears to be a factor of 10 error and the velocities should be 0.24, 0.73 and 1.10 $m \cdot s^{-1}$. Performance on each of the tests was highly reproducible from day to day. There were no significant differences in isokinetic force among three repetitions at each of the angular velocities. The mean isokinetic force had a higher correlation with the box lift than the peak isokinetic force did. Isokinetic force decreased with increasing speed. They considered the box lift and isokinetic test superior to isometric testing because they are dynamic; the isokinetic assessment was much quicker to complete than the ILM assessment which took several minutes. They considered isokinetic lifting to be safer because it was performed in concentric mode against hydraulic resistance, whereas lowering the weight stack of the ILM loads the muscles eccentrically, which could overload muscles that had just failed to complete a lift.

2.5 Non-isovelocity Accommodating Resistance Devices

2.5.1 Advantages of Accommodating Resistance Devices

O'Hagan *et al.* (1995) lists the advantages of accommodating resistance devices over other types of strength testing devices (Table 2.9):

Table 2.9: Advantages of Accommodating Resistance Devices (O'Hagan *et al.,* 1995)

1	'High' and 'low' resistance loads can be used
2	The resistive force precisely matches the strength curve of the applied force
3	The imposed resistance is passive-reactive
4	They are small and weigh little relative to the high resistive loads provided.
5	They often do not provide resistance to eccentric actions. In some, but not other, circumstances this may be seen as a disadvantage.

2.5.2 The Biokinetic Ergometer

Garg *et al.* (1988) used a Biokinetic ergometer to simulate one-handed starting of a lawn-mower engine. This is "an electromagnetic dynamometer operating in a quasi velocity-regulated mode ... the resistance is proportional to the intensity of effort applied". They state that the operating velocity increased above the selected regulation velocity in proportion to the magnitude of the applied force. The device consisted of a handle attached to a flexible tension line wound around a drum connected via a one-way clutch and belt drive to a d.c. generator. "When the velocity of rotation ... exceeds the selected velocity, a reactive ... force ... is produced which is equal to the applied mechanical force." This description implies that no net force is transmitted to the device at this point, i.e. no acceleration can occur, i.e. it is truly isokinetic. However, they specifically state that they used the device "as opposed to an isokinetic device" "to allow for the acceleration pattern encountered in a normal human motion".

They measured force and distance using a load cell and a potentiometer attached to the handle and rope. Their results are summarised in Table 2.10. Typical force-time and velocity-time curves are shown in Figure 2.14. Four different conditions, simulating typical pulls made to start different lawn mowers, were used. Each pull was 1.1 m long. They also measured static strength in the direction of pull at the start position of each pull. 50 males and 49 females acted as subjects. Peak velocities reached 3.3 $m \cdot s^{-1}$. Static strengths were significantly greater than dynamic strengths which can be attributed to length-tension differences and the force-velocity effect, since the peak dynamic force did not occur at the start of the pull, and the mean will have included all of the weaker parts of the pull. Handle location had significant effects on peak and mean strength.

Age was also found to have a significant effect with a general tendency for strength to decrease with increasing age. Linear regression of peak and mean strength against peak velocity resulted in r values of 0.85 and 0.84 respectively. They consider that one-handed dynamic pulling strength could be adequately estimated from peak or mean velocities. This, of course, will be device dependent.

Table 2.10: Results obtained by Garg *et al.* (1988). All values are the means of four conditions

Variable	Males	Females
Peak force	302.8 N	185.0 N
Peak velocity	2.4 m·s^{-1}	2.0 m·s^{-1}
Work done	204.8 J	115.2 J
Time of peak force	0.25 s	0.20 s
Cycle time	0.80 s	0.87 s
Time between peak F and peak V	0.07 s	0.13 s
Peak dynamic / peak static strength	55%	58%
Mean dynamic / mean static strength	34%	39%

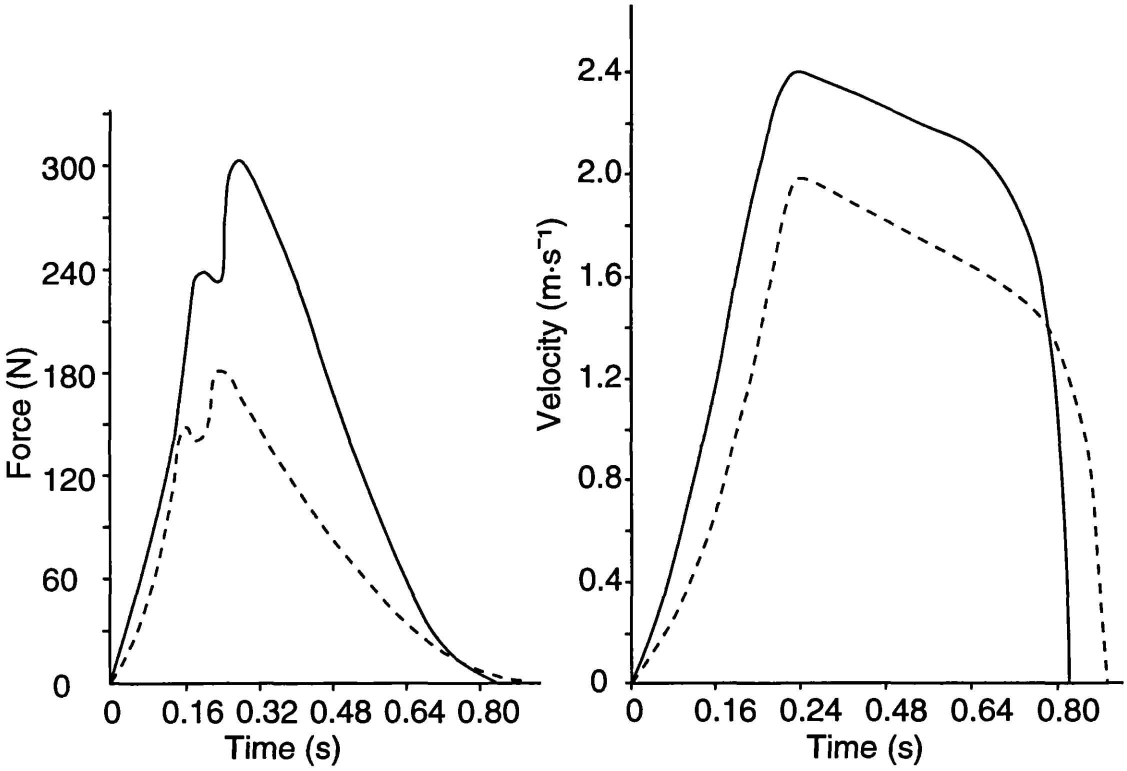


Figure 2.14: Figures 2 and 3 from Garg *et al.* (1988) (combined): Variation with time of dynamic pulling strength and velocity of pull for typical male (——) and female (- - -) pulls

Garg and Beller (1990) used this device to examine how one-handed dynamic pulling strength was affected by 'speed of pull', start height of the handle, and angle of pull. This was done to help design manual-start gasoline powered engines. They clearly state that the device is not isokinetic, but then quote mean velocities attained for the three different resistances to motion selected as if they were constant velocities (see Table 2.11). They quote small standard deviations for the velocities at their three settings, but give very much wider ranges, which suggests that there are errors in the data. Also, it is clear from their description of the device that the relationship between force exerted and 'speed' is non-linear.

Table 2.11: Table 2 from Garg and Beller (1990). Original legend: "Observed mean and peak speeds and pulling angles". Data from nineteen males

Variable	Set value	Observed values		
		Mean	SD	Range
Mean speed ($m \cdot s^{-1}$)	Slow	0.68	0.04	0.4 - 0.9
	Medium	0.97	0.03	0.6 - 1.3
	Fast	1.14	0.05	0.6 - 1.6
Peak speed ($m \cdot s^{-1}$)	Slow	0.96	0.05	0.8 - 2.3
	Medium	1.43	0.05	0.8 - 2.3
	Fast	1.87	0.07	1.0 - 2.8
Pulling angle (°)	15	15.6	0.26	14 - 21
	25	25.8	0.34	17 - 30
	35	34.9	0.11	31 - 36

Garg and Beller (1994) also used this device to examine the effect of speed and box width on lifting strength. In particular, it was believed that "the use of different lifting speeds, actual boxes in place of a handle bar, and mean strength in place of peak strength, might have significant effects on isokinetic lifting strength and, therefore, on its relationship with static strength and maximum acceptable weight", and that use of boxes instead of a handle bar would provide a more appropriate simulation of actual lifting tasks. For all the dynamic tasks, subjects lifted tote boxes from the floor to a bench at 0.8 m high at a frequency of 0.2 lifts min^{-1}.

They claim they measured isokinetic strength, when they had previously explicitly stated that the device is not isokinetic. Moreover, the 'cycle times' (in fact the time to lift the load to 0.8 m), by definition constant for an isokinetic device, ranged from 1.02 to 2.90 s for a single 'isokinetic' velocity of 0.41 $m \cdot s^{-1}$, with standard deviations around 0.45 s (see Table 2.12). For a 0.8 m lift, these translate into velocities ranging from 0.28 to 0.78 $m \cdot s^{-1}$. Also, the mean 'cycle' time increased as the box width increased!

They recommend, that as "the complexities associated with isokinetic strength" are not fully understood, static strengths and maximum acceptable weights should be used for job design and evaluation. The various dynamic tests do have all manner of complexities associated with them, but this does not indicate that they should be abandoned since the complexities of static and psychophysical tests are also legion!

Maximum acceptable weight decreased as box size increased, but it can be shown from their data that load moment stayed approximately constant. Peak static strength was 12% higher than mean static strength, which probably reflects the use of the protocol recommended by Caldwell *et al.* (1974) for isometric testing. Mean and peak static strength decreased with horizontal distance at a greater rate than maximum acceptable weight did, but total load moment stayed approximately constant. Peak 'isokinetic' strength was 53% higher than mean strength for all three box sizes, which shows that the relationship between mean and peak strength was roughly constant, which would be anticipated given pulls of the same type against the dynamometer described.

Table 2.12: Table 6 from Garg and Beller (1994). Original legend: "Lifting cycle time(s)". Data from nine males

		Cycle time (s)		
Strength type	**Box size**	**Mean**	**SD**	**Range**
Isokinetic lifting at 0.41 m·s^{-1}	Small	1.78	0.42	1.02 - 2.18
	Medium	1.93	0.48	1.10 - 2.50
	Large	2.18	0.49	1.30 - 2.90
Isokinetic lifting at 0.51 m·s^{-1}	Small	1.47	0.28	0.94 - 1.94
	Medium	1.54	0.36	0.94 - 2.12
	Large	1.65	0.36	0.94 - 2.22
Isokinetic lifting at 0.6 m·s^{-1}	Small	1.23	0.22	0.82 - 1.50
	Medium	1.30	0.25	0.86 - 1.70
	Large	1.43	0.29	1.02 - 1.98
Maximum acceptable weight	Small	1.03	0.27	0.66 - 1.58
	Medium	1.10	0.30	0.71 - 1.62
	Large	1.20	0.30	0.78 - 1.75

2.5.3 The Grieve hydrodynamometer

Grieve (1984) used a water-filled dynamometer to measure power outputs of dynamic pulls. An annular piston, fitted with a baffle plate to restrict flow, was pulled through a water-filled tube. He reported that the resistance to movement was proportional to the square of velocity, and that, to prevent the water boiling, the area had to be sufficient to avoid pressure below the piston dropping to below saturated vapour pressure during a pull. Position was sampled at 130 Hz, and velocity, force and power output derived from these measurements.

Grieve and van der Linden (1986) used the same dynamometer to investigate the effect of height on force, speed and power output in a single horizontal concentric pull by the upper limb. They measured both force and position, at a sampling rate of 250 Hz, for resistances of 15, 120, 600 and 5000 kg·m^{-1}, resulting in peak velocities ranging from 2.2 m·s^{-1} to 0.3 m·s^{-1} respectively. Contrary to their expectations, they found no significant differences in either static or dynamic performance at eye height, shoulder height, and elbow height, which they concluded was probably not due to a common factor but to a complex interplay of limitations. They described the conditions at the handle during the pull using a force-velocity-position surface. They confirmed the importance of horizontal reach distance on the dynamic performance, and showed that the total work done in a concentric pull increased with the resistance.

Grieve (1993) constructed a new hydrodynamometer from a 2 m high tube 200 mm in diameter. Resistance could be set by using bungs to close holes in a leaky piston. Subjects lifted a handle from a rest 400 mm from the floor. Using optical switches, Grieve (1993) used the time taken to lift through the 0.7 - 1.0 m range to calculate mean power output from calibration tables. This range was selected because it encompassed the region of greatest static lifting strength, and occurred after the initial accelerative phase of the lift, when device and muscle activation effects would be important.

Fothergill (Fothergill, 1992; Fothergill *et al.,* 1996) modified this hydrodynamometer by adding force, displacement and velocity transducers. He measured one and two handed exertions by 9 males and 9 females lifting from 0.4 m to head height at each of three resistances. Isometric lifting strength was measured at six body landmarks between head height and knee height. Gender, number of hands, resistance and height caused significant variation in both strength and power normalised to body weight. Power increased with number of hands. He linked the observation that the dynamic forces measured correlated poorly with body weight with the discussion by Pheasant (1977) of the 'live' and 'dead' axes of force. Since on this device the line of force passes through the foot base, it corresponds closely with the live axis, meaning that the factors limiting strength are musculoskeletal rather than the distribution of body weight.

Fothergill (1992)'s subjects started to lift with an over arm grip (wrists pronated). Cine film of two subjects lifting against a range of resistances showed how lifting techniques changed as the resistance to lift increased. Leg and back extension were completed when the hands reached hip height. At low resistances subjects lifted smoothly using abduction and flexion of the shoulders to shoulder height, followed by lateral rotation of the upper arms at about head height, concluding with extension of the elbows and flexion and adduction of the shoulders as the hands approached full reach height. At high resistances the subjects suddenly, when the hands were at about chest height, completely adducted the shoulders and fully extended the wrists to give an underarm grip. At the same time they also flexed the knees and hips to lower the body. This allowed the lift to continue with an upward thrust generated with the legs and elbow extension and shoulder flexion. It would appear that the cause of this change of strategy was a lack of strength in the lateral rotators of the shoulders and the need to reduce the loads on the wrists and elbows.

2.5.3 The Omnitron hydraulic dynamometer

Hortobagyi *et al.* (1989) used a Omnitron hydraulic dynamometer This device is effort-dependent, using oil forced through adjustable valve openings to provide the resistance. It is not clear what the measurement they took was, except that it was "the peak score of the 10 trials". It is therefore not clear whether this was the instantaneous peak force recorded or a mean. Russell *et al.* (1992) examined the reliability of the Omnitron using an upper body testing protocol. Their data suggested that there is a learning effect when testing novice subjects. Using measures of intraclass reliability they found that the reliability could be maximised by using at least two tests of at least two repetitions, but was very high when a single test session was used.

2.6 Characteristics of dynamic lifts

2.6.1 Speed of lifting

Anderson and Chaffin (1986) state that virtually all proposed techniques of safe manual handling recommend that the load be lifted in a slow and controlled manner. The purpose of this is to reduce moments of inertia and to facilitate the ability of the individual to react to unforeseen circumstances.

In contrast to this, Grieve (1970) had previously described weightlifting as the defeat of gravity, saying that the earlier a lifter engages gravity, the more spectacular the short term advantage, and that a long-drawn out struggle is to be avoided at all costs. He contrasted lifting by exerting a steady force slightly greater than the load with exerting a single jerk causing the weight to coast to the desired height. The first method would take a very long time and be fatiguing, and limit maximum weight lifted to the upwards strength of the weakest posture. He suggested that real lifting is a compromise between the two methods. He demonstrated that the exact way that impulses are applied and decay are vitally important, and that an explosive effort as early as possible is more effective at gaining height than the same total impulse over time. On this basis he criticised the suggestion that isometric strength has relevance to dynamic lifting.

Grieve (1975) found that in isoinertial lifts performed as quickly as possible an impulsive force was applied to the load. In most cases, this peaked within 100 ms of lift-off. The ratio of the peak force to the weight of load decreased as the load increased. For lighter loads the force at the feet fell below body weight later in the lift. For heavier loads this force did not fall below body weight. In crouch lifting, forces at the feet developed more than 100 ms before lift-off and peaked at lift-off or soon after, meaning that the body travelled upward faster than the load until the force at the hands peaked. In stoop lifts the load travelled faster than the body throughout most of the lift with both starting from rest at lift-off. Much higher lower-body velocities were acquired in a crouch-lift for a given force than were acquired in a stoop-lift.

Mital and Karwowski (1985) selected a Mini-Gym speed of 0.75 $m \cdot s^{-1}$ as "the speed of actual lifting movement, determined in a separate experiment", but do not give details of this other experiment. Mital *et al.* (1986a) claim that 0.75 $m \cdot s^{-1}$ is approximately the actual speed of lifting of manual lifting tasks, but fail to substantiate this. Aghazadeh and Ayoub (1985) chose this speed because Pytel and Kamon (1981) had used 0.73 $m \cdot s^{-1}$, and their experience of studying films of lifting actions was that a mean duration of lift from floor to 1.27 m high was 1.7 s (i.e. a mean speed of 0.75 $m \cdot s^{-1}$).

Kumar *et al.* (1988) criticise Pytel and Kamon (1981) for instructing their subjects to start their motion with a jerk which "could be difficult to control, could be unsafe, and also would tend to artificially inflate the peak strength values due to the inertial effects".

The inertial effects are not specified and are difficult to imagine with a device as small as the Mini-Gym. They also claim that increased lifting speed "could cause a greater hazard to a person than is now indicated by static strength values" (*sic*). They offer no evidence for this beyond claiming that static strengths measured in optimum postures are an indicator of maximal capability. This implies that they do not understand the force-velocity curve (Chapter 2.1) which causes the force exerted to decrease as the velocity attained by the person increases, thereby preventing the over-exertion injuries which can occur in maximal static exertions.

Stevenson *et al.* (1990a) note that the very fast type of lifting elicited by the ILM contravenes the normal recommendation that loads be lifted in a slow and controlled manner. Because the lifts were fast, high and very variable forces and accelerations were obtained. They inferred from this that predictions of maximal isoinertial lifting capacity based upon static strength are inadequate.

Garg and Beller (1994) found the mean speed of lifting maximum acceptable weights was greater than the mean speeds attained for any of their three resistances. They concluded that since 'speed' affects 'isokinetic' lifting strength, job-specific 'isokinetic' strength measurements should be made at the speed used to lift the load. They comment that data on lifting speeds of heavy loads is lacking and that it is not clear how object characteristics affect speed of lifting. The reduction in strength as 'speed' increased led them to concur with the recommendation that heavy loads should be lifted slowly and smoothly. They argue that there is a conflict between subjective perceptions and 'isokinetic' lifting capability because high-speed lifting is perceived as less stressful than low-speed lifting. Perhaps they should have concluded that the physical stress the subjects rated was the force produced, which also decreased as speed increased.

2.6.2 The force / velocity and power / velocity relationships

Grieve and van der Linden (1986) note that in a movement which begins and ends at rest, substantial portions of the movement may be accomplished before peak output is achieved and optimal use will be made of the force-velocity characteristics of a fully active muscle group for only a brief period. They also found that peak hydrodynamometer power output occurred earlier in the pull as resistance increased.

Kumar *et al.* (1988) found that peak strength decreased with increasing speed of lift and occurred progressively higher and later during the lifting cycle. Further examination of their data shows that peak strength occurred more rapidly in faster lifts for males, but more slowly for females. Presumably this is a function of both the force-velocity curve and the rate of recruitment of motor units in the relevant muscles.

Timm (1988) found that as speed increased, isokinetic peak force, peak force normalised to body weight, mean force, mean force normalised to body weight and total work decreased whereas height of peak force and mean power increased as speed increased. These patterns were consistent across all the test speeds. Two-way ANOVAs showed significant differences for all parameters except height of peak force. There was a general trend of decreasing force and work as speed increased, but power increased with speed. These findings are consistent with both the force-velocity and the power-velocity curves. Post-hoc analysis failed to show significant differences between heights of peak force across test speeds and the age spectrum even though the height of peak force increased with test speed and with subject age while peak force decreased in both instances.

Garg and Beller (1990) found that 'speed', height and angle of pull all had significant effects on mean and peak dynamic pulling strengths, with speed having a much greater effect than either height or angle. Strength decreased as a function of speed and handle height and showed a peak at an angle of 25° to the horizontal. Body part (elbow, shoulder or back) and 'speed' had significant effects on Ratings of Perceived Exertion (RPE), but the effects of handle height and angle of pull were of no practical significance. RPE for the three body parts decreased as pulling speed increased and overall ratings of comfort increased. The shoulder was the most stressed body part, followed by the elbow and back. Speed affected comfort the most, and angle the least.

They concluded that it is important to know speed, height and angle of pull when determining job physical strength requirements, especially for high speed pulling tasks. They note that increasing mean speed from 0.7 to 1.1 $m \cdot s^{-1}$ can reduce strength exerted by more than 50% and that their finding that peak dynamic strength occurred progressively earlier as speed of pull increased contradicted Kumar *et al.* (1988) who reported that peak isokinetic strength occurred later in the cycle as velocity of lift increased. They concluded that pulling tasks should be performed at slow speeds to maximise strength and minimise over-exertion injuries. This conclusion ignores the power requirement of the task, since greater powers can be obtained at higher velocities, and power is probably the most useful input measure to the device. Their assumption that slower speeds are safer because strength is greater is contradicted by their finding that RPE decreased as speed increased. They recommend that the pulling force required to start a gasoline powered engine should be reduced proportionately if a high cranking speed is required to start the engine, again assuming that power output is fixed, rather than velocity dependent, as is actually the case.

Garg and Beller (1994) found that increases in both speed of lifting and box width decreased 'isokinetic' lifting strength significantly, with speed having the larger effect. RPE of the low back decreased with speed of lifting and increased with box width. The RPEs of maximum acceptable weight, static strength and 'isokinetic' strength at 0.41 $m \cdot s^{-1}$ were not significantly different.

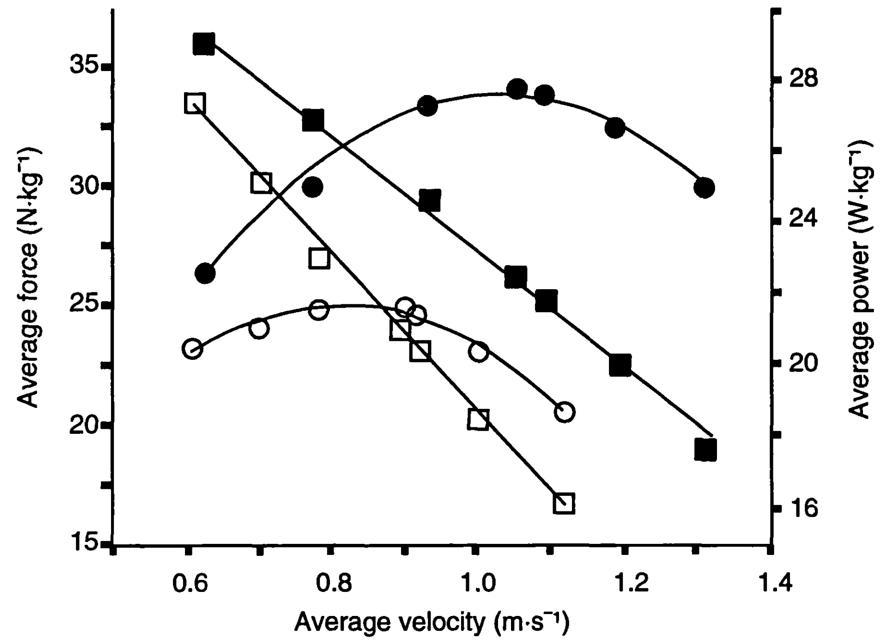


Figure 2.15: Fig.3 from Bosco *et al.* (1995) (redrawn). According to the original legend: "Average force (*F*) (*squares*) and average power (*P*) (*dots*), developed during half-squat exercises performed with various loads (from 35% to 210% of the subject's body mass) are shown according to the average vertical velocity (*V*) for male (*filled symbols*) and female (*open symbols*) jumpers."

Bosco *et al.* (1995) used data collected in half-squat exercises over a range of weights to derive force-velocity and power-velocity relationships (Figure 2.15). Males had higher values of force and power than females. They found significant sex differences in force, but not in velocity and power for heavy loads.

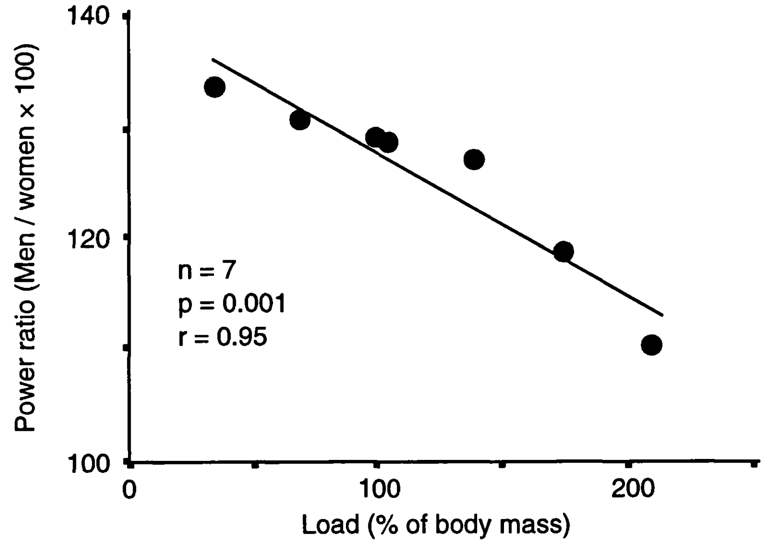


Figure 2.16: Fig. 4 from Bosco *et al.* (1995) (redrawn). Original legend: "Power ratio (men : women in percentages) found in half-squat exercise according to the loads used (from 35% to 210% of the subject's body mass, n = 7)."

The greatest gender differences in force, velocity and power were found at light loads. The female : male power ratio increased almost linearly as the load relative to body mass increased (Figure 2.16). They considered that the velocity of maximum knee extension is more important than the force in characterising sex differences.

Fothergill *et al.* (1996) found one-handed exertions to be slower than two-handed exertions, and, as expected, increases in resistance decreased the speed of the exertions. Resistance level weakly affected position of peak power, but not peak force. Peak one-handed strength and power occurred at lower heights than two-handed strength and power (2.5% and 2.0% of stature difference), but in all cases was about midway between knee and knuckle height. Differences in lifting strength between resistances were greatest at knee height, and decreased as the lift progressed above knee height. He also found that peak hydrodynamometer power occurred at a lower height for the highest of three resistances than for the other two resistances (a difference of 3% of stature). Both power and velocity decreased as the resistance increased.

2.6.3 Lift strategy

Stevenson *et al.* (1987) examined the effect of lift strategy on prediction of performance on a freestyle box lifting task. The most common strategy (30% of males, 60% of females, 59 subjects) involved a relatively straight back, with the box lifted to waist height, and then thrust to the height of the target platform. Only 8% used a straight back and a smooth continuous motion to the destination. They obtained correlations of 0.66 for males and 0.78 for females between free-style ILM performance and box lifting capacity using the most common lifting strategy. They concluded that constrained task protocols are not valid measures of task performance, that the ILM in its present form should not be used as a predictive test of lifting ability and that using the ILM as an indicator of general body strength would require the removal of as many constraints as possible. They found that ILM measurements, including maximum lift score and kinetic profile, account for no more than 60% of the variance in task performance scores and argue that better predictions would require a two dimensional lift envelope to make the testing system more closely resemble actual lifting tasks.

Table 2.13: Dynamic measures obtained by Stevenson *et al.* (1990a) from ILM lifts to 1.83 m performed by 33 female and 99 male soldiers. Mean overhead grip reach is 118% stature (Pheasant, 1986)

Parameter	Height of parameter as percent stature	Anatomical landmark	% total lift time Males	% total lift time Females
Maximum force	46%	Mid thigh	3%	5%
Maximum power	64%	Waist height	16%	20%
Maximum velocity	77%	Chest height	20%	28%
Minimum force	103%	Head height	33%	46%
Second maximum force	113%	Above head height	60%	72%

Stevenson *et al.* (1990a) mention briefly a pilot study where 20 subjects were filmed performing the 1.83 m ILM test. As a result they characterise an ILM lift as consisting of an initial leg / back extension pulling phase, a wrist changeover manoeuvre, and a final arm extension pushing phase. They also link the heights at which certain events occurred during the lift to fixed percentages of stature (Table 2.13). They linked their finding that minimum acceleration / force occurred at just above head height to the end of the wrist changeover manoeuvre, which they describe as a prolonged process occurring between the points of maximum velocity and minimum acceleration.

Peak velocity must occur when acceleration drops to zero, i.e. at the point at which the subject does not have sufficient strength to impart additional momentum but can exert only enough force to support the weight stack. This is consistent with a height of 77% stature. When this point is reached the subject must change grip and apply an upward force greater than the weight of the stack before the velocity drops to zero. Success on the ILM therefore depends on imparting as much momentum as possible in the early part of the lift to carry the subject through this wrist changeover. This fits completely with the suggestions of Grieve (1970) on the defeat of gravity in weight lifting.

Charteris *et al.* (1994) used an ultrasonic motion monitor to replicate the isoinertial lifts of Stevenson *et al.* (1990a). They describe the lift of a 25 kg bar sliding in vertical tracks as involving "an accelerative pull, a hitch of the wrists to get the bar above the grip, and a push to full overhead stretch". They found that all the displacement, velocity, force, power and energy parameters were sensitive to the motion adjustments in the bar associated with the wrist-hitch. They found similar dynamic patterns to those found by Stevenson *et al.* (1990a). They also found that a free-lift of a bar bell was very similar to the uni-planar isoinertial lift.

2.7 Gender differences in strength

Lewis *et al.* (1986) reviewed previous work on physiological gender differences in the context of sports conditioning and summarised their findings as showing 1) little difference in the effect of different modes of progressive resistance strength training; 2) similar relative strength gains between men and women; 3) some conflict of body composition changes; 4) male and female athletes within specific events have similar muscle fibre type compositions; 5) less muscle hypertrophy is elicited in women than in men. They also concluded that aerobic exercise will benefit both men and women and that gender differences should make no difference in exercise prescription, which should be based upon individual physical work capacity.

2.7.1 Gender differences in muscle characteristics

Bishop *et al.* (1987) tested the hypothesis that the sex difference in muscle size, as reflected by fat-free weight (FFW) and limb fat-free cross-sectional area (FFCSA), would account for the majority of the sex difference in strength and the known variability in the sex difference between upper and lower body strength. They measured

47 males and 50 females with similar long-term participation in sports activities (a group of swimmers and a group of non-athletes). After adjustment for FFW and FFCSA only upper-body strength showed significant differences. Females had much smaller upper-arm and forearm FFCSAs relative to FFW than the males, but had larger relative thigh FFCSAs. FFW and limb FFCSA together accounted for 92-100% of the sex-related variance in strength for the swimmers and 95-100% for the non-athletes. They concluded that the relationship between FFCSA and FFW accounted in part for the sex difference in lower-body strength being smaller than in upper-body strength. They also concluded that once FFW and FFCSA are accounted for there are minimal sex differences in strength and upper and lower body sex differences are comparable.

Bishop *et al.* (1989) used the same subjects to compare upper and lower body limb FFCSAs of males and females after adjustment for differences in FFW. Significant differences were found for the arm and forearm for the non-athletes, but not for the swimmers. In other words, per kilogram of lean body mass, untrained women had less upper limb muscle than untrained men, but athletic females and males had the same amount of upper limb muscle per kilo of lean body mass. (Clearly, further studies are needed to verify this finding, particularly by measuring actual muscle masses or cross-sectional areas, rather than estimating them). Bishop *et al.* (1989) therefore supported the contention of Wilmore (1974) that the greater gender difference in upper-body strength relative to lower body strength is due to culturally based differences in physical activity. They therefore suggested that long-term activity should be considered in the design of sex difference studies, and that more research is needed to determine which of these differences are a product of biology or of culture and sample selection.

Castro *et al.* (1995) examined isometric strengths of the upper and lower limbs. Both upper arm and thigh torque / muscle cross-sectional area showed no significant differences between males and females. For torque per unit of mean body weight or lean body mass, large gender differences remained for the upper arm. They interpret these results to mean that differences in the absolute strength of males and females reflect differences in muscle cross-sectional areas, and conclude that gender differences in absolute strength are explained primarily by differences in the distribution of lean body mass, which they attribute to the differences caused by the adolescent growth spurt rather than prolonged gender differences in physical activity levels.

2.7.2 Gender differences in dynamic strength

Many studies have reported female and male strengths. The measures made and the resultant female : male ratios from a number of these are summarised in Table 2.14. The main lesson that can be learnt from this table is the variability of gender differences, which is a point which has been made repeatedly in the past, by authors such as Laubach (1976) and Pheasant (1983).

Table 2.14: Summary of female : male ratios reported for dynamic strength

Study	Measure	f:m ratio
Laubach (1976)	MAWL	59% - 84%
Hosler and Morrow (1982)	Isokinetic arm strength	36%
	Isokinetic leg strength	56%
McDaniel *et al.* (1983)	ILM lift to 1.83 m	50%
	ILM lift to elbow height	52%
Jacobs *et al.* (1988)	Operational lift test (OLT)	50%
	ILM lift to 1.52 m (PLT)	51%
	Isokinetic lift at 0.24 $m \cdot s^{-1}$ (ILT)	59%
	Isokinetic lift at 0.73 $m \cdot s^{-1}$ (ILT)	55%
	Isokinetic lift at 1.10 $m \cdot s^{-1}$ (ILT)	54%
Kumar *et al.* (1988)	Isokinetic back lifts	67-72%
	Isokinetic arm lifts	66-69%
Timm (1988)	Mean isokinetic strength in lift to overhead at 0.15 $m \cdot s^{-1}$	51%
	Mean isokinetic strength in lift to overhead at 0.30 $m \cdot s^{-1}$	50%
	Mean isokinetic strength in lift to overhead at 0.46 $m \cdot s^{-1}$	49%
	Mean isokinetic strength in lift to overhead at 0.61 $m \cdot s^{-1}$	52%
	Mean isokinetic strength in lift to overhead at 0.76 $m \cdot s^{-1}$	44%
	Mean isokinetic strength in lift to overhead at 0.91 $m \cdot s^{-1}$	42%
Bryant *et al.* (1990)	Peak force on ILM to 1.83 m	49%
Stevenson *et al.* (1990a)	ILM mass to 1.83 m	53%
	Peak force on ILM to 1.83 m	51%
	Mean force on ILM to 1.83 m	53%
Stevenson *et al.* (1990b)	Set style box lifting to 1.33 m	52%
	Free-style box lifting to 1.33 m	56%
	Ergonomic redesign box lifting to 1.33 m	64%
Weisman *et al.* (1992)	Mean isokinetic strength in lift to overhead	77%
Fothergill *et al.* (1996)	Mean hydrodynamometer strength to 1.8 m	53%
	Mean hydrodynamometer power to 1.8 m	39%

Pytel and Kamon (1981) found that 94.1% of the variance in a maximum dynamic lift of a tote box could be accounted for by dynamic lift strength measured on the Mini-Gym and sex. The separate genders had high correlations (0.87 and 0.92 for 10 males and 10 females respectively) between the two measures of strength.

Hosler and Morrow (1982) compared isokinetic arm and leg strengths of 85 males and 85 females measured at $20° \cdot s^{-1}$ using Cybex devices. Gender alone accounted for 60% and 74% of the variance for the bench press (arm strength) and the leg press (leg strength) respectively. When body size and composition variables were included in the analysis they accounted for 78% and 63% of the variance of the bench and leg presses and the variance accounted for by gender was reduced to 1% and 2% respectively. Lean weight and gender made the largest contribution when stature and body diameters were controlled. Gender had the largest effect on the leg press, whereas lean weight had the largest on the bench press. This is reflected in the female : male ratios of 56% for the leg press and 36% for the bench press which can be derived from the measurements they report.

McDaniel *et al.* (1983) found very little overlap between male and female distributions for the ILM, with 90% of females but only 1% of males unable to lift 70 lb to 1.83 m.

Falkel *et al.* (1985) examined gender differences in muscular strength and endurance of the upper and lower limbs with nine males and seven females matched for mean maximal aerobic power for both leg and arm crank exercises. They measured isokinetic strength and endurance of the knee and elbow flexor and extensor muscle groups at $30°\cdot s^{-1}$ on a Cybex II. Gender differences disappeared for knee flexion and extension and elbow extension, but not elbow flexion, when torques were normalised by lean body weight. Further normalisation to remove the effect of differences of limb length between males and females would have further reduced gender differences. There was a significant upper to lower body strength ratio difference between the genders for elbow flexor : knee flexor strength, but not for elbow extensor : knee extensor strength. They attributed some of the lack of gender differences to the fact that they had matched the groups for aerobic power. They concluded that the ratios between upper and lower body strength appear to be related to muscle mass and are consistent for men and women, and thus women are not at a relative disadvantage in the performance of upper body strength activities. They also found the fatigue decrement during isokinetic endurance exercise to be the same for both genders.

de Koning *et al.* (1985) examined the force-velocity relationship in arm flexion. Untrained females had 38% lower maximal static moment, 43% lower maximal power, and 10% lower maximal angular velocity than untrained men. There was no difference between the males and females in the shapes of the curves. They deduced that differences in maximal power are largely due to differences in maximal static moment, and suggested that the differences were partly due to differences in arm and muscle dimensions.

Jacobs *et al.* (1988) showed that there were significant gender differences for the regressions of either isokinetic or ILM lifting performance on box lifting performance, but when gender and body weight were included in the regressions, the R^2 values increased from 0.93 to 0.95.

Timm (1988) found that male performance generally exceeded female performance, but females consistently exerted their peak forces at higher absolute heights than the males. If these heights were expressed relative to stature then the difference would be even greater. This implies a gender specific difference in either initial posture or lifting technique. A possible reason is males lifting more quickly than females, activating their muscles more quickly, and reaching peak strength earlier. The nature of the device may also have affected this.

Stevenson *et al.* (1990a) compared the genders using 37 ILM lift parameters, finding that women performed the lift more slowly, and produced less force and power. Gender differences in timing were small. Mean times were identical up to the point of minimum acceleration at the change from the pulling phase to the pushing phase but women took longer than men to complete the wrist changeover (time to second peak acceleration) and much longer to complete the lift after that. This partly reflected the fact that the women were shorter and therefore changed grip lower down and carried out the push up for longer and further than the males.

They argue that the females were at a disadvantage because they were smaller and had to start the lift at a greater percentage stature, meaning that they had less distance to accelerate the load before the wrist changeover, and had to push for a longer distance than the males. They therefore argue that the ILM was unfair to females and could have seriously underestimated female lifting potential. However, this conclusion can only be true if you wish to compare lifting relative to stature. It is emphatically not true if the ILM is used as a screening test for real tasks which have to be carried out between fixed heights. Also, McDaniel (1996) criticises their conclusion on the basis that the difference in stature between men and women is only 8%, and lowering the starting position by 8% does not affect the test results.

Stevenson *et al.* (1990b) found that lifting performance of females improved relative to that of males as protocol constraints were removed. For box lifts to a height of 1.33 m, capacity was less for a 'set-style' (straight back, bent knees), than a 'free-style' protocol, and most where the subjects were permitted to carry out an 'ergonomic redesign' of the task. Correlations between box lifting and ILM performance were consistent across gender for set-style lifting where up to 50% of the variance could be predicted. Female free-style box lifting performance correlated much more poorly with ILM performance while the correlation with male performance only dropped slightly. On the 'ergonomic redesign' the correlation increased to 0.85 for males but became very small for females. They concluded that male lifting capabilities were reflected reasonably well by ILM tests, but falsely concluded, based upon the results of the 'ergonomic redesign', that ILM tests were poor predictors of the actual lifting capabilities of females. Stevenson *et al.* (1996a) admitted that, in fact, males and females adopted totally different approaches to the 'ergonomic redesign', with the females constructing steps to walk up with the load while the males modified the way they handling the box. McDaniel (1996) criticises them for drawing such powerful conclusions from a sample of only 10 females and for having confounded their study design by having three different groups of subjects. To reach the conclusions they did would require differential analysis of the actual male and female techniques used in the 'ergonomic redesign' task and for the same subjects to perform the three different conditions.

Stevenson *et al.* (1996a) summarised their previous work in the context of using the ILM as a selection tool and its 'gender fairness'. Regression analysis showed that ILM mass and associated dynamic parameters possessed much greater power for predicting the box-lifting performance of males ($R^2 = 66\%$) than for females ($R^2 = 33\%$), with marked differences in the independent variables retained in the regression equations. They concluded that the same linear regression model should not be used for both men and women. The accuracy of logistic discriminant analysis deteriorated as the cut-off level was raised from 18.2 kg to 27.3 kg. 33% of all female lifters were incorrectly classified by the ILM test as having failed to lift 27.3 kg on a box-lifting task. Table 2.15 lists their reasons why giving males and females the same starting and target heights creates different physical demands on them.

Table 2.15: Reasons for dissimilar physical demands on men and women caused by giving men and women the same starting and target heights for dynamic lifts. (After Stevenson *et al.*, 1996a)

1	Females have less distance to generate momentum in the early part of the lift.
2	Females spend more time [and distance] in the pushing phase above shoulder height.
3	Gender differences in upper-body strength are more pronounced than lower body strength (Laubach, 1976). Therefore females are at even more of a disadvantage because they spend more time [and distance] using their upper body.

All the isokinetic measures of Newton *et al.* (1993) showed highly significant differences between males and females. They therefore analysed and presented data separately for males and females.

Grieve (1993) measured power output over the 0.7 - 1.0 m range of 56 male and 73 female military recruits lifting from 0.4 m to chest height. He found almost no overlap between the distributions of power/weight ratios for males and females.

Fothergill *et al.* (1996) showed that females performed dynamic exertions more slowly than males. Gender did not significantly affect the height, relative to stature, at which peak strength or power occurred. Relative to stature, males and female strengths responded in the same way to height. Strength differences between one and two-handed exertions were greater for males than for females, and were affected by height. The mean female : male ratio for isometric strength was 0.60, and 0.76 when normalised to body weight, meaning that strength differences were larger for dynamic exertions.

2.8 Use of dynamic strength measures to predict lifting capacity

Myers *et al.* (1984) used the ILM to test 1003 females and 980 males about to commence basic training in the US Army. 951 of these were tested on job-related criterion tasks 8-16 weeks later. ILM lifting capacity to 1.52 m accounted for 67% of the variance in the criterion measures of physical competence. Lean body mass and an isometric upright pull accounted for an additional 3% and 1% respectively. The test had high validity (R = 0.84). Fairness analysis showed a minimal over-prediction for women, with non-significant slope differences and only slight intercept differences.

Aghazadeh and Ayoub (1985) used isokinetic lifting strength and anthropometric and static strength measurements from nine males to create models for predicting lifting capacity. They found that dynamic strength resulted in a better model with a greater prediction capability than static strength could provide.

Mital and Karwowski (1985) found poor correlations ($r < 0.4$) between static strengths and psychophysical maximum lift capacity measured on 19 males and 6 females. They found better correlations ($0.5 < r < 0.7$) between 'Simulated Job Dynamic Strength' (SJDS), measured at 0.75 $m{\cdot}s^{-1}$ with the Mini-Gym, and maximum lift capacity. They therefore concluded that the dynamics of a manual handling activity cannot be ignored.

Jiang *et al.* (1986a) developed models to predict capacity for four types of manual handling activity using data from 12 males. They found that limiting-activity based models produced the most accurate predictions and that isoinertial strength-based models had the advantage of ease of testing and good face validity.

Jiang *et al.* (1986b) developed models predicting psychophysically determined lifting, lowering and carrying capacities at three frequencies from isoinertial and isometric strengths. Data were collected from the 12 males used by Jiang *et al.* (1986a). Adding body weight to the capacities improved the correlations between them and the strength variables. The score on a 1.83 m ILM lift was the best single predictor ($r = 0.85$ to 0.95). Second order polynomial regression models using this score as a predictor gave R^2 values between 0.791 and 0.950.

Jiang and Ayoub (1987) re-analysed data of Ayoub *et al.* (1978) from 73 males and 73 females. They used Principal Components Analysis to derive factor-score based models in order to predict Maximum Acceptable Load for lifting tasks. A strength and an anthropometric factor accounted for 85% of the variance among seven measures of strength and anthropometry. The model included the two factors, the frequency of lift and a constant representing the range of lift, and had an overall R^2 value of 0.924. Three previous models developed by Ayoub *et al.* (1978) had R^2 values ranging between 0.754 and 0.903. They commented that "since there is no sex variable in the predictive model as shown in the previous model (Ayoub *et al.,* 1978), the sensitive problem of gender discrimination is thus avoided". They concluded that factor-score-based models have the advantage of providing a more explainable and meaningful structure for determining maximum acceptable loads than other models.

Ayoub *et al.* (1987) provided a brief overview of the USAF strength selection programme, of which McDaniel *et al.* (1983) reported part. 13 simulated tasks were devised which accounted for approximately 90% of the physically demanding tasks identified within Air Force Speciality Codes (AFSCs). Stepwise regression was used to determine which of eight selection tests were the best predictors of performance by 527 USAF personnel on the simulated tests. X1, the ILM lift to 1.83 m, was the best predictor for most of the tasks, with correlations ranging from 0.53 to 0.87, and further variables added very little. As a result, single variable models were used but, to normalise the data, a weighted regression of $(X1)^2$ was used. The results were used to develop assignment criteria for AFSCs.

Nottrodt and Celentano (1987) reported similar work undertaken for the Canadian Forces. Analysis of military trade requirements showed that the predominant requirement was lifting, with strength the limiting factor. 83% of lifting tasks started at floor level and finished between waist and shoulder height. Two tasks were chosen to represent 100 trades: lifting from the floor to 1.33 m, and a lift, 5 m carry, and place at a height of 0.75 m. The maximum weight that could be lifted smoothly and comfortably in a box 610 × 380 × 250 mm with handles was determined for each task for 31 males and 25 females, who were not trained lifters, nor lifted extensively as part of their job.

The ILM was the best overall predictor of task performance. The use of performance standards to predict successful or unsuccessful lifting task performance was investigated using cut-off criteria of 32 kg and 41 kg for the two tasks, and two separate methods for establishing cut-off scores. They found similar results for the two techniques, resulting in 39% and 9% more correct screening decisions than using no screening test for tasks 1 and 2 respectively.

Wu and Hsu (1993), following Jiang *et al.* (1986b), used ILM performance as a predictor of maximum acceptable weight of lift (MAWL) of a group of 12 Chinese males. They also found that it was a better predictor than isometric strengths. Prediction models using isoinertial strength to both 1.83 m and elbow height performed best, whereas Jiang *et al.* (1986b) had recommended only the 1.83 m ILM test. Adding ILM performance to elbow height to the model increased R^2 from 74% to 82%.

Duggan and Legg (1993) measured performance of 384 male army recruits on a series of strength tests. Performance on a Quasi-isokinetic lift test was a poor predictor of maximum isometric lift capacity, giving rise to a much lower correlation ($r = 0.46$) than the modified Cybex apparatus, as used by Aghazadeh and Ayoub (1985), at a lift speed of 0.47 m·s^{-1} ($r = 0.72$). Unlike previous studies, there was not a clear superiority of dynamic tests over static tests as predictors of isoinertial lifting capacity. Using the same hydrodynamometer as Grieve (1993) they found a mean power output of 431.1 (SD 119.0) W. There was a linear correlation of 0.67 between hydrodynamometer power output and maximum incremental lifting capacity to 1.52 m on an ILM. Using multiple regression they showed that, when combined with measures of height and weight, both the hydrodynamometer and an isometric upright pull at a height of 380 mm, were equally good predictors of ILM performance ($r = 0.77$, $R^2 = 0.59$-0.60). They concluded that the hydrodynamometer lift was the most suitable of the dynamic tests, with a high level of criterion-related validity and reasonable face validity, while being significantly cheaper than the Cybex dynamometer.

CHAPTER 3

HYDRO-RESISTIVE MEASUREMENT OF DYNAMIC LIFTING STRENGTH

3.1 Nomenclature

F_H	Force exerted at the hands
m	Mass of the piston and rope
a	Linear acceleration of the piston and rope
F_D	Drag force
Fr	Frictional force
I	Total moment of inertia of rotating parts
α	Angular acceleration of rotating parts
C_D	Drag coefficient
ρ	Density of water
V	Velocity of hands / rope / piston
A_P	Frontal area of the piston
c	Constant relating F_D and V^2
Re	Reynolds number
d	Characteristic dimension of the object, i.e., thickness of the plate
ν	Kinematic viscosity of water
F_C	Force on the cantilever
θ	Angle between the rope and the vertical at the cantilever
h	Effective vertical distance between the lower pulleys and the cantilever pulley
Δh	Change in h
k	Stiffness of the cantilever
l	Effective horizontal distance between the lower pulleys and the cantilever pulley
T	Water temperature
A_H	Cross-sectional area of the holes in the piston
A_F	Total flow area (A_H + area of gap between piston and tube wall)
A_T	Cross-sectional area of the tube

3.2 Introduction

The literature review in Chapter 2 has shown that many of the published descriptions of devices that have been used to measure dynamic strength are inadequate and demonstrate lack of understanding of the characteristics of the devices. Therefore this chapter describes in detail a fully instrumented modification of the hydrodynamometer referred to by Grieve (1993), Fothergill *et al.* (1995, 1996) and Duggan and Legg (1993) and explains the underlying physical principles which govern its operation.

In isometric exertions (Caldwell *et al.*, 1974) the resistance to acceleration (the inertia) is infinite because no motion occurs. Isoinertial devices (Kroemer, 1983) and psychophysical tests (Snook and Ciriello, 1991) are governed by Newton's Second Law and have constant resistance to acceleration. They have strong face validity because most real lifting tasks involve constant masses.

In theory, isokinetic devices offer infinite resistance to acceleration once the pre-set speed has been attained. Only the more expensive 'isokinetic' devices provide truly iso-velocity conditions (O'Hagan *et al.*, 1995). The device described by Pytel & Kamon (1981) has poor speed control, but the device of Kumar *et al.* (1988) has highly sophisticated and accurate speed control. Accommodating resistance devices offer pseudo-isokinetic conditions with the resistance produced depending on the effort applied (O'Hagan *et al.*, 1995). In a hydro-resistive device, or 'hydrodynamometer' (Grieve and van der Linden, 1986; Hortobagyi *et al.*, 1989), motion itself is resisted by a drag force caused by the movement of a body through a viscous incompressible fluid, such as water. Isokinetic, accommodating resistance, and hydro-resistive devices have common advantages in that either the velocity or the relationship between velocity and effort can be preset, and they are fail-safe in that if the subject ceases to exert, the resistive force disappears.

3.3 Materials and methods

3.3.1 Fluid mechanics of a hydrodynamometer

An ideal hydrodynamometer has friction free moving parts with zero mass and no moment of inertia, with the result that the applied force is equal to the drag force. In reality, part of the applied force is used to overcome friction, and to provide linear and angular acceleration to any moving parts. This can be expressed as:

$$F_H = m \cdot a + F_D + Fr + I \cdot \alpha \qquad (3.1)$$

If the frictional forces are neglected and any rotating parts have small moments of inertia, then this equation becomes:

$$F_H = m \cdot a + F_D \qquad (3.2)$$

Fox and McDonald (1994) show, for incompressible flow over any body, (or, as in this case, for movement of a body through an incompressible fluid) that:

$$F_D = C_D \cdot \tfrac{1}{2} \cdot \rho \cdot V^2 \cdot A_P \qquad (3.3)$$

This means that the relationship between drag force and velocity of the body can be controlled by altering the frontal area, A_P, of the body.

For a body of fixed shape, Equation 3.3 can be simplified to:

$$F_D = c \cdot V^2 \qquad (3.4)$$

permitting the constant, c, to be determined empirically by measuring F_D and V^2.

It is also true that:

$$Re = (V \cdot d) / \nu \qquad (3.5)$$

Slow moving viscous flows over smooth objects are characterised by smooth laminar motion of fluid particles. Fast moving flows of low viscosity over objects with sharp edges are characterised by turbulent motion of fluid particles. Turbulent flow will occur in all realistic dynamic lifts performed on this type of device.

When the fluid is water, the kinematic viscosity, ν, and hence Re, is extremely sensitive to temperature. However, Fox and McDonald (1994) specifically state (p 420) that:

> *"The drag coefficient for a finite plate normal to the flow depends on the ratio of plate width to height and on the Reynolds number. For Re (based on height) greater than about 1000, the drag coefficient is essentially independent of Reynolds number."*

and:

> *"The drag coefficient for all objects with sharp edges is essentially independent of Reynolds number (for Re >≈1000) because the separation points are fixed by the geometry of the object."*

It is therefore clear that for turbulent flow caused by moving a body through water, temperature does not affect the relationship between drag force and velocity.

Combining Equation 3.2 and Equation 3.4 gives:

$$F_H = m \cdot a + c \cdot V^2 \qquad (3.6)$$

For a truly isokinetic device, or if, at any instant, the acceleration of the moving parts of the device is zero, this becomes:

$$F_H = c \cdot V^2 \qquad (3.7)$$

This relationship is approximately true if F_H is large compared to the inertial forces, i.e. V is high, and m is kept to the minimum possible.

3.3.2 The hydrodynamometer

This device (Figure 3.1) consists of a water-filled vertical nylon tube (2 m height, 200 mm internal diameter) open at the top. It is mounted on a steel framed wooden base-board on which the subject also stands. A steel framework rigidly supports the tube and provides mountings for a series of pulleys and a rest which holds the handle, which the subject exerts on, in its start position at a height of 400 mm. An inextensible flexible stranded stainless steel wire rope passes from the handle, and over the series of pulleys, into the top of the tube. Two smaller pulleys are mounted to prevent the rope from slipping from the pulleys when the rope is slack. A drain cock fitted at the base of the tube allows the water to be drained from it, and a pair of wheels are fitted so that the whole device can be tilted onto them and wheeled from place to place.

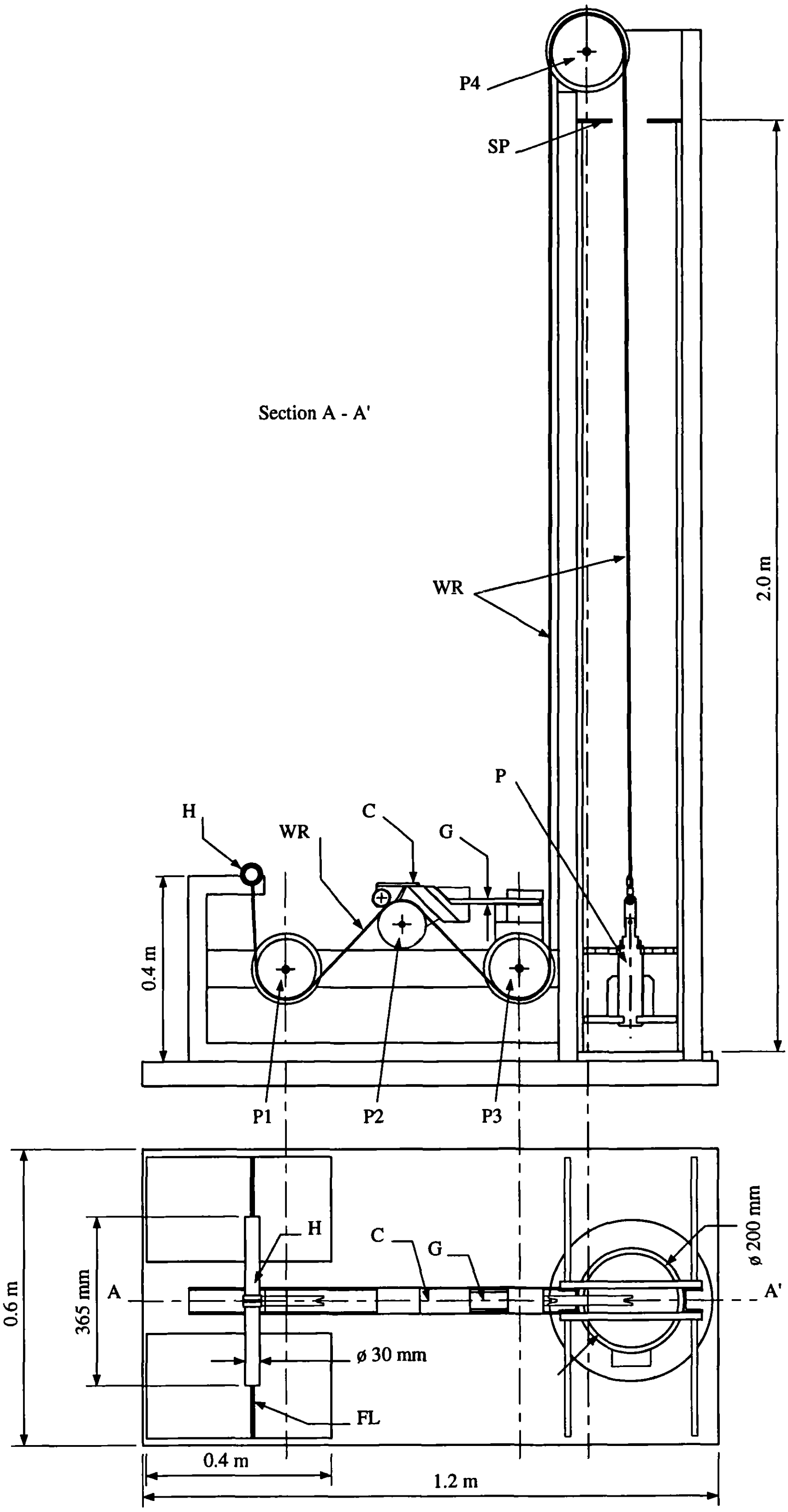


Figure 3.1: Vertical section on plane A-A' and plan view of the hydrodynamometer, showing important dimensions. H is the handle grasped by the subject; P is the piston assembly; (both H and P are shown in their resting positions); P1 - P4 are pulleys the wire rope, WR, passes around; C is the cantilever; G is the site of the strain gauges; Fl is the footline marked beneath the handle; SP is the splash plate at the top of the tube. The tube is filled with water to within a few centimetres of the splash plate

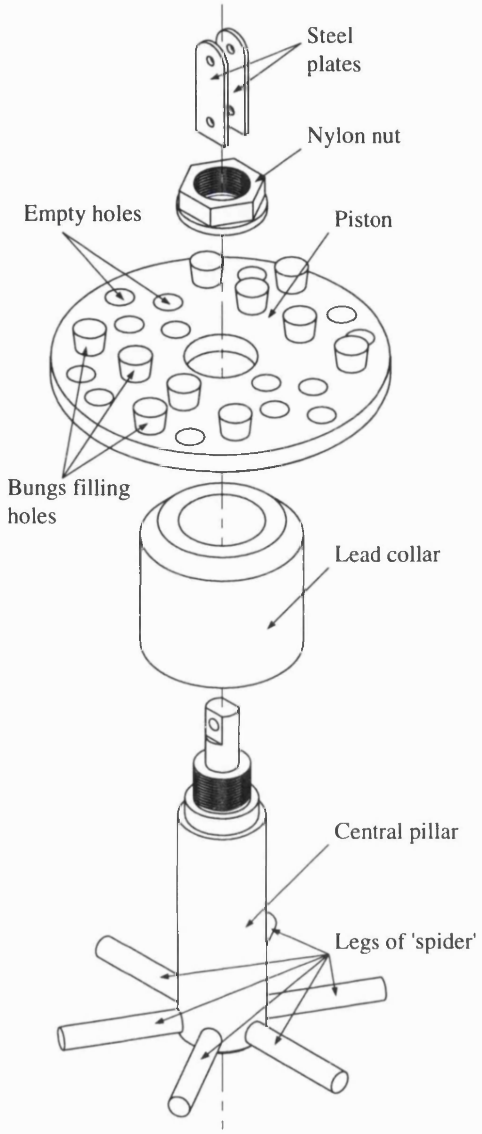


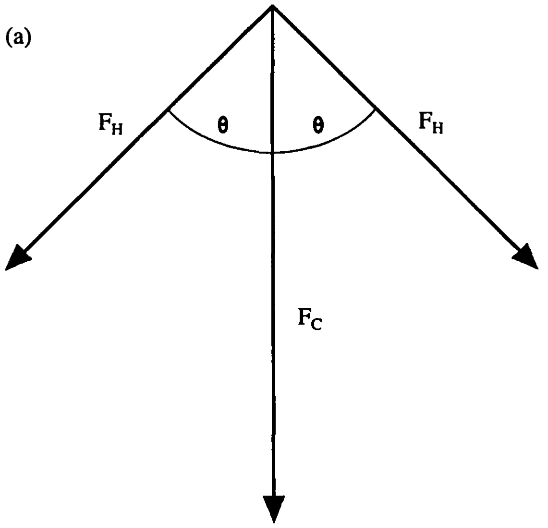
Figure 3.2: Exploded isometric view of the piston assembly (total mass 5.85 kg). The lead collar (4.55 kg) slides down the central pillar and rests against the legs of the spider. The piston rests against the shoulder at the top of the pillar and the nut is screwed down to hold it. A bolt holds the steel plates to the cheeks at the top of the pillar and a bolt through the top of the top of the plates passes through an eye in the end of the wire rope

The rope suspends a piston inside the tube (Figure 3.2). It consists of a nylon disc (12 mm thick, 199 mm diameter) mounted at the top of a central pillar. A lead collar on the pillar ensures prompt return of the piston to the start position near the bottom of the tube. A 'spider' at the lower end of the pillar stabilises the motion of the assembly. 17 mm diameter holes in the disc can be closed with rubber bungs and different discs provide different numbers of holes. Both of these features allow the frontal area, A_P, of the piston to be changed. The tube is filled to within a few centimetres of the top. A splash plate is fitted at the top of the tube to minimise water losses. The combination of the splash plate and the almost full tube prevent the piston leaving the water. The handle reaches a height of 2.2 m before the bungs in the piston hit the splash plate.

3.3.3 Instrumentation

The rope passes at angles of approximately 45° over a cantilevered pulley equidistant between the two pulleys at the base of the device. The central part of the cantilever consists of a piece of gauge plate (50 mm wide, 10 mm thick) on which are mounted four foil strain gauges compensated for steel (RS Components no 632-168), wired as a Wheatstone bridge. These are connected via a 5 wire shielded lead to an amplification circuit (RS Components strain gauge amplifier 308-815 and PCB 435-692) with a gain of 680. A switch and series calibration resistor are wired in parallel to one arm of the Wheatstone bridge. This allows a calibration change to occur in the bridge balance when the switch is closed. The amplifier output is connected via a shielded lead to the analogue port of an interface card fitted to a computer.

The downward force, F_C, on the cantilever is a function of the angle of the rope, θ, and of the tension in the rope, F_H. (Figure 3.3a). θ will change as the cantilever deflects under load (Figure 3.3b), i.e. F_C will be a function of both F_H, and the cantilever deflection, Δh.



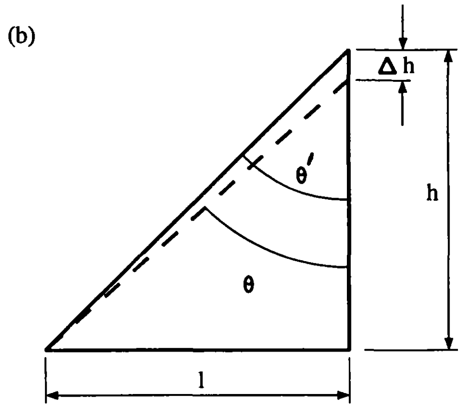


Figure 3.3a: Diagram showing the relationship between vectors of the force in the rope, F_H, and the resultant force, F_C, on the cantilever. θ is the angle between the rope and the vertical

Figure 3.3b: Diagram showing how θ changes when the cantilever is loaded with the force F_C. The point of application of F_C deflects vertically by a distance Δh, resulting in the angle θ' changing to θ. l and h represent the physical dimensions between the point where the rope leaves pulley P1 and makes contact with pulley P2

Thus:

$$F_C = 2 \cdot F_H \cdot \cos \theta \qquad (3.8)$$

If the cantilever does not exceed its elastic limit and assuming that any horizontal deflection of the cantilever is much less than the vertical deflection then:

$$\Delta h = k \cdot F_C \qquad (3.9)$$

and:

$$\mathrm{Tan}\,\theta = l / (h - \Delta h) \qquad (3.10)$$

Combining Equations 3.8, 3.9 and 3.10 gives:

$$F_H = F_C / (2 \cdot \mathrm{Cos}\,(\mathrm{Tan}^{-1}\,(l / (h - k \cdot F_C)))) \qquad (3.11)$$

allowing the three constants, l, h and k, to be estimated.

A shaft encoder (RS Components no 341-581) environmentally protected to IP43 rating is used to measure position and velocity. The encoder was chosen instead of a rotary or linear potentiometer because it is factory calibrated, is not susceptible to wear over its lifetime and does not have a fixed range. It is pinned coaxially to the shaft of the rear lower pulley (P3 on Figure 3.1) of the device and connected to the digital inputs of the interface card. Two TTL outputs, phase shifted by 90°, provide 360 pulses per revolution, giving a total of 1440 changes of state (edges) per revolution making it possible to find the direction of motion from the sequence of pulses (see Figure 3.4). As the pulley has an effective diameter of 127 mm (5"), the distance the rope travels between edges is 278 μm.

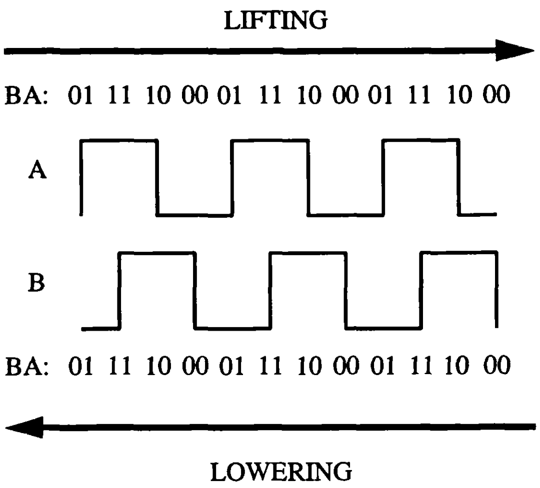


Figure 3.4: Possible combinations of output from the shaft encoder showing how sequences of changes of state ('edges') differ during lifting and lowering

3.3.4 Calibration

The cantilever was calibrated in a two stage process:

1) Known weights were suspended from a rope passed over the cantilever pulley, P2. A linear relationship between applied force and output from the strain gauge circuit was obtained (R^2= 99.98%). From this, the force equivalent to the change in output due to the calibration resistor was calculated. This allows thermal effects such as heating and baseline drift to be eliminated.

2) The relationship between force in the rope and force on the cantilever was determined by exerting forces on the handle with a ring force transducer inserted

in the rope below the handle. The output from the transducer in the rope was amplified using another circuit of the same type and was fed to another channel of the A-D converter. This allowed simultaneous measurements to be taken of the force exerted at the hands and the force acting on the cantilever. The ring transducer had first been calibrated by hanging weights on it in a manner identical to that used for the cantilever, and the relationship between force and output had been found to be linear ($R^2 = 100.00\%$).

A single subject carried out a series of five exertions on a piston with 14 holes, and three exertions on a piston with no holes. Non-linear regressions were carried out on the data collected using Equation 3.11 as the regression equation. The results are shown in Table 3.1 and Figure 3.5.

Table 3.1: Results of a non-linear regression of F_H against F_C using the NONLIN function of Statgraphics Plus v5.22. All values where either force was less than zero were eliminated from the data set. A regression equation of the form $F_H = F_C / (2 \cdot Cos(Tan^{-1}(l/(h - k \cdot F_C))))$ was used with initial values of 100, 100 and 0.01 for l, h and k respectively. For 14 holes, data from 5 pulls were combined. For 0 holes, data from 3 pulls were combined

No of holes	l / mm	h / mm	k / mm·N^{-1}	$Tan^{-1}(l/(h-k \cdot F_C))$	R^2	No of values
14	96.130	103.595	-0.017120	42.86°	99.854%	4175
0	95.971	103.880	-0.009036	42.74°	99.968%	5640

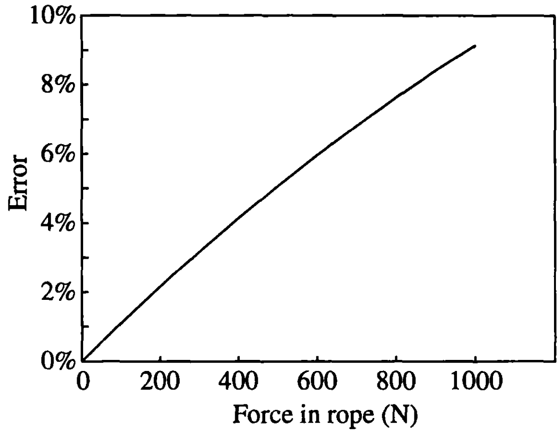


Figure 3.5: Relationship between the force in the rope and the errors that would occur if no correction was made for the deformation of the cantilever

3.3.5 Computer hardware

Data is collected using an Archimedes A310 computer (Acorn Computers Limited, Cambridge, UK) with a 25 MHz ARM 3 (Advanced RISC Machines Ltd., Cambridge, UK) processor, 4MB of RAM, RISC OS 3.10, and a Wild Vision ADC1208-16 interface card (Computer Concepts Ltd., Hoddesdon, UK). Software is largely written in BBC Basic V, with speed critical parts written in ARM assembler. Machine code routines built into the ADC1208 act as extensions to the operating system and allow direct control of the ports on the card.

The ADC1208-16 has an eight input analogue port, which uses a 12 bit A-D converter to sample at up to 166 KHz , and an eight line bidirectional digital port. The card is memory mapped in the Archimedes memory and the card maintains a parameter block.

3.3.6 Data collection and reduction

A single analogue channel of the ADC1208-16 is sampled at a rate of 12499 Hz for a period of 8 seconds. This is done as a background processing task under fast interrupts, allowing other activities to occur at the same time. Once A-D conversion has been initiated, an ARM code loop is used to read the digital port continuously. Each value obtained is stored in a memory location calculated from the number of analogue samples still to be collected, which is available in the ADC1208-16 parameter block. This loop terminates when the A-D conversion finishes.

This sampling method allows synchronous sampling of both the force transducer connected to the analogue port and the shaft encoder connected to the digital inputs. Digital values occurring at variable intervals are associated with individual values from the analogue port collected at a known frequency. A few, usually early, analogue samples do not have digital values associated with them. Normally several values are obtained for each analogue value and the last value read is kept. In approximately 300/ 100000 (i.e. 0.3%) no value is read.

Once data collection is complete, data reduction takes place by scanning the array of digital inputs. When a change in input from the encoder is detected a counter is incremented and the digital input value and the associated analogue input are stored in a new array.

Because force in the rope will increase before movement occurs, the point at which the force first crosses a preset threshold is found. The start of movement is found as the next upward edge (see Figure 3.4) from the shaft encoder. This eliminates electronic noise and minor movements the subject may make while waiting for the signal to start. The rise in force before movement starts is recorded by taking every tenth force sample between these two points. The movement array is then scanned from the start of movement. For each new edge, the direction of motion is determined and the height of the handle is calculated. The time at which the edge occurred is calculated from its position in the array.

Once all edges have been detected, velocity is found as the first derivative of height. Power at each edge is calculated as the product of the corresponding force and velocity. Graphs are plotted (against time) of height, force, velocity and power and the data can be saved for later analysis.

Because pulses are generated by the shaft encoder at equal intervals of height, they will occur at differing intervals of time, which means that pulses occur more frequently at high velocities than at low velocities. Moreover, at high velocities, greater changes in velocity will occur between pulses than at low velocities. Both of these effects introduce increasing amounts of noise into values of velocity and acceleration derived from the height and time data using instantaneous slopes. To overcome this problem, velocity and then acceleration are calculated from the mean slope between two pulses equidistant from the pulse of interest. A separation of 21 pulses is used, so that the mean slope is found over a 5.838 mm change in height. This removes significant amounts of noise from the velocity curves without excessive smoothing.

3.3.7 Instructions to the subject / protocol

The nature of the device is explained to the subject and the method of lifting is demonstrated. Since the lift will pass through the shoulder region, the need to change grip from an overhand lift to an underhand upward push is mentioned. It is emphasised that the resistance to lift is effort dependent in that "*The harder you pull, the harder it gets*" and that the purpose is to obtain the maximal power that a subject can produce. The subject is given chance to practice lifting the handle and then performs at least two maximal efforts. A rest pause of at least 30 s is enforced between lifts. If possible, this is done by cycling through a group of subjects.

The subject stands on the base of the device with his toes on a line marked vertically beneath and parallel to the start position of the long axis of the handle, which he holds with a two-handed overhand grip. The force vector from the hands is therefore directed through the foot base of the subject. (This is a safety feature to minimise the moment about the low back by minimising the horizontal distance). When given the command to lift, the subject lifts the handle as hard and as fast as possible from the start position to beyond a predefined end position. Isokinetic studies, e.g. Weisman *et al.* (1992), have used similar instructions. Once the handle has reached the end position, the subject keeps hold of it and allows the weight of the piston to return it and the handle to their start positions. The only force required at the end of the lift is that needed to support the apparent weight of the piston.

3.4 Results

3.4.1 Relationship between force and velocity

Figure 3.6 illustrates typical force, velocity, and power profiles. In order to confirm the expected relationship between F_H and V, data from 78 subjects, each of whom performed three lifts, were used in a multiplicative regression of the form $F_H = a \cdot V^b$. The results of this are shown in Figure 3.7 and Tables 3.2 and 3.3.

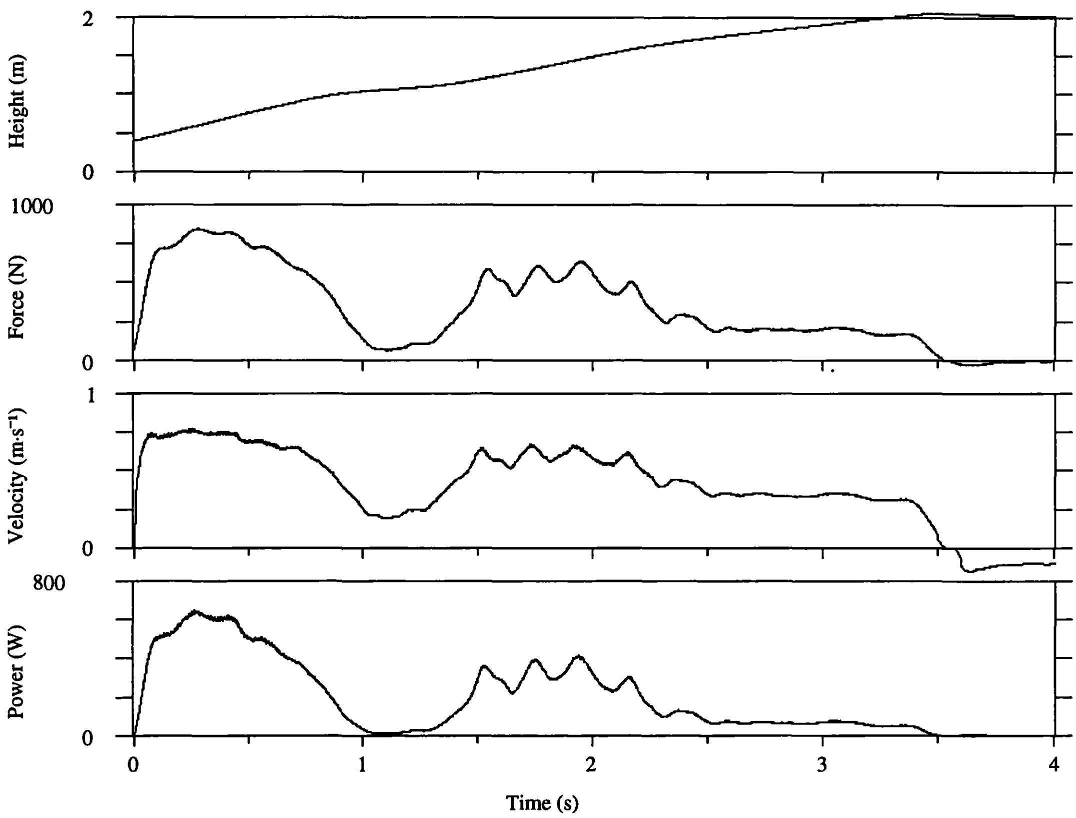


Figure 3.6: Example of the time histories, from the start of movement, of the handle height, force in the rope, velocity of pull, and power output produced during one pull

Table 3.2: Results of a regression of the form $F_H = a \cdot V^b$ carried out using values of F_H and V acquired at points of zero acceleration from a total of 228 exertions from 0.4 m to at least 1.8 m by 78 subjects. A multiplicative model was specified using the Simple Regression procedure of Statgraphics Plus v5.22. This uses a log transformation followed by a linear regression

Parameter	Estimate	Standard error	t value	Probability
Ln a	7.7315	0.001541	5015.97	0.00000
a	2279.02			
b	2.0264	0.002843	712.75	0.00000

Table 3.3: Analysis of variance for the above regression model

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Model	4307.02	1	4307.02	508013.3	0.00000
Residual	99.18	11698	0.008		
Total (Corrected)	4406.20	11699			

Correlation coefficient = 0.988682; R^2 = 97.75%; Standard error of estimate = 0.0920769

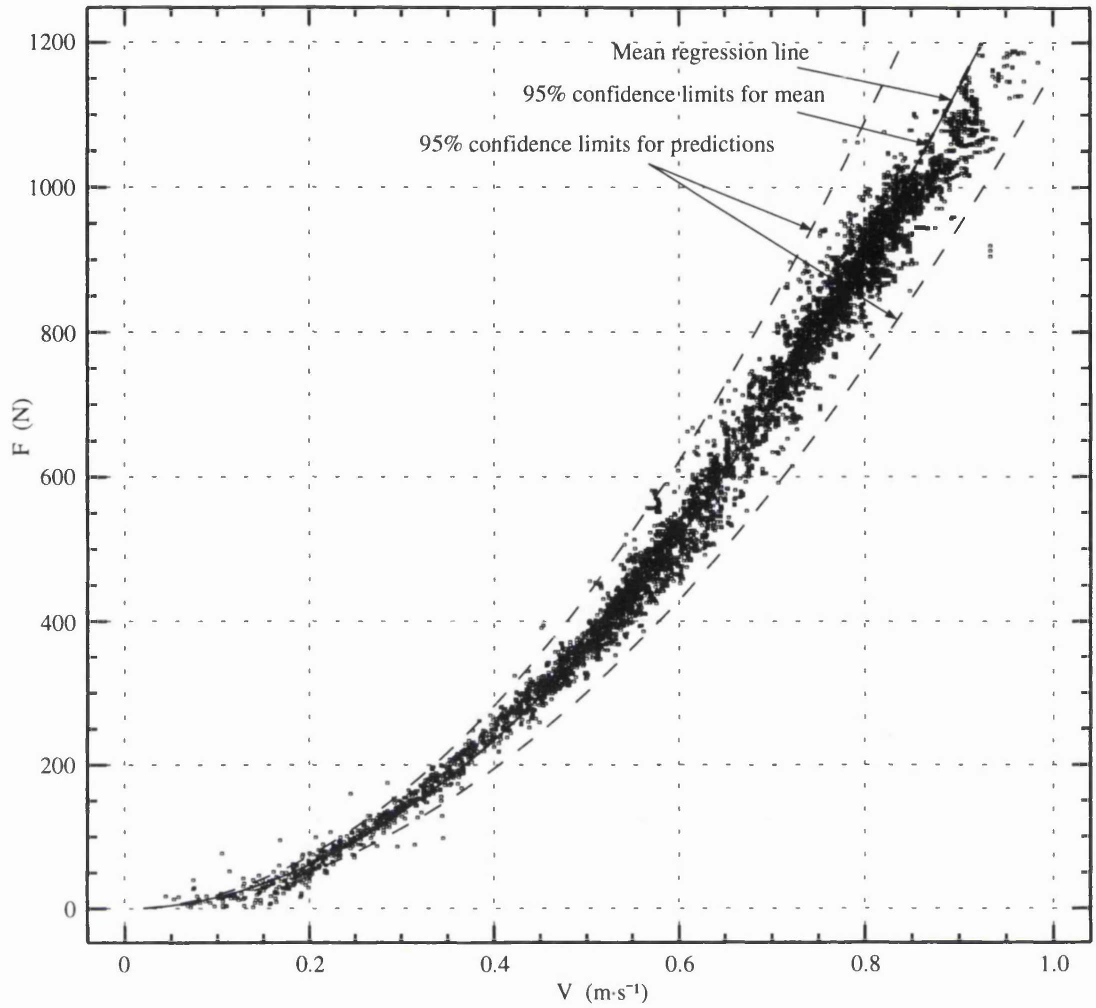


Figure 3.7: Scatter plot, mean regression line, 95% confidence limits for the mean and 95% confidence limits for the predictions obtained from a regression of F_H against V using a multiplicative model of the form $F_H = a \cdot V^b$. Values of F_H and V were obtained at points of zero acceleration from a total of 228 exertions over a range from 0.4 m to at least 1.8 m carried out by 78 subjects

3.4.2 Effect of number of holes on piston resistance / drag coefficient

The effect of piston area was examined by taking measurements with different numbers of holes in the piston. A single subject performed three exertions at each of eight resistances ranging from 24 holes to zero holes, either to a height of approximately 2.1 m, or for a period of 8 seconds, whichever occurred first. Figure 3.8 and Table 3.4 show the results obtained from linear regressions between values of F_H and V^2 obtained at points of zero acceleration.

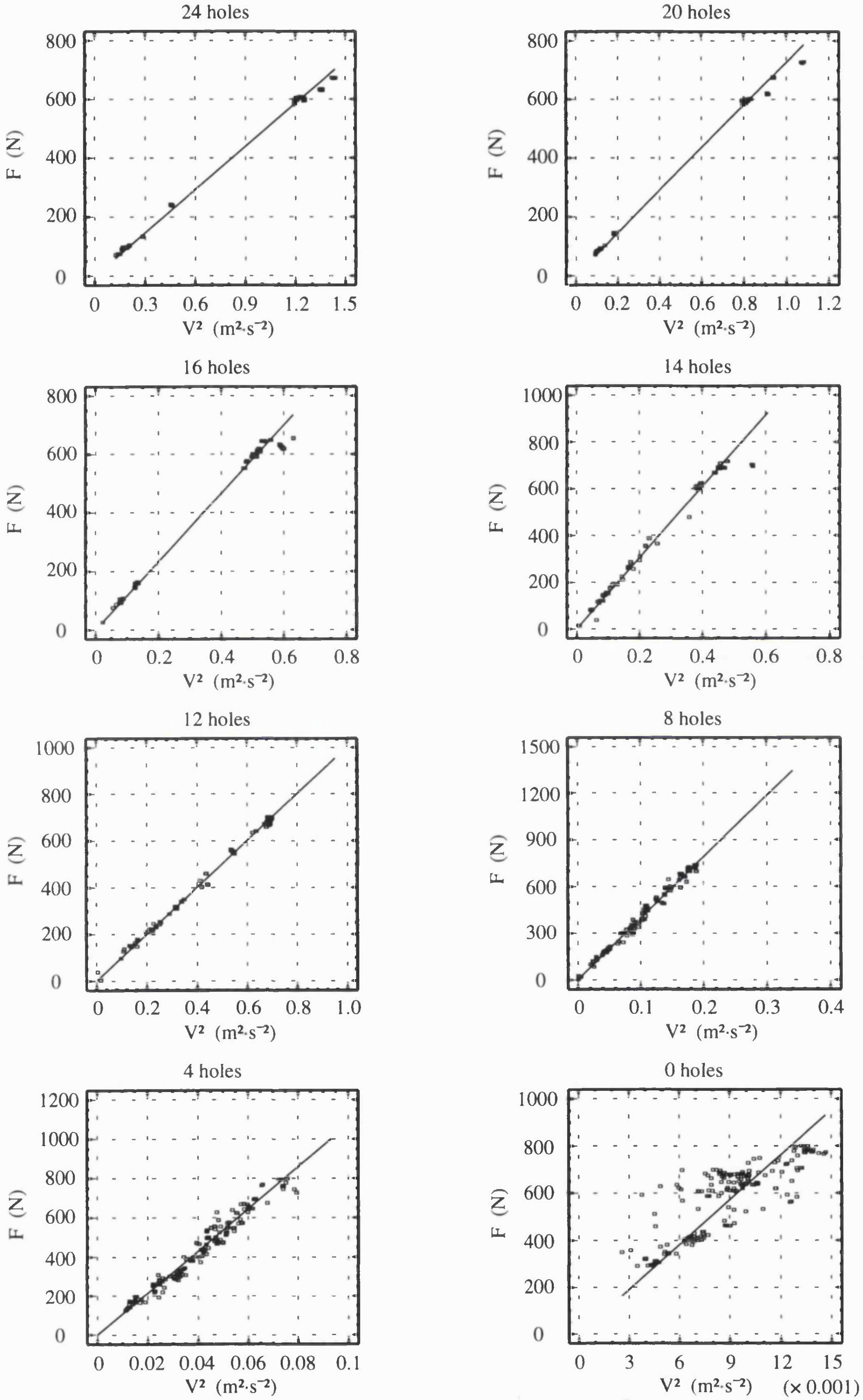


Figure 3.8: Plots of linear regressions of the form $F_H = c \cdot V^2$ calculated for eight different numbers of holes in the piston. Values of F_H and V were obtained at points of zero acceleration from three pulls carried out in each condition by a single subject

Table 3.4: Results of a regression of the form $F_H = c \cdot V^2$ for different numbers of holes, using values of F_H and V obtained at zero acceleration. Data from three pulls at each number of holes were used. All pulls were carried out by a single subject. For each number of holes, values of the effective cross-sectional area of the holes, A_H, the piston area, A_P, and the flow area, A_F, are given, as are the relative flow area and the drag coefficient

No of holes	c / kg·m^{-1}	SE (c) / m·s^{-1}	R² / %	F ratio	No of values	A_H / mm^2	A_P / mm^2	A_F / mm^2	A_F/A_T / %	C_D
24	488.4	0.805	99.93	368080	277	5448	25655	5761	18.34	38
20	725.9	1.288	99.92	317601	259	4540	26563	4853	15.45	55
16	1166.7	2.091	99.85	311325	459	3632	27471	3945	12.56	85
14	1523.7	3.608	99.81	178321	347	3178	27925	3491	11.12	109
12	2005.0	2.710	99.94	547418	320	2724	28379	3037	9.67	141
8	3948.6	7.937	99.79	247491	516	1816	29287	2129	6.78	270
4	10741.8	40.253	99.48	71211	374	908	30195	1221	3.89	712
0	63446.8	765.085	97.05	6877	210	0	31103	313	1.00	4080

3.4.3 Effect of water temperature

The effect of water temperature on the force-velocity relationship of the device was examined by taking a series of measurements at six water temperatures ranging between 5°C and 25°C. The device was filled with water which had been cooled with ice and two subjects performed three exertions each upon a piston with 14 holes to a height of approximately 1.5 m. Cold water was then drawn off from the bottom of the device, and the temperature measured at the same time. The same quantity of hot water was added to the device and the contents were thoroughly mixed by repeatedly pulling the piston through the water. The temperature was recorded and the procedure repeated. Linear regressions were carried out between F_H and V^2. The results, which are shown in Table 3.5, show minimal variation in the regression coefficients and no discernible trend.

Table 3.5: Results of a regression of the form $F_H = c \cdot V^2$, using values of F_H and V obtained at eight water temperatures at zero acceleration. Data from exertions performed by two subjects carrying out three pulls each at each temperature were used

T / °C	c × 10³ / kg·m^{-1}	SE(c) × 10⁶ / kg·m^{-1}	R²	No of values
5.0 - 6.5	1.544	0.942	99.95%	1243
12.3 - 13.2	1.557	1.175	99.95%	936
16.1 - 16.3	1.549	1.113	99.94%	1126
18.9 - 18.9	1.543	1.167	99.93%	1273
21.9 - 22.0	1.560	1.156	99.93%	1255
25.3 - 25.7	1.538	1.219	99.95%	799

3.4.4 Training effects / repeatability

72 subjects (9 females, 63 males) all completed, on one occasion, three exertions on the hydrodynamometer to a height of 1.8 m. The peak power and mean power over two ranges were analysed using one-way analyses of variance with repeated measures. Table 3.6 shows that there were significant increases ($p < 0.0001$) in power output over all of the measures examined.

Table 3.6: Results of one-way repeated measures Anova of repeatability data. 63 males and 9 females each performed, on one occasion, three exertions from a height of 0.4 m to at least 1.8 m. Mean ± SD values are given.

Dependent variables	Probability	Repetition 1	Repetition 2	Repetition 3
Peak power	$p < 0.0001$	694 ± 232 W	763 ± 237 W	818 ± 244 W
Mean power				
0.7 - 1.0 m	$p < 0.0001$	443 ± 167 W	443 ± 177 W	505 ± 188 W
0.4 - 1.7 m	$p < 0.0001$	306 ± 101 W	337 ± 108 W	358 ± 114 W

In a second study, on two separate occasions, 20 subjects (10 male, 10 female) each completed two exertions on the hydrodynamometer to a height of at least 2 m. The peak power, time of peak power and mean power over two ranges were analysed using three way split-plot analyses of variance to examine the effects of gender, day and repetition. The significant results are summarised in Table 3.7, and show that males were significantly ($p < 0.0001$) more powerful than females. No significant differences were found between the two days of testing ($p > 0.05$), but, again, significant increases ($p < 0.01$) were found with repetition. A significant interaction was found between gender and repetition ($p < 0.05$). Also, a significant difference was found between times of peak power on the two days, but the difference in means was only 0.1 s.

Table 3.7: Results of three way split plot Anova, with repeated measures on days and repetitions, of repeatability data. 10 males and 10 females each performed two repetitions on two occasions. Mean ± SD values are given.

Source of variance = Gender

Dependent variables	Probability	Male	Female
Peak power	$p < 0.0001$	812 ± 150 W	444 ± 112 W
Mean power			
0.7 - 1.0 m	$p < 0.0001$	520 ± 129 W	199 ± 59 W
0.4 - 1.7 m	$p < 0.0001$	371 ± 65 W	173 ± 42 W

Source of variance = Day

Dependent variable	Probability	Day 1	Day 2
Time of peak power	$p < 0.05$	0.314 s	0.409 s

Source of variance = Repetition.

Dependent variables	Probability	Repetition 1	Repetition 2
Peak power	$p < 0.001$	591 ± 199 W	665 ± 246 W
Mean power			
0.7 - 1.0 m	$p < 0.01$	342 ± 174 W	377 ± 199 W
0.4 - 1.7 m	$p < 0.0001$	257 ± 101 W	287 ± 121 W

Source of variance = Gender x Repetition

Dependent. variables	Probability	MRep1	MRep2	FRep1	FRep2
Peak power	$p < 0.05$	754 W	869 W	427 W	461 W
Mean power					
0.7-1.0 m	$p < 0.05$	491 W	550 W	194 W	204 W
0.4-1.7 m	$p < 0.001$	345 W	396 W	169 W	177 W

3.5 Discussion

3.5.1 Force and velocity

The results from the multiplicative regression confirm the theoretical statement that when the acceleration is zero, F_H is a function of V^2.

3.5.2 Piston resistance

The utility of this device for measuring dynamic exertions over a wide range of conditions is shown by the fact that the drag coefficient, C_D, can be altered from 38 to 4080 merely by changing the number of bungs fitted in the piston. Values of C_D smaller than 38 can be obtained by changing the piston for one with a greater number of holes, thus allowing the study of low-drag, high velocity dynamic lifts.

3.5.3 Water temperature

The recognition that water temperature does not have an effect on the relationship between force and velocity contradicts earlier statements by Grieve and van der Linden (1986) and Grieve (1993), and simplifies mathematical modelling of the device.

3.5.4 Repeatability

It is clear that there is a definite warming up effect with subjects able to produce more powerful exertions on later pulls than on their initial pull. From the second study it can be concluded that the device gives highly repeatable results since no significant differences were found between the first and second days of testing. Similar results were obtained by Weisman *et al.* (1990b) who attributed some of the differences they found in isokinetic lifting to order effects, in particular a warming-up effect, but they did not find a day to day training effect.

Examination of the means for the gender x repetition interaction showed that, over the 0.7 - 1.0 m range, males increased their power output by 11.9%, whereas females increased by only 5.1%. This may be due to a wide variety of reasons, such as differential motivation of male and female subjects, or might be due to females exerting a greater proportion of their true physiological maximum power on the first repetition.

CHAPTER 4

THE 'GENDER FREE' PROJECT

4.1 Introduction

Previous phases of the CHS 'gender free' project which the work reported in this thesis was linked to had involved the identification of the most physically demanding tasks within military occupations (Rayson, 1998) and the identification and piloting of a suitable battery of physical performance tests which could be used to predict performance (Rayson *et al.*, in press). The hydrodynamometer used in this study had previously been used to test military recruits (Grieve, 1993, Duggan and Legg, 1993), and it was therefore included in the pilot study as a possible predictor of task performance (Rayson *et al.*, 1995, Rayson *et al.*, in press). The decision was made to include the hydrodynamometer in a cross-sectional study of experienced soldiers in a wide range of military occupations. The purpose of this phase of the study was to determine which tests were the best predictors of performance of 'Representative Military Tasks'. The final phase of the project was a longitudinal study, using a reduced number of tests, of the effect of Basic Training on the performance on the tests of new recruits. For reasons of cost and mechanical complexity the hydrodynamometer was excluded from this final phase of the CHS project (Rayson *et al.*, 1996, Rayson, 1997).

It was fortuitous that the opportunity to include the hydrodynamometer in the pilot and cross-sectional phases of the CHS project arose. It provided access to large numbers of physically fit males and females to act as subjects.

4.2 Methods / study design

4.2.1 Subjects

The 'gender-free' study was designed to be a cross-sectional study of serving military personnel across the range of specialities in the British Army. The study design and methods have been reported by Rayson and Holliman (1995), from where much of the following information is extracted. The purpose of Rayson and Holliman (1995) was to report on the prediction of task performance of trained soldiers. Prior work (Rayson, 1998) had led to the identification of four generic criterion tasks or 'Representative Military Tasks' (RMTs) which covered the broad categories of physical tasks expected of trained soldiers. The RMTs consisted of a single lift (SL); a repetitive lift and carry (RL); a carry (C) and a loaded march (LM). Three performance standards were defined for each RMT with Level 1 being the most demanding, and Level 3 the least physically demanding. Each military specialisms was categorised by the combination of the different levels on the RMTs that reflected the physical demands of the tasks that such units are required to carry out.

Four groups of approximately 100 subjects were recruited to take part in the study. The units that the subjects in the different groups were drawn from are listed in Table 4.1:

Table 4.1: Units members of the different groups of subjects were drawn from

Group A	Royal Artillery
	Royal Armoured Corps
	Royal Engineers
Group B	Army Air Corps
	Royal Electrical and Mechanical Engineers
	Royal Army Medical Corps
	Royal Army Dental Corps
Group C	Royal Signals
	Royal Logistic Corps
	Adjutant General's Corps
	Royal Army Veterinary Corps
	Intelligence Corps
	Queen Alexandra's Royal Auxiliary Nursing Corps
Group D	Infantry

Each group of subjects was tested at appropriate levels of the RMTs. Two groups (Group A, Group D) were drawn from units whose job requirements had been largely linked to Level 1 performance on the RMTs. One group (Group B) had jobs requiring performance at Level 2 on the RMTs, and one group (Group C) had jobs requiring performance at Level 3. The precise combinations of test carried out are listed in Table 4.2. Group C were measured at their own Level for the Repetitive lift (RL10) and also at the next higher Level (RL22).

Table 4.2: Levels of the different RMTs carried out by the groups of subjects

RMT	Group A	Group B	Group C	Group D
Single lift (SL)	---	SL	SL	SL
Repetitive lift (RL)	RL44	RL22	RL10 / RL22	---
Carry (C)	C	C	C	---
Loaded march (LM)	LM20	LM20	LM15	LM25

The whole study had been approved by the Ethics Committee of the Centre for Human Sciences. Prior to testing all subjects received a detailed briefing as to the purpose and nature of the study and completed consent forms. All subjects were medically screened prior to participation in the study. Subjects wore civilian PT clothing during all fitness testing and appropriate military clothing while performing the RMTs. Soldiers were asked to perform all tasks to their individual safe maximum.

4.2.2 The test battery

The single lift involved progressive maximal lifting of a weighted ammunition box from the ground to two heights (1.7 m and 1.45 m). Subjects were advised on safe lifting techniques, but essentially the lift was freestyle. Subjects first attempted a load of

10 kg, and after each successful attempt 5 kg (or 4 kg after 40 kg) were successively added to the box until the subject could not safely achieve the lift within a ten second time frame, or until a maximum load of 72 kg had been achieved. An upper weight limit of 72 kg was set due to the limiting size of the ammunition box. The maximum successful load was recorded as the score.

The carry required subjects to walk up and down a 30 m course at a prescribed pace of 5.4 km/hr, carrying two fuel cans (20 kg each) for as long as possible. There were few rules, other than maintaining the prescribed pace and carrying the cans in a conventional manner. The test was continuous and no rest was allowed. The maximum duration that the subjects managed to achieve constituted the score.

The repetitive lift required subjects to lift a weighted ammunition box (10 kg, 22 kg, or 44 kg depending on role) at a prescribed rate (6, 3 or 1 shuttles per minute according to role), and carry it 10 m to and from a platform of 1.45 m for a maximum of one hour. Subjects were advised on safe lifting techniques, but essentially the manoeuvre was freestyle. The maximum duration that subjects managed to achieve, up to a maximum of 60 minutes, constituted the score.

For the loaded march subjects were required to complete a 12.8 km course as quickly as possible, with (according to role) a 15 kg, 20 kg or 25 kg backpack (Bergen). Subjects were advised to pace themselves sensibly.

All subjects were also tested using a battery of Physical Selection Tests over a three day period. Each group of subjects was subdivided into groups of approximately 15. Each subject was issued with a numbered bib for ease of identification. Each subgroup arrived at the gymnasium where testing was occurring at hourly intervals but always at the same time on each day. On arrival, they were all put through a warm-up routine, were further subdivided into groups of three or four, and over a period of approximately one hour were rotated through a series of test / measurement stations. The aim of the study was to collect all measurements from all of the subjects, and all subjects in each Group were tested in the course of one day. Anthropometric measurements taken included height in cm, body mass in kg and biceps, triceps, subscapular and supra-iliac skinfolds thicknesses in mm. These skinfolds were used to estimate body fat mass using the equations of Durnin and Womersley (1973) and hence lean body mass (fat-free mass).

The Incremental Lift Machine (ILM) (McDaniel *et al.*, 1983) formed one test station. The maximal weights that subjects could lift to 1.7 m and 1.45 m were determined using an incremental protocol. Subjects stood on the ILM platform with feet shoulder width apart, grasped the handles of the load carriage with palms down, arms straight, knees bent and back as straight as possible and lifted the handles until they passed a mark at 1.7 m. No restrictions were placed on the lifting technique used. The initial weight of the carriage was 90 lb. After each successful lift the weight was increased by 10 lb, up to a maximum of 200 lb, and the lift was repeated until the subject chose to stop or failed to reach 1.7 m. After the last unsuccessful lift the weight was reduced by 5 lb and the lift repeated. The score recorded was the greatest weight successfully lifted. After a one-minute rest the subject attempted the last unsuccessful weight to a height of 1.45 m and continued until failure at that height.

4.2.3 Repeatability study

On a later occasion, the Group C subjects returned for a further day of testing which was used to take repeated measures on all the tests to enable their reliability to be assessed. The group of subjects was split into four subgroups, each of which performed a quarter of the original tests.

4.2.4 Hydrodynamometer test protocol

Data were collected using the hydrodynamometer described in Chapter 3.3.2, the instrumentation described in Chapter 3.3.3, and the computer hardware described in Chapter 3.3.5, with the methodology of Chapter 3.3.6.

The principle of the hydrodynamometer was explained to each small group of subjects, and the device demonstrated. The need for a change of grip was mentioned. Subjects were instructed that they should start with an overhand grip and pull as hard and as fast as possible on the handle from the start height to at least 2 m high. A marker was placed on the rope which would pass another marker when the handle reached 2 m. They were told to stand on the base-board of the device with their toes on the marked line. They were told to remain on the base-board during the lift, but this was not rigorously enforced, and some stepped back part way through the lift. They were told that when they had finished the lift they should keep hold of the handle and allow the weight to lower the piston through the water.

Each subject was allowed to practice the lift at a relatively slow speed to 'get a feel for' the device and to enable them to realise the need to change grip. Each subject then took it in turns to perform lifts on the device until each one had performed two maximal lifts. This procedure ensured that subjects had a chance to rest briefly between maximal exertions. Two pulls were performed because it was known that performance tended to improve, and the subjects were not familiar with the device. Because of this effect, which was assumed to be a learning effect, it was expected that only data from the second pull would be used. Only two pulls were permitted because of the need to complete testing of each sub group of four subjects within 15 minutes.

4.2.5 Data collected

Of the 379 subjects (304 males, 75 females) who were entered into the cross-sectional phase of the Gender-free trials, hydrodynamometer data were collected from 320 (249 males, 71 females). Due to equipment problems the data from all Group A subjects were either lost or unusable . Other data were lost due to subjects withdrawing for a variety of reasons or operator error. Usable hydrodynamometer data were obtained from 287 subjects. The data that were utilised were from the second pulls that subjects performed only, which were from 270 subjects (201 males and 69 females). Repeatability data for the hydrodynamometer were collected from 21 subjects (11 males and 10 females) from Group C. The subject numbers are summarised in Table 4.3.

Table 4.3: Numbers of males and females in the different Groups with usable hydrodynamometer data and usable data from second pulls

	Males			**Females**		
	All	**Usable**	**2nd pulls**	**All**	**Usable**	**2nd pulls**
Group A	76	0	0	4	0	0
Group B	69	64	51	22	21	21
Group C	55	54	54	49	48	48
Group D	104	100	96	0	0	0
Totals	304	218	201	75	69	69

4.2.6 Data processing

The correction for the deflection of the cantilever as the force in the rope increased was made after all data had been collected. Anthropometric data for the subjects and performance data on the RMTs and the Physical Selection Tests were made available. Each lift on the hydrodynamometer was characterised as a series of 'Events' and a series of mean values over various 'Ranges' of lift. Data analysis was carried out using Statgraphics Plus v5.22 (Statgraphics Inc.), a statistical software package which runs under DOS on an IBM compatible PC. Graphical output from Statgraphics was exported as CGM files which were then converted to the Acorn Draw format using a utility called CGM->Draw. Tabulated output was exported as text files.

4.2.7 Identification of 'Events' during a dynamic lift

Following the example set by Canadian studies of the ILM (Stevenson *et al.,* 1990a, Bryant *et al.,* 1990) distinct 'Events' were identified which occurred during the course of lifts on the hydrodynamometer. The Events consisted of fixed hand heights and maxima and minima in the force, velocity and power curves. A computer algorithm was used to scan through the force data to identify either the maximum or minimum between limits which were expected to lie either side of the Event of interest. The corresponding Events in the velocity and power data were identified as the maximum or minimum values, as appropriate, within 40 samples (approximately 11.1 mm rope travel) either side of the Event in the force curve. Each set of graphs was then displayed on the computer screen to allow visual checking of the Event locations. Where an Event had been incorrectly located, the computer mouse was used to identify the region of the true location and the largest, or smallest as appropriate, value within 40 samples either side of the mouse location was returned as the new Event location.

The chosen Events are listed in Tables 4.4 and 4.5 and are marked on an example set of output graphs reproduced in Figure 4.1. It must be realised that, because of differences between individuals in terms of lifting style, not all Events occurred in all lifts.

Table 4.4: Event numbers for landmark heights

Event type	Event number
Handle height of 0.7 m	1
Handle height of 1.0 m	2
Handle height of 1.45 m	3
Handle height of 1.7 m	4

Table 4.5: Event numbers for maxima and minima of the different performance measures

Event type	Force	Velocity	Power
First peak below 0.9 m	5	12	19
Next dip below 0.9 m	6	13	20
Next peak below 0.9 m	7	14	21
First grip change below 1.7 m	8	15	22
Largest peak after (8), before any subsequent grip change	9	16	23
Second grip change below 1.7 m	10	17	24
Largest peak below 1.7 m following second grip change	11	18	25

Figure 4.1 illustrates the fact, discussed in Chapter 3, that force, velocity and power at any instant are all mathematically related to each other, and shows that Events 5, 12 and 19; 6, 13 and 20; 7, 14 and 21; 8, 15 and 22; 9, 16 and 23, 10, 17 and 24; and 11, 18 and 25 are all closely related to each other in time, if not actually co-instantaneous. The Events defined in Table 4.5 could therefore, in principle, be reduced to only seven. By contrast the inertial characteristics of the ILM result in peak force and peak velocity being separate in time because peak velocity occurs at zero acceleration.

4.2.8 Definition of 'Ranges' of a dynamic lift

In addition to the Events defined as per the Canadian ILM studies, mean values over various ranges were also calculated. These are defined in Table 4.6.

Table 4.6: Numbers allocated to means of various Ranges

Range	Mean force	Mean velocity	Mean power	Mean work	Mean impulse
0.4 m - Event (8)	26	40	54	68	82
0.4 m - Event (10)	27	41	55	69	83
0.4 m - 1.45 m	28	42	56	70	84
0.4 m - 1.7 m	29	43	57	71	85
0.7 - 1.0 m	30	44	58	72	86
0.7 m - Event (8)	31	45	59	73	87
0.7 m - Event (10)	32	46	60	74	88
0.7 m - 1.45 m	33	47	61	75	89
0.7 m - 1.7 m	34	48	62	76	90
Event (8) - Event (10)	35	49	63	77	91
Event (8) - 1.45 m	36	50	64	78	92
Event (8) - 1.7 m	37	51	65	79	93
Event (10) - 1.45 m	38	52	66	80	94
Event (10) - 1.7 m	39	53	67	81	95

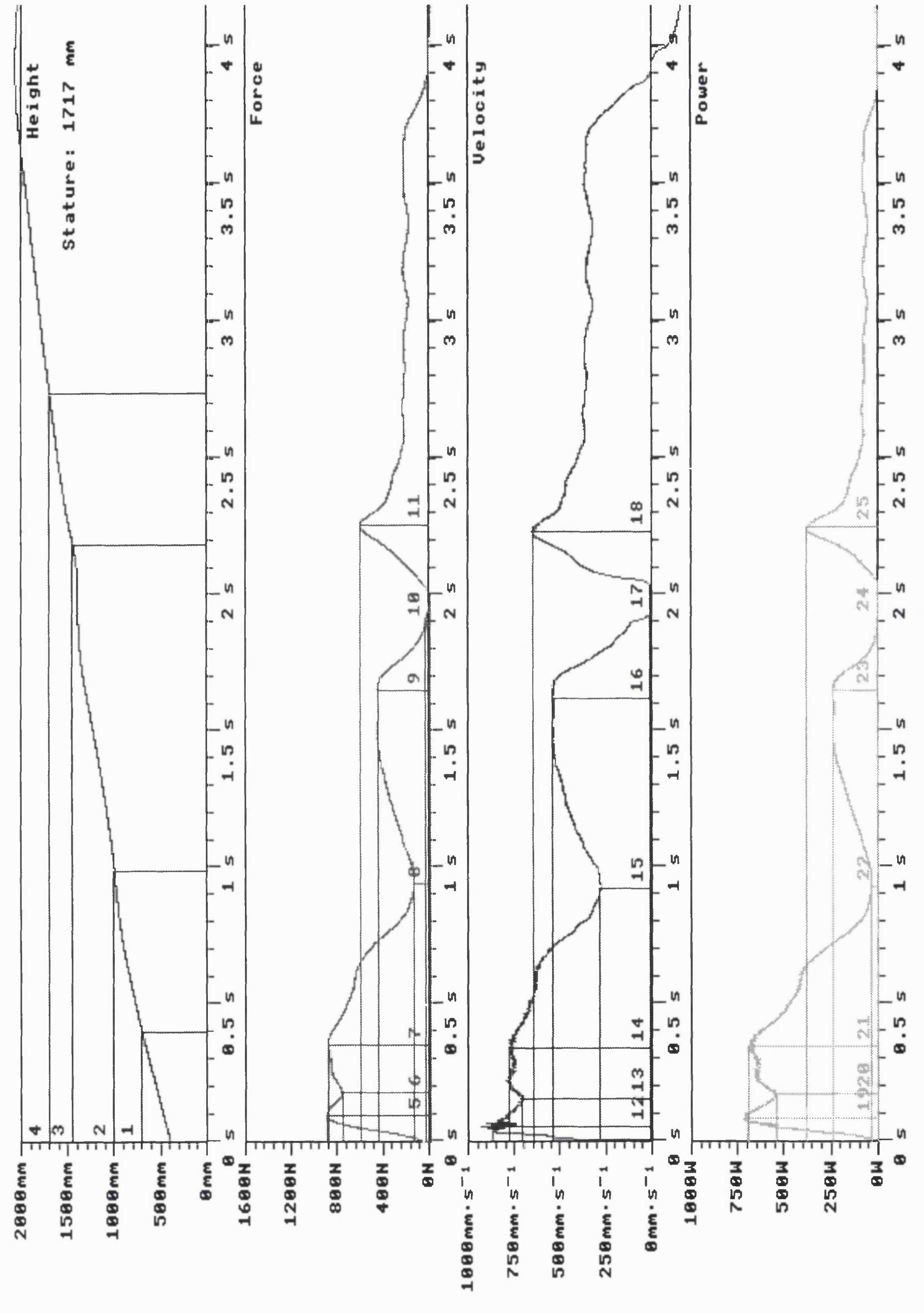


Figure 4.1: Screen grab of display showing displacement, force, velocity and power, with times and magnitudes of 'Events' identified

The different heights used to define the Ranges were chosen for a variety of reasons. The 0.4 m height is the starting height of the exertion; the 1.45 and 1.7 m heights were chosen because they had already been chosen as target heights for the Single Lift RMT and for lifts on the ILM. This enabled comparisons to be made between performance in other modalities of lifting test, such as the ILM and maximal box lifting, and performance on the hydrodynamometer. The 0.7 to 1.0 m Range was chosen because early work using the hydrodynamometer (Grieve, 1993, Duggan and Legg, 1993) had measured mean power output between these heights. Events (8) and (10) were chosen because they represented distinct points in the output curves where velocity, and hence force and power, effectively dropped to zero, thus allowing the lifting range to be separated into discreet performance zones.

4.3 Results

4.3.1 Anthropometric characteristics of subjects

Table 4.7 summarises the anthropometric data collected from the 270 subjects from whom usable data from their second pulls on the hydrodynamometer were obtained.

Table 4.7 shows that the male sample was normally distributed with regard to height and fat-free mass, but not body mass. The female sample was normal with respect to stature and body mass, but not fat-free mass. Both distributions were positively skewed with regard to isometric lifting strength at 850 mm and age, indicating long tails of more than expected stronger individuals and older individuals in the distributions. The male distribution of isometric strength and both age distributions were also positively kurtic, (leptokurtic) indicating that the distributions were more peaked than a normal distribution, i.e. more individuals than expected were near the mean.

Comparison of height and weight shows that the male subjects matched the British male population exactly on mean height but had a slightly smaller coefficient of variation. Females were 15 mm taller than the population, though this was not statistically significant. On body mass, both genders matched the population to within 1 kg.

Table 4.7: Characteristics of 201 males and 69 females whose hydrodynamometer data were used, with stature of British adults aged 19-25, and body mass of British adults aged 19-65 (Pheasant, 1986)

Variable:	**Stature (mm)**			**Body mass (kg)**		
Gender	**All**	**Males**	**Females**	**All**	**Males**	**Females**
Sample size	270	201	69	270	201	69
Mean	1728.2	1760.0	1635.5	71.0	74.1	62.1
Std. deviation	83.3	62.3	65.7	11.1	10.4	7.6
Minimum	1482	1579	1482	49	50	49
Maximum	1916	1916	1845	112	112	81
Std. skewness	-2.602	-1.252	1.169	3.883	3.720	1.883
Std. kurtosis	-0.974	0.161	0.885	1.521	1.921	-0.394
GB mean		1760	1620		75	63
GB std. dev.		73	61		12	11
Variable:	**Fat-free mass (kg)**			**Isometric strength @ 850 mm (N)**		
Gender	**All**	**Males**	**Females**	**All**	**Males**	**Females**
Sample size	270	201	69	270	201	69
Mean	55.4	59.9	42.2	1299.4	1469.7	801.4
Std. deviation	9.6	6.2	3.8	438.3	351.2	244.3
Minimum	35.0	42.8	35.0	245.3	686.0	245.0
Maximum	78.5	78.5	54.3	2943.0	2943.0	1510.0
Std. skewness	-1.666	1.649	2.905	2.537	5.892	2.397
Std. kurtosis	-2.273	1.071	2.117	2.072	6.106	1.300
Variable:	**Age (years)**					
Gender	**All**	**Males**	**Females**			
Sample size	270	201	69			
Mean	23.97	23.97	23.99			
Std. deviation	4.61	4.83	3.91			
Minimum	18	18	19			
Maximum	41	41	40			
Std. skewness	8.041	6.758	4.493			
Std. kurtosis	4.880	3.339	4.912			

4.3.2 Correlation between anthropometric variables

Table 4.8 gives the matrix of correlation coefficients of the measures of stature, body mass, fat-free mass and isometric lifting strength at 850 mm.

Table 4.8: Correlations between the anthropometric characteristics of the 270 subjects whose hydrodynamometer data were utilised

	Stature	**Body mass**	**Fat-free mass**
Body mass	0.6331		
Fat-free mass	0.8093	0.8425	
Isometric strength at 850 mm	0.7497	0.6824	0.8080

4.4.3 Correlations of measures of different Ranges

Appendix 6 contains a full correlation matrix of the values obtained from the different Ranges. Since not all Events occurred in all pulls, missing values were eliminated pairwise when calculating the correlation coefficients. Values greater than +0.7 and -0.7 were marked and, where possible grouped, to show where common variance of greater than 49% occurs. The ways in which the Range variables formed groups are shown in

Table 4.9. Relationships between variables are considered further in Chapter 7, where Principal Components Analysis is used to explore them more formally.

In Table 4.9 correlations between the different measures over a single Range are high because all the measures are functions of force; the Ranges in Group 1 overlap to a great extent, causing the measurements to correlate very highly; the measurements between the first change of grip and 1.7 m overlap to a greater or lesser extent with the other measurements in group 2; and in groups 3 and 4 measurements from either the first or second change of grip to 1.45 and 1.7 m overlap and therefore correlate.

Table 4.9: Groups of highly related Range variables on a hydrodynamometer pull

Group 1

Range	Mean force	Mean velocity	Mean power	Mean work	Mean impulse
0.4 m - Event (8)	26	40	54	68	82
0.4 m - Event (10)	27	41	55	69	83
0.4 m - 1.45 m	28	42	56	70	84
0.4 m - 1.7 m	29	43	57	71	85
0.7 - 1.0 m	30	44	58	72	86
0.7 m - Event (8)	31	45	59	73	87
0.7 m - Event (10)	32	46	60	74	88
0.7 m - 1.45 m	33	47	61	75	89
0.7 m - 1.7 m	34	48	62	76	90

Group 2

Range	Mean force	Mean velocity	Mean power	Mean work	Mean impulse
Event (8) - 1.7 m	37	51	65	79	93
with					
0.4 m - Event (10)	27	41	55	69	83
0.4 m - 1.45 m	28	42	56	70	84
0.4 m - 1.7 m	29	43	57	71	85
0.7 m - Event (10)	32	46	60	74	88
0.7 m - 1.45 m	33	47	61	75	89
0.7 m - 1.7 m	34	48	62	76	90
Event (8) - Event (10)	35	49	63	77	91
Event (8) - 1.45 m	36	50	64	78	92

Group 3

Range	Mean force	Mean velocity	Mean power	Mean work	Mean impulse
Event (8) - 1.45 m	36	50	64	78	92
with					
Event (8) - 1.7 m	37	51	65	79	93

Group 4

Range	Mean force	Mean velocity	Mean power	Mean work	Mean impulse
Event (10) - 1.45 m	38	52	66	80	94
with					
Event (10) - 1.7 m	39	53	67	81	95

CHAPTER 5

DYNAMIC LIFTING AS MEASURED USING THE HYDRODYNAMOMETER

5.1 Introduction

With a device such as the hydrodynamometer which measures lifting actions over the range from below knee height to above head height, and especially when accurate force, displacement and time data have been collected from a large number of subjects, it is possible to examine many hypotheses about dynamic lifting. The purpose of this chapter is to examine a selection of these questions in detail, especially in the light of previous work which has been carried out. The question of gender differences throughout the lift and the factor structure underlying dynamic lifting exertions are dealt with in the following two chapters. The questions dealt with in this chapter fall into the following areas:

1: What is a typical or mean lift on the hydrodynamometer?

2: What is the relationship between performance in the early and the later parts of a lift on the hydrodynamometer? How does this relate to previous work on lifting strength and guidelines for the design of tasks?

3: Does the hydrodynamometer distinguish between the subjects from different Groups and hence between soldiers who perform different jobs?

4: What are the relationships between performance on the Incremental Lift Machine (ILM), maximal box lifting performance and performance on the hydrodynamometer?

5: Where does the peak lifting force occur on the hydrodynamometer? Does it occur at a constant proportion of stature?

6: Why do some subjects exhibit a double peak in the very early stages of the lift? Is this a function of the individual or of the device?

7: Why do some subjects perform a double grip change when the majority performed a single grip change? How does this affect performance?

8: What gender differences exist in the levels of maximal exertion recorded?

5.2 Methods

Because of the known (Chapter 3) warming up effect on the device, the data collected during second pulls were used to ensure that maximal values were obtained. Appropriate variables were extracted from the data set in order to test the hypotheses of interest. The variables analysed and the statistical tests used will be described in the appropriate parts of the results / discussion section.

5.3 Results / discussion

5.3.1 The mean lift on the hydrodynamometer

In order to describe the typical or mean lift on the hydrodynamometer, descriptive statistics were calculated for the measures of height, time, force, velocity and power for all 25 Events. Descriptive statistics were also calculated for force, velocity, power, work and impulse over the 14 different Ranges. This was done for the complete set of 270 subjects and separately for the 201 males and 69 females. These full summary data for each Event and each Range are recorded in Appendix 1, Tables A1.1 to A1.39.

Table 5.1: Numbers of males and females recording the different Events

Event	All	Males	Females
Event 1 2 3 4	270	201	69
Event 5 12 19	129, 132, 131	116, 118, 117	13, 14, 14
Event 6 13 20	129, 132, 131	116, 118, 117	13, 14, 14
Event 7 14 21	270	201	69
Event 8 15 22	269	201	68
Event 9 16 23	269	201	68
Event 10 17 24	74	56	18
Event 11 18 25	74	56	18

Since the style of lifting varied between individuals, different numbers of subjects recorded the different Events. Table 5.1 shows how these numbers varied.

It was felt that it was most useful to describe the mean lift on the hydrodynamometer in terms of power output at each Event and the height and time of each Event. This meant that data from Events 1-4 and 19-25 was used for these purposes. Figure 5.1 shows mean power ± 1 standard deviation for each Event for males and females. For Events 1 - 4 these occurred at fixed heights. Events 19-25 occurred at variable heights. Therefore the mean and standard deviation for each power value is plotted on the vertical axis at the mean height for the Event, and the mean ± 1standard deviation of each of these heights is plotted horizontally. Tables 5.2 and 5.3 list, for males and females, the means ± 1 SD for the heights of the Events and the times at which they occurred.

The complete lift to 1.7 m took on average 2.874 s (SD 0.520 s), at an average force of 492 N (SD 121 N) and a mean velocity of 0.542 $m{\cdot}s^{-1}$ (SD 0.079 $m{\cdot}s^{-1}$), producing a mean power output of 315 W (SD 114 W), with the mean work done being 643 J (SD 157 J) and the mean impulse being 1087 N·s (SD 127 N·s). The fastest subject (a male) completed the lift in 1.980 s, whereas the slowest (a female) took 5.221 s. Males reached the 1.7 m height significantly faster than females, with a mean of 2.630 s (SD 0.248 s) as opposed to a mean of 3.586 s (SD 0.444 s), two sample t-test, t = 22.1062, $p = 0.00000$.

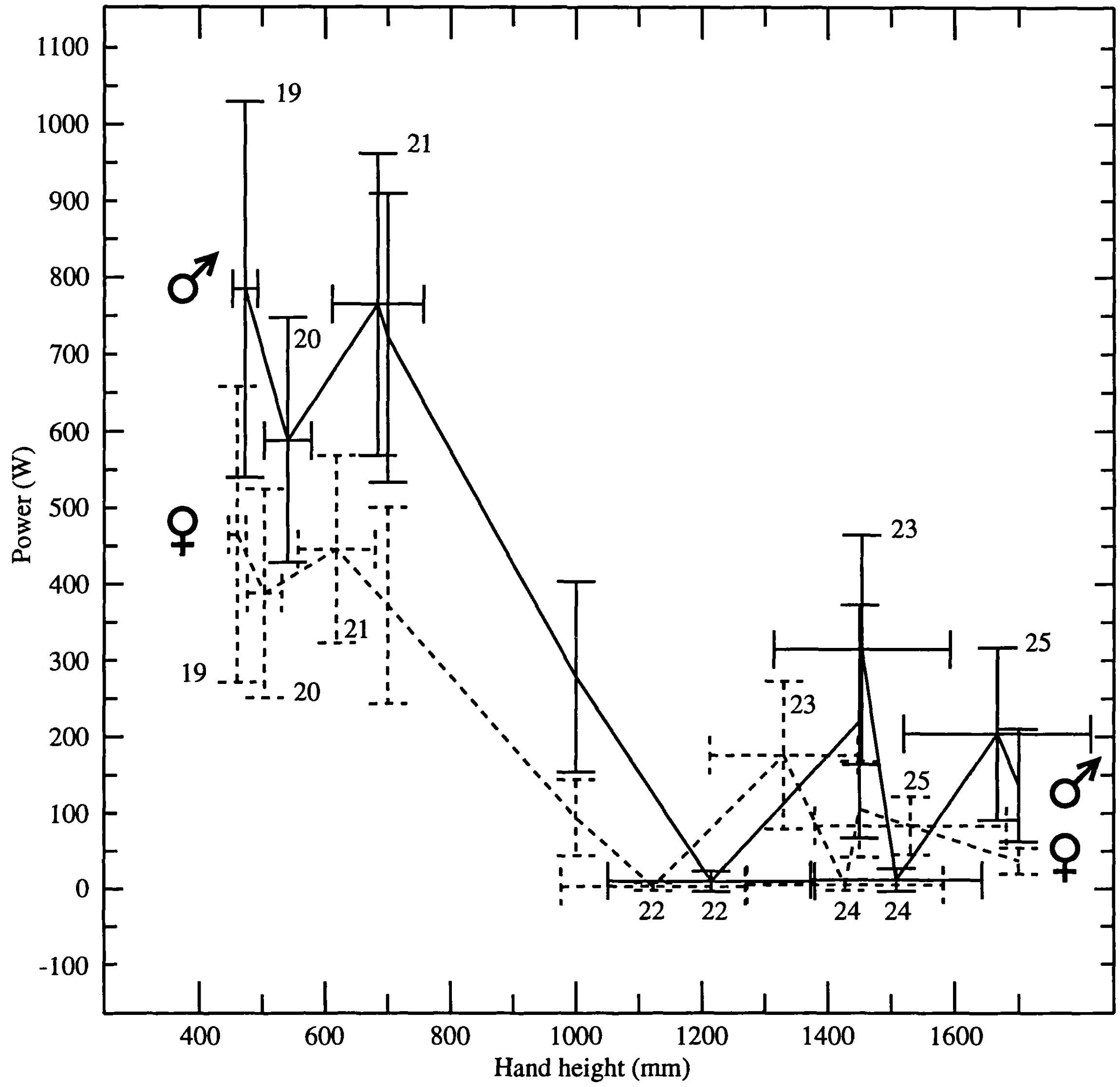


Figure 5.1: Mean powers ± 1 standard deviation for males and females at hand heights of 0.7, 1.0, 1.45 and 1.7 m (Events 1-4) and Events 19-25. Mean hand heights ± 1 standard deviation are shown for Events 19-25

Table 5.2: Heights and times of power related Events of the mean male lift

Event	n	Height (Mean ± SD)		Time (Mean ± SD)	
		mm	% stature	s	% to 1.7 m
0.7 m height	201	700±0	39.8±1.4	0.414±0.047	15.8±1.5
1.0 m height	201	1000±0	56.9±2.0	0.885±0.120	33.7±3.7
1.45 m height	201	1450±0	82.5±3.0	2.054±0.215	78.2±4.5
1.7 m height	201	1700±0	96.7±3.5	2.630±0.248	100.0±0.0
Initial peak (19)	118	472±20	26.8±1.3	0.099±0.033	3.9±1.4
Dip after initial peak (20)	117	541±38	30.7±2.2	0.189±0.045	7.4±2.0
Main peak (21)	200	684±73	38.9±4.0	0.391±0.107	15.0±4.2
First grip change (22)	201	1215±164	69.1±9.1	1.435±0.362	54.9±14.3
Peak after 1st grip change (23)	201	1454±140	82.6±7.4	2.062±0.347	78.9±13.9
Second grip change (24)	56	1508±135	85.9±7.8	2.183±0.338	80.8±13.2
Peak after 2nd grip change (25)	56	1667±147	95.0±8.8	2.680±0.433	98.9±15.2

Table 5.3: Heights and times of power related Events of the mean female lift

Event	n	Height (Mean ± SD)		Time (Mean ± SD)	
		mm	% stature	s	% to 1.7 m
0.7 m height	69	700±0	42.9±1.71	0.508±0.058	14.3±1.54
1.0 m height	69	1000±0	61.2±2.44	1.210±0.225	33.9±5.30
1.45 m height	69	1450±0	88.8±3.54	2.729±0.323	76.2±3.26
1.7 m height	69	1700±0	104.1±4.15	3.586±0.444	100.0±0.00
Initial peak (19)	14	460±14	27.8±1.03	0.098±0.019	2.9±0.81
Dip after initial peak (20)	14	503±28	30.5±2.08	0.163±0.023	4.9±0.94
Main peak (21)	69	618±62	37.8±3.58	0.374±0.115	10.6±3.43
First grip change (22)	68	1123±147	68.6±8.52	1.652±0.407	46.5±11.7
Peak after 1st grip change (23)	68	1330±117	81.3±6.61	2.392±0.401	67.3±11.0
Second grip change (24)	18	1427±155	87.7±8.93	2.676±0.411	71.7±12.7
Peak after 2nd grip change (25)	18	1530±151	94.0±8.44	3.162±0.417	84.7±13.5

Table 5.4: Mean ± SD time differences (ms) between related force, velocity and power Events

Event	t(force) - t(velocity)	t(force) - t(power)	t(velocity)-t(power)
Initial peak (5,12,19)	43±14	10±9	-33±15
Dip after initial peak (6,13,20)	21±21	7±8	-14±22
Main peak (7,14,21)	21±31	7±19	-14±27
First grip change (8,15,22)	4±33	26±47	23±56
Peak after 1st grip change (9,16,23)	13±45	5±17	-8±42
Second grip change (10,17,24)	2±33	23±54	21±53
Peak after 2nd grip change (11,18,25)	20±38	4±12	-16±35

Table 5.5: Mean ± SD height differences (mm) between related force, velocity and power Events

Event	ht(force)-ht(velocity)	ht(force)-ht(power)	ht(vel.)-ht(power)
Initial peak (5,12,19)	36±13	8±7	-28±13
Dip after initial peak (6,13,20)	15±16	5±6	-10±17
Main peak (7,14,21)	16±24	5±13	-11±21
First grip change (8,15,22)	1±4	1±4	-1±4
Peak after 1st grip change (9,16,23)	7±26	3±10	-4±25
Second grip change (10,17,24)	1±5	1±5	0±3
Peak after 2nd grip change (11,18,25)	10±19	2±5	-8±18

The values of peak and minimum force, velocity and power which characterise the different Events occurred at slightly different times and hence heights. These differences will be functions of both measurement error and also of the hydraulic characteristics of the hydrodynamometer, in particular the turbulent nature of the fluid flow within it. In order to examine these differences the three different data sets were compared by calculating the difference in time and height for each Event from each possible pair of data sets. Table 5.4 lists the means and standard deviations of the time differences between force and velocity, between force and power, and between velocity and power. Table 5.5 lists the height differences for these three comparisons.

As can be seen from these tables, these Events are closely related in time and height, with differences in the order of tens of milliseconds and tens of millimetres. However, the velocity related Events systematically occurred before, and hence lower than, the power related Event,and the force related Events occurred last. This suggests that it is typical on this device for there to be a time lag between force application and a change in velocity. Obviously, power, as the product of force and velocity, will have averaged the difference between the two.

5.3.2 Power output in the early and later parts of the lift.

Relationship between mean power from 0.7 to 1.0 m and mean power to 1.45 / 1.7 m

An important issue, particularly in the light of earlier use of measurements of mean power over the range from 0.7 m to 1.0 m (Grieve, 1993; Duggan and Legg, 1993), is the relationship between performance in the later part of the lift and performance in the early part of the lift. Linear regression was used to investigate firstly whether it is possible to predict accurately mean power to 1.45 m or 1.7 m from mean power between 0.7 m and 1.0 m. Secondly, it was used to investigate the relationship between power before the first grip change and power above the first grip change.

The results of a linear regression of mean powers over the 0.7 m to 1.0 m range and the 0.7 m and 1.45 m range are shown in Tables 5.6 and 5.7 and Figure 5.2. This showed that over 87% of the variance in the mean power between 0.7 m and 1.45 m could be explained by the mean power over the first 300 mm of this range.

Linear regression of mean powers over the 0.7 m to 1.0 m and 0.7 - 1.7 m ranges showed that over 85% of the variance in the mean power between 0.7 m and 1.7 m could be explained by the mean power over the first 300 mm (Tables 5.8 and 5.9 and Figure 5.3).

Grieve (1993) had measured mean power over the 0.7 m - 1.0 m range because it included the height of maximum isometric lifting strength, because it was a region where the musculature was maximally activated, but was after the initial acceleration from rest, and before the "posturally awkward conditions at around shoulder height". This pair of results show that his assumption that power over this range could be used to characterise the whole-body dynamic lifting performance of an individual, is well founded since at least 85% of the variance in mean power of a lift to 1.7 m can be explained by mean power over the 300 mm range from 0.7 m to 1.0 m.

Relationship of mean powers below and above the first grip change

While the above analysis shows that mean power above 0.7 m is largely determined by mean power to 1.0 m it does not say anything about the relationship between mean power in non-overlapping ranges. Therefore a set of linear regression analyses were carried out. These examined the relationships of a) mean power below the first grip change and between the first and second grip changes (Tables 5.10 and 5.11 and Figure 5.4); b) mean power below the first grip change and between the first grip change and 1.7 m (Tables 5.12 and 5.13 and Figure 5.5); and c) mean power below the first grip change and between the second grip change and 1.7 m (Tables 5.14 and 5.15 and Figure 5.6). In interpreting these regressions it must be remembered that only 74 subjects changed grip twice while 269 changed grip at least once so that regressions involving the second grip change as a boundary are only based on 74 points instead of 269.

In regression (a) an R^2 value of only 37% was obtained. This means that while there is a relationship between power before the first grip change and between the first and second changes, the predictive power is fairly poor.

In regression (b) an R^2 value of 45% was obtained, meaning that less than half the variance in power output in a lift above the grip change can be accounted for by power below the grip change, i.e. the first half of a lift has less effect on the second half of a lift than do other factors. In other words power between 400 mm and 1215 mm (mean height of the first grip change), i.e. between 22.7% and 69.1% of stature, i.e. from below knee height to chest height) has less effect on power between 1215 and 1700 mm, i.e. 69.1% and 96.6% of stature, i.e. from chest height to head height than other factors do. This reflects the difference between an upward pulling exertion involving leg, back and arm strength and an upward pushing exertion largely involving the arms and supports the differentiation drawn by authors such as Chaffin (Chaffin and Anderson, 1991) between arm strength and other static measures of strength such as leg strength or composite strength.

In regression (c) an R^2 value of only 32% was obtained, showing that power output below the first grip change is a poor predictor of power output above the second grip change. Again this shows, as with the other two regressions, that the relationships between capacity in different parts of a lifting exertion are not strong, particularly when different muscle groups and actions are involve. Thus means that it would be unwise to attempt to predict lifting strength in one region from lifting strength in another region. This issue will be discussed further in Chapter 7 where Factor Analysis of the data is used to show that the different exertions carried out during the lift are effectively independent.

Table 5.6: Regression analysis: Mean power between 0.7 and 1.45 m = a + b × Mean power between 0.7 and 1.0 m

Parameter	Estimate	Standard error	t value	Probability
Intercept	47.1933	5.7611	8.192	0.00000
Slope	0.51939	0.01207	43.032	0.00000

Table 5.7: Analysis of variance of the above regression model

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Model	2646290.5	1	2646290.5	1852	0.00000
Residual	382986.92	268	1429.06		
Total (Corrected)	3029277.4	269			

Correlation coefficient = 0.93465; R^2 = 87.36%; Standard error of estimate = 37.8029

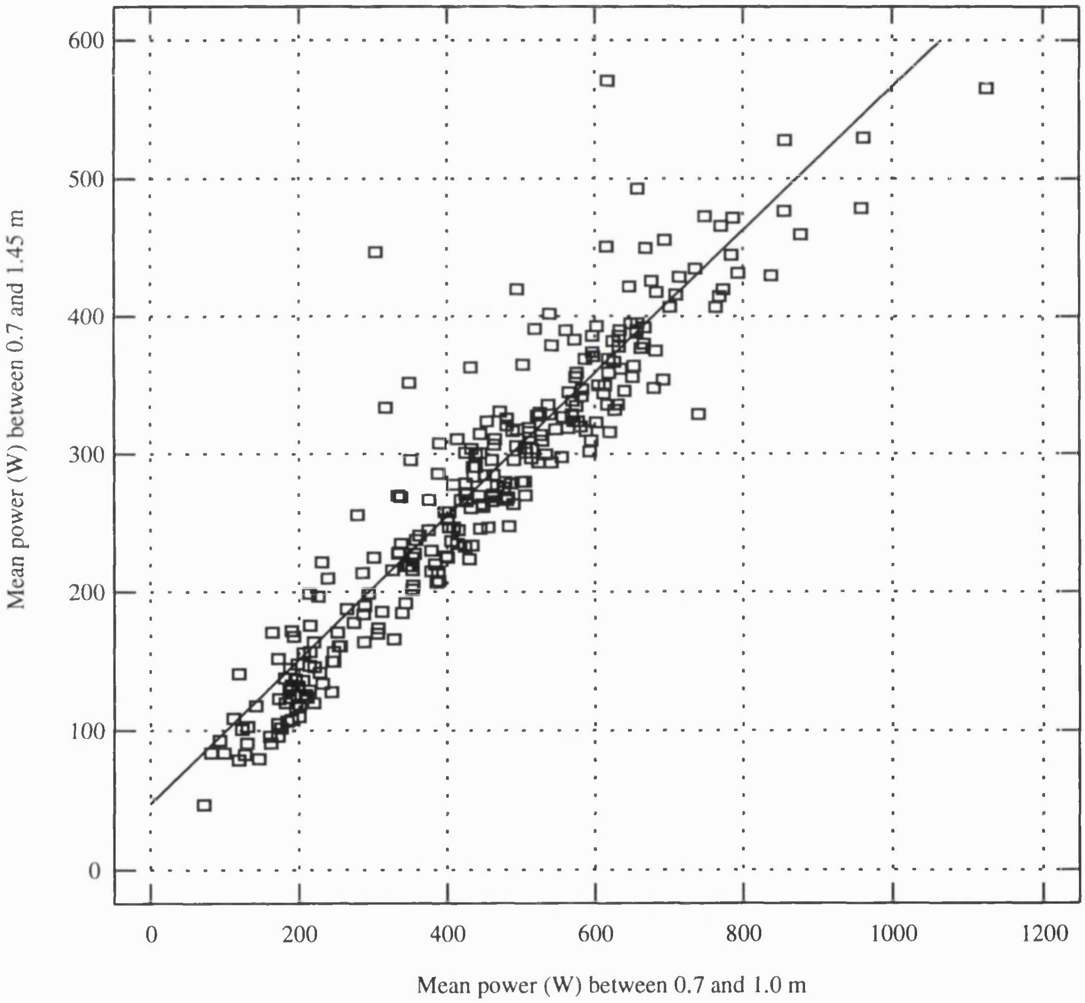


Figure 5.2: Regression of power between 0.7 m and 1.0 m on power between 0.7 m and 1.45 m

Table 5.8: Regression analysis: Mean power between 0.7 and 1.7 m = a + b × Mean power between 0.7 and 1.0 m

Parameter	Estimate	Standard error	t value	Probability
Intercept	32.9266	5.90882	5.573	0.00000
Slope	0.48812	0.0123793	39.430	0.00000

Table 5.9: Analysis of variance of the above regression model

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Model	2337215.0	1	2337215.0	1555	0.00000
Residual	402878.24	268	1503.28		
Total (Corrected)	2740093.3	269			

Correlation coefficient = 0.923563; R^2 = 85.30%; Standard error of estimate = 38.7721

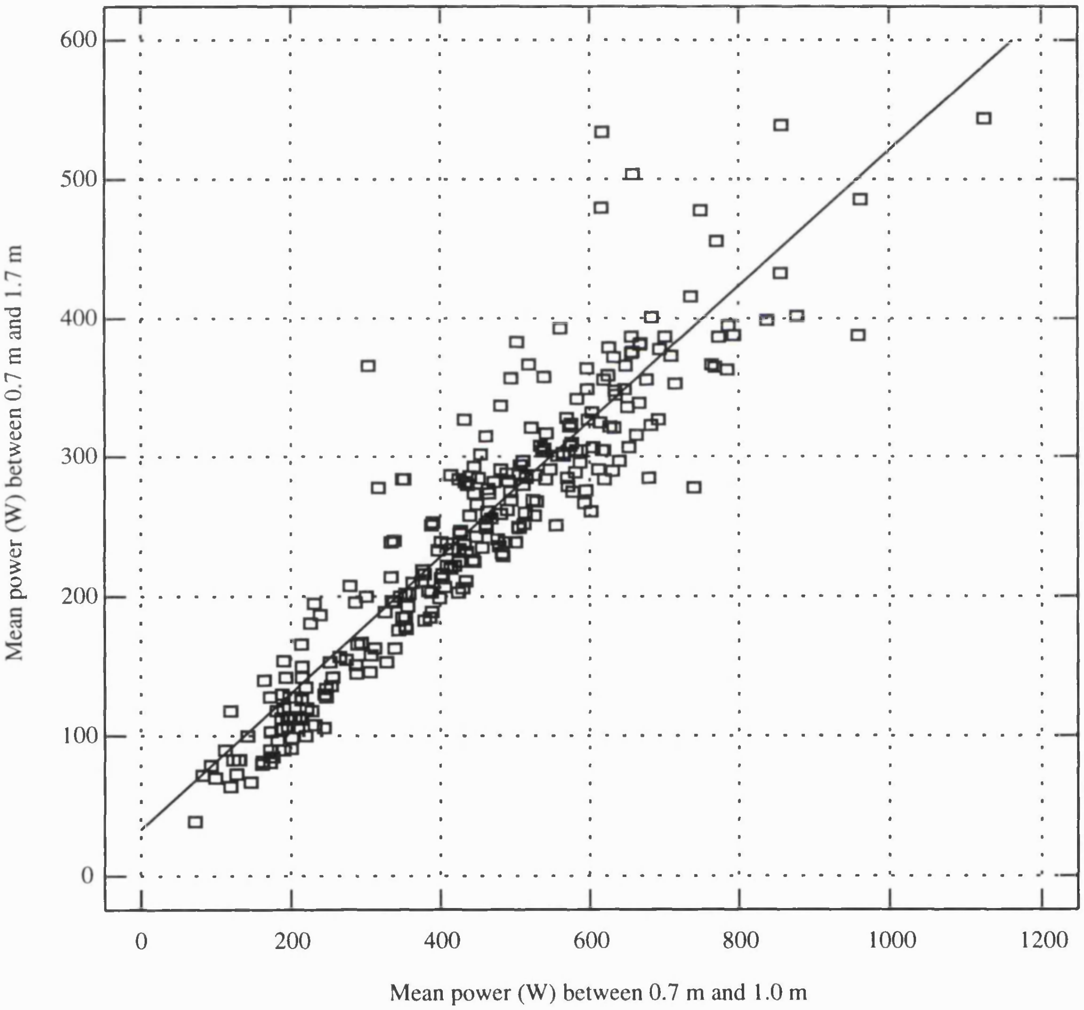


Figure 5.3: Regression of power between 0.7 m and 1.0 m on power between 0.7 m and 1.7 m

Table 5.10: Regression analysis: Mean power between first and second grip changes = a + b × Mean power between 0.4 m and first grip change

Parameter	Estimate	Standard error	t value	Probability
Intercept	3.204	24.002	0.133	0.89418
Slope	0.32605	0.05052	6.454	0.00000

Table 5.11: Analysis of variance of the above regression model

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Model	192645.07	1	192645.07	41.7	0.00000
Residual	332967.38	72	4624.55		
Total (Corrected)	525612.45	73			

Correlation coefficient = 0.605405; R^2 = 36.65%; Standard error of estimate = 68.004

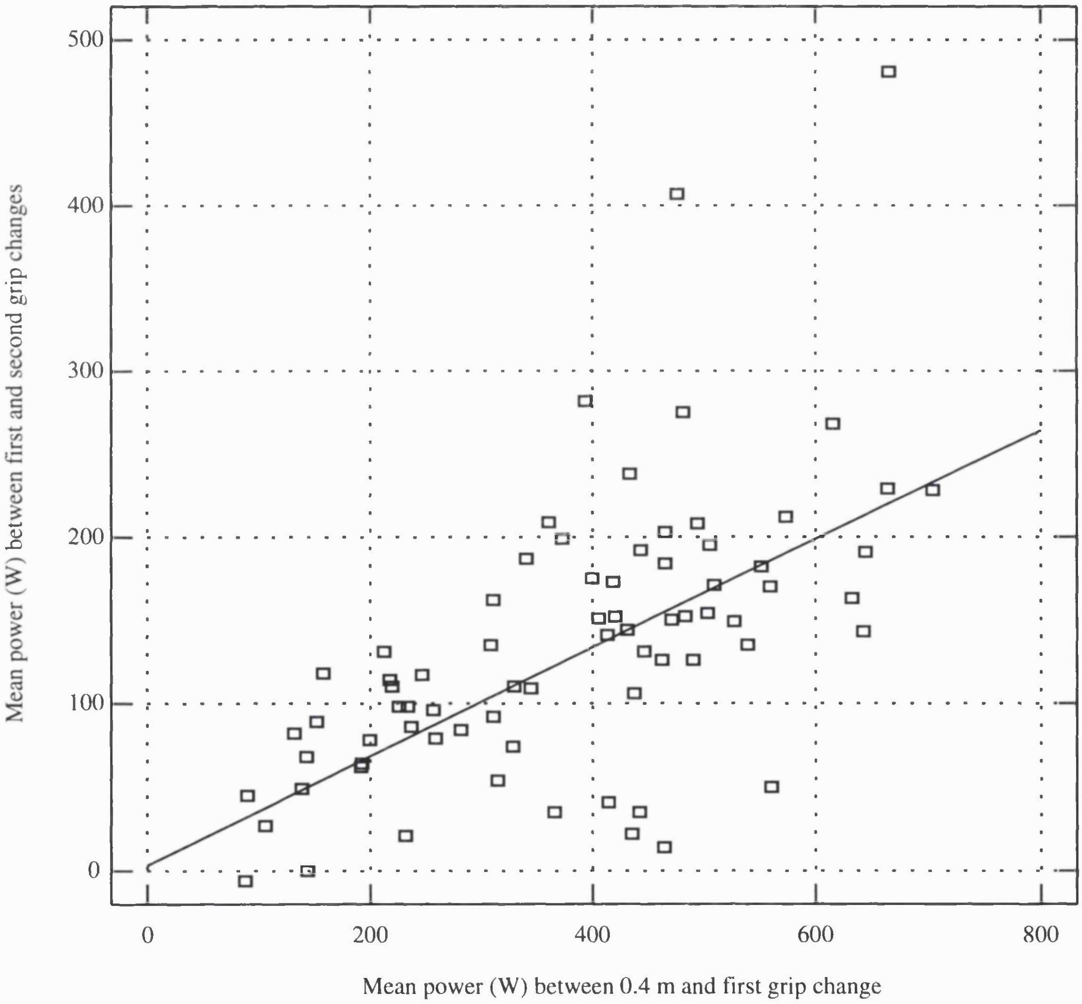


Figure 5.4: Regression of power below the first grip change on power between the two grip changes

Table 5.12: Regression analysis: Mean power between 0.4 m and the first grip change = a + b × Mean power between the first grip change and 1.7 m

Parameter	Estimate	Standard Error	t-value	Probability
Intercept	3.09401	11.7531	0.263	0.79256
Slope	0.395414	0.0268307	14.737	0.00000

Table 5.13: Analysis of variance of the above regression model

Source	Sum of Squares	D.F.	Mean Square	F-Ratio	Probablity
Model	905466.5	1	905466.5	217.2	0.00000
Residual	1104781.5	265	4169.0		
Total (Corrected)	2010248.0	266			

Correlation coefficient = 0.671137; $R^2 = 45.04\%$; Standard error of estimate = 64.5677

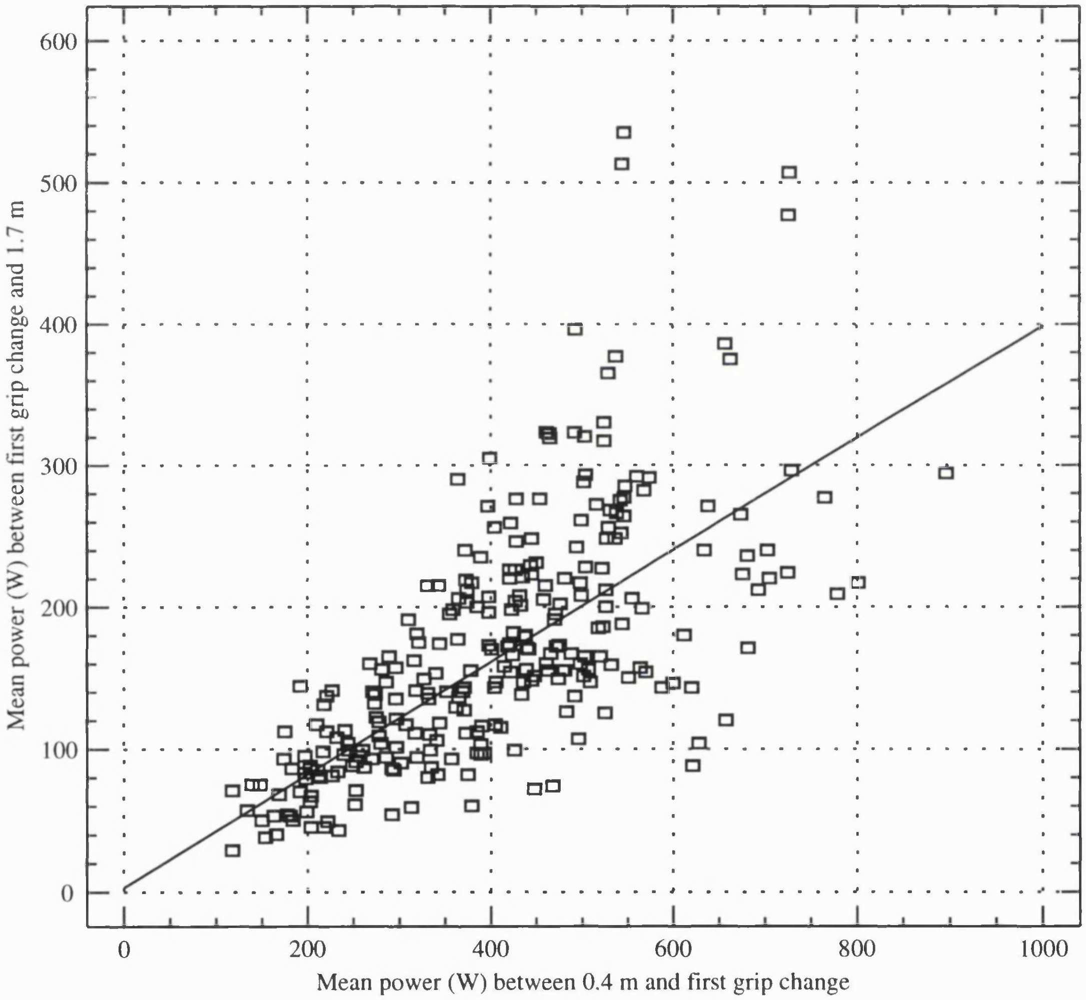


Figure 5.5: Regression of power below the first grip change on power between the first grip change and 1.7 m

Table 5.14: Regression analysis: Mean power between second grip change and 1.7 m = a + b × Mean power between 0.4 m and first grip change

Parameter	Estimate	Standard error	t value	Probability
Intercept	-10.2394	20.2334	-0.506	0.61447
Slope	0.24624	0.043398	5.674	0.00000

Table 5.15: Analysis of variance of the above regression model

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Model	102090.76	1	102090.76	32.2	0.00000
Residual	212467.88	67	3171.16		
Total (Corrected)	314558.64	68			

Correlation coefficient = 0.569695; R^2 = 32.46%;   Standard error of estimate = 56.3131

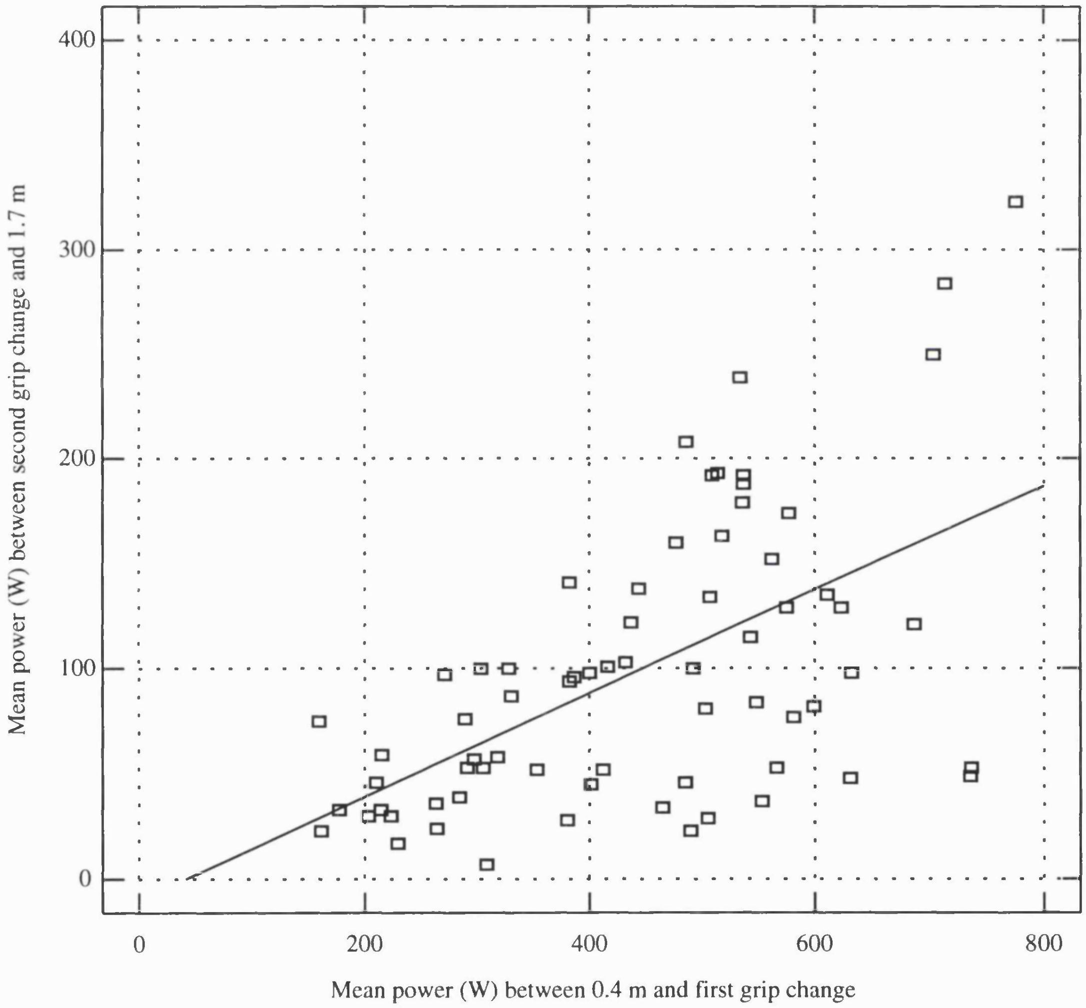


Figure 5.6: Regression of power below the first grip change on power between the second grip change and 1.7 m

5.3.3 Differences between subjects in the different Groups

As discussed in Chapter 4.2.1, subjects were recruited to the different Groups according to how the criterion levels of the RMTs reflected the differing physical requirements of their jobs. Given this, comparison of the performance of the different groups is of interest since demonstrable differences would both reflect on current recruitment practices and allow screening of workers to occur.

Mean power data between 0.7 and 1.0 m were used for these comparisons. Summary statistics for this are given in Appendix 2, Tables A2.1 to A2.17 for males, females and the mixed groups. As stated in Chapter 4, no usable hydrodynamometer data were collected for Group A. Group D were tested on the RMTs against the Level 1 criteria and contained no females. Groups B and C contained both males and females and were tested against the Level 2 criteria and the Level 3 criteria respectively. Therefore, because of the varying proportions of males and females within the groups, one-way analyses of variance were carried out for all subjects (Tables 5.16 and 5.17) and for males (Tables 5.18 and 5.19) and females (Tables 5.20 and 5.21) separately.

Table 5.16: One-way Anova of mean powers produced between 0.7 m and 1.0 m by Groups B, C and D

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability
Between groups	459720.5	2	229860.26	6.564	0.0016
Within groups	9349756.1	267	35017.81		
Total (corrected)	9809476.6	269			

Table 5.17: Mean powers produced between 0.7 m and 1.0 m by Groups B, C and D

Group	n	Mean (W)	95% Tukey HSD intervals	
B	72	461.708	424.955	498.461
C	102	385.088	354.209	415.967
D	96	475.323	443.494	507.152
All subjects	270	437.604	418.625	456.583

Comparison of the means across the Groups shows that as the physical demands of the job decreased, so did performance on the hydrodynamometer, i.e. Group D was more powerful than Group B, which was more powerful than Group C.

Table 5.18: One-way Anova of mean powers between 0.7 m and 1.0 m of males in Groups B, C and D

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability
Between groups	357947.2	2	178973.58	8.803	0.0002
Within groups	4025452.5	198	20330.57		
Total (corrected)	4383399.7	200			

Table 5.19: Means powers between 0.7 m and 1.0 m of males in Groups B, C and D

Group	n	Mean (W)	95% Tukey HSD intervals	
B	51	572.196	538.856	605.536
C	54	542.833	510.433	575.234
D	96	475.323	451.023	499.623
All males	201	518.040	501.246	534.834

Tables 5.18 and 5.19 show that the significant difference between groups obtained is, contrary to expectation, due to the males in Group D being the weakest group, and that the difference between males in Group B and Group C is non-significant.

Table 5.20: One-way Anova of mean powers between 0.7 m and 1.0 m of females in Groups B and C

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability
Between groups	2964.00	1	2964.0005	0.594	0.4518
Within groups	334344.20	67	4990.2120		
Total (corrected)	337308.20	68			

Table 5.21: Means powers between 0.7 m and 1.0 m of females in Groups B and C

Group	n	Mean (W)	95% Tukey HSD intervals	
B	21	193.381	171.631	215.131
C	48	207.625	193.239	222.011
All females	69	203.290	191.291	215.289

For females also, the difference between Group B and Group C was found to be non-significant ($p = 0.452$, Table 5.20). Comparison of the two genders (Tables 5.19 and 5.21) shows that males were very much more powerful than females, with a female : male ratio of means of 33.8% for Group B and of 38.2% for Group C. Figure 5.7 illustrates this.

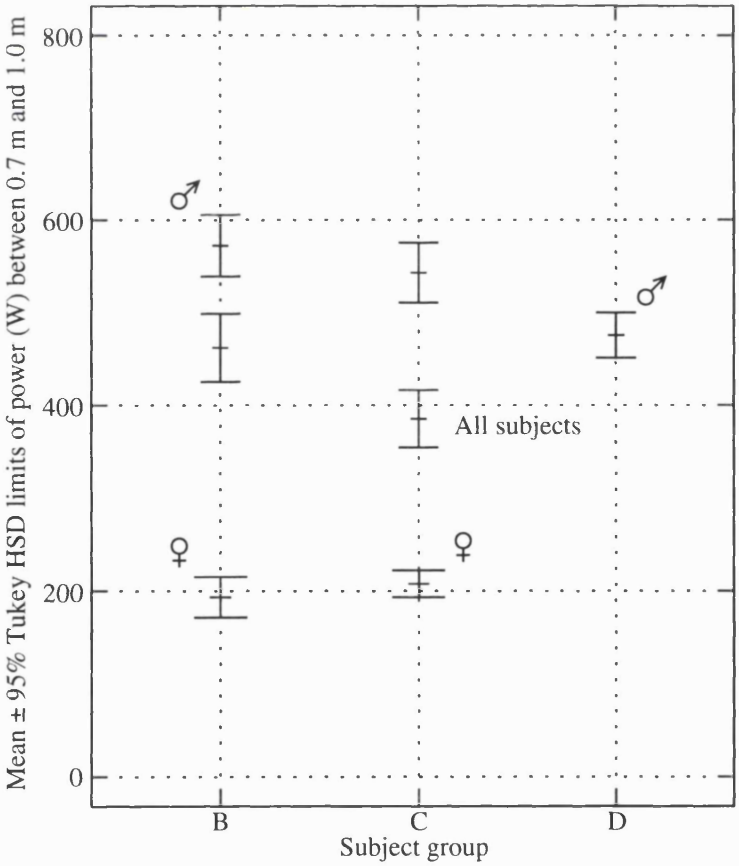


Figure 5.7: Mean powers, with 95% Tukey HSD intervals, between 0.7 m and 1.0 m of Groups B, C and D

It follows that the superiority of the Group D soldiers was due to the presence of females in Groups B and C depressing the mean performance of these Groups. This suggests that the physically more capable soldiers have not ended up in the more demanding specialisms. In fact, it appears that a reverse selection effect has occurred, with the weakest males ending up in a specialism (infantry) which is seen as one of the most demanding roles within the Army and had the most demanding RMT levels assigned to it. This may be a function of the entry requirements for particular trades leading to better qualified individuals, who do tend to be larger, entering the units that supplied Groups B and C in preference to the infantry. It may also be a function of the policy of recruiting to units, particularly infantry units, from defined geographical areas.

It is clear that the soldiers in Group B who had to meet the more demanding Level 2 criteria were not different from the subjects in Group C who had to meet the Level 3 criteria. Two possible explanations are that either that performance on this test was not a good measure and discriminator of the different physical demands of the two Levels, or that all of the subjects had sufficient excess capability that they could have performed the requirements of both levels. It is impossible to determine with the available evidence which of these explanations is the correct one, but the fact that the women were so much less powerful than the men but were presumed capable of the necessary tasks suggests that the second explanation is more likely to be true. In this context it is worth noting that the criterion levels on the RMTs have subsequently been revised and units in Groups B and C that were assigned to different levels are now assigned to the same levels (M.P. Rayson, 1999, personal communication).

This issue was investigated further by comparing the anthropometric data of the males in the three groups using one-way analyses of variance. Tables 5.22 to 5.25 show the results for stature, body mass, fat-free mass and isometric lifting strength at 850 mm.

Table 5.22: One-way Anova of stature of males in the different Groups

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Probability
Between groups	28698.55	2	14349.277	3.800	0.0240
Within groups	747738.04	198	3776.455		
Total (corrected)	776436.60	200			

Table 5.23: One-way Anova of body mass of males in the different Groups

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Probability
Between groups	1036.740	2	518.370	4.940	0.0081
Within groups	20776.709	198	104.933		
Total (corrected)	21813.449	200			

Table 5.24: One-way Anova of fat-free mass of males in the different Groups

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Probability
Between groups	11.5734	2	5.7867	0.151	0.8600
Within groups	7592.9961	198	38.3485		
Total (corrected)	7604.5696	200			

Table 5.25: One-way Anova of isometric lifting strength at 850 mm of males in the different Groups

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Probability
Between groups	793726	2	396863	3.318	0.0383
Within groups	23442709	196	119606		
Total (corrected)	24236435	198			

Table 5.26 shows the summary data for the three groups for the four different measures. Means and 95% Tukey HSD intervals are plotted in Figures 5.8 and 5.9. These results show that the males in Group B were significantly taller than the males in Groups C and D. However, Groups B and C had almost identical body weights and their isometric lifting strengths were not significantly different. By contrast, Group D were significantly lighter (approximately 4.5 kg) than groups B and C and were significantly weaker (approximately 150 N) than Group B. Interestingly, the three groups had virtually identical fat-free masses.

Table 5.26: Anthropometric characteristics of male subjects in the different groups

	Stature (mm)			Body mass (kg)		
	B	C	D	B	C	D
Sample size	51	54	96	51	54	96
Mean	1780.45	1754.80	1752.16	76.078	76.389	71.697
Std. deviation	65.76	66.40	55.99	11.822	10.747	8.984
Minimum	1625	1579	1600	60	50	50
Maximum	1916	1896	1890	112	100	98
Std.skewness	-0.688	-1.774	-0.293	3.198	-0.360	2.109
Std.kurtosis	-0.605	0.715	0.082	1.724	-0.356	0.689
	Fat-free mass (kg)			**Isometric strength at 850 mm (N)**		
	B	**C**	**D**	**B**	**C**	**D**
Sample size	51	54	96	51	54	94
Mean	60.163	60.092	59.649	1551.4	1509.9	1407.3
Std. deviation	6.651	6.297	5.876	421.8	344.0	298.3
Minimum	45.4	42.8	46.5	725	686	794
Maximum	78.5	74.2	74.2	2943	2334	2403
Std. skewness	2.028	-1.355	1.824	3.852	0.946	3.559
Std. kurtosis	1.061	0.816	0.175	3.551	0.335	2.971

The implication of this group of findings is that the group D subjects were the least dynamically powerful and statically the weakest because they were the lightest group, and that this lack of weight was expressed by a low body fat content. This reflects the finding of Sharp and Vogel (1992) that males who were rated as overweight by the US Army body fat standard lifted significantly more on the ILM than those who were not overweight. In fact, it would be possible to characterise the Group D subjects as being 'runt-like' (M.P. Rayson, 1999, personal communication).

The issues of the relationships between the different anthropometric measures and hydrodynamometer performance are discussed in more detail in Chapter 6 where the data from both males and females are considered using analysis of covariance to correct for these factors.

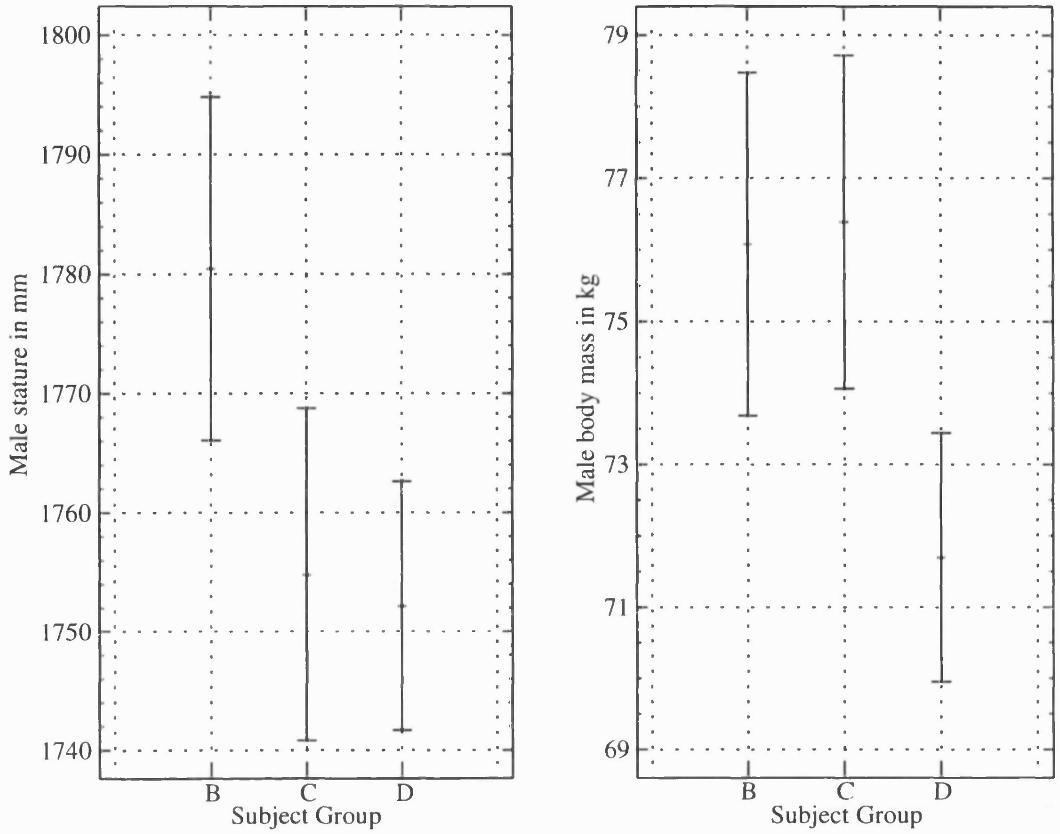


Figure 5.8: Means and 95% Tukey HSD intervals of stature and body mass of male subjects.

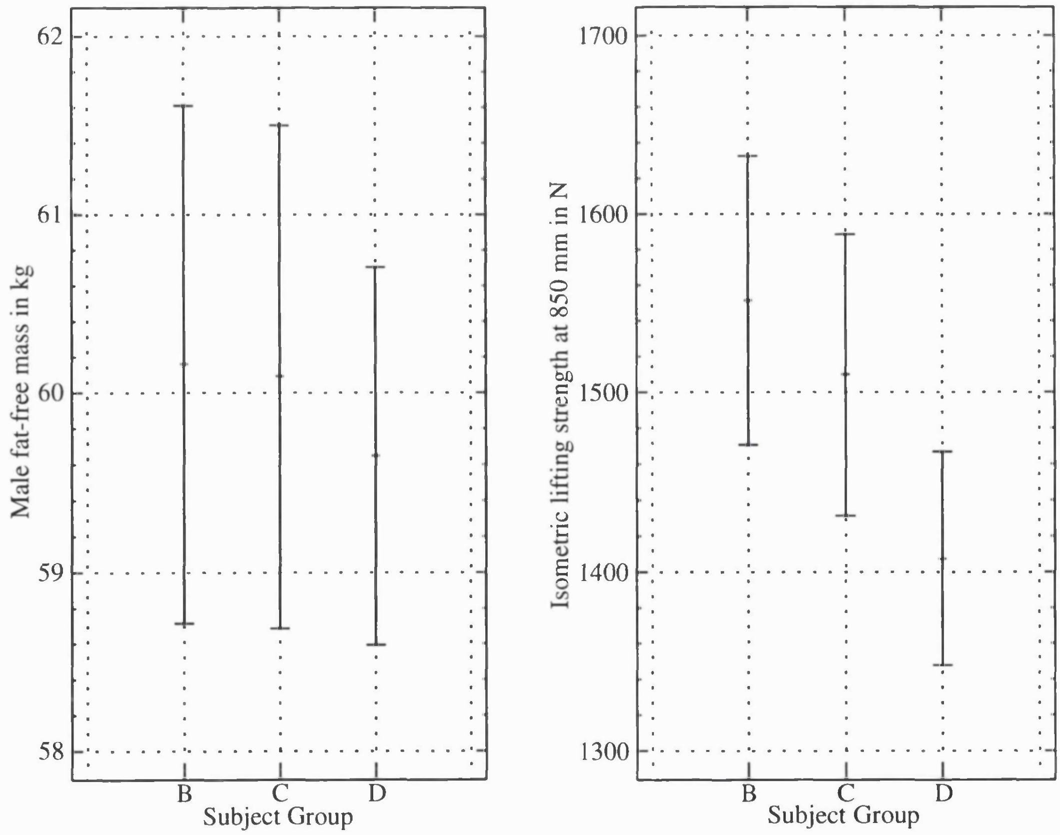


Figure 5.9: Means and 95% Tukey HSD intervals of fat free mass and isometric lifting strength at 850 mm of male subjects.

5.3.4 *Performance on the ILM, maximal box lifting performance and performance on the hydrodynamometer*

In a preliminary study of 69 male and 9 female soldiers Rayson *et al.* (1995) examined the relationship between work done on the ILM to a height of 1.7 m and work done on the hydrodynamometer to the same height. They found a correlation coefficient of 0.80. When they split the analysis between males and females they found correlations of 0.58 and only 0.06 respectively. A linear regression to predict work done on the ILM from hydrodynamometer work and gender had an R^2 value of 75%.

Because both devices were used in this study the same analysis was carried out, with the addition of a comparison of the work done on both devices to 1.45 m. Comparisons were also made with the work done in the maximal single box lifts to 1.45 m and 1.7 m.

There were differences in the start heights of the three lifts. The hydrodynamometer started at 0.4 m, and the ILM at 0.3 m. The single lift started with the box on the ground, but subjects normally grasped the handles attached to the top of the box at approximately 0.3 m. Since subjects usually changed grip part way so that their hands were grasping the bottom of the box, the distance the hands moved on the single lift was less than the distance the load moved. On the ILM and hydrodynamometer the load and the hands moved the same distance. Also, because work was done on the ILM and in the single lift by moving constant masses, work increases linearly as a function of height, whereas on the hydrodynamometer work varies as instantaneous force varies.

ILM data were missing for 14 subjects so the regressions were based on data from 193 males and 63 females. Seven subjects reached the upper limit of 205 lb (912 N) for the lift to 1.45 m and three reached this limit for the lift to 1.7 m. Single lift data were available for for all 270 subjects, but because an artificial upper limit of 72 kg had been imposed, 88 subjects had reached this maximum for the lift to 1.45 m, and 34 had reached it for the lift to 1.7 m. While the regressions were carried out with all the single lift data, caution must be used in interpreting them.

Summary data of work done on both devices to 1.45 and 1.7 m and the single lift are shown in Table 5.27. The larger values for the ILM and single lift partly reflect the greater distances that these lifts occurred through.

Table 5.27: Summary statistics for work done to 1.45 m and 1.7 m on the hydrodynamometer, the ILM, and the Single Lift

Variable	hydro145	hydro170	ilm145	ilm170	sl145	sl170
Sample size	270	270	256	256	270	270
Mean	561 J	643 J	709 J	783 J	826 J	831 J
Std deviation	129 J	157 J	190 J	241 J	213 J	259 J
Minimum	249 J	268 J	256 J	249 J	199 J	233 J
Maximum	863 J	1059 J	1049 J	1277 J	1081 J	1267 J
Std skewness	-1.859	-1.471	-0.592	-0.245	-6.252	-2.076
Std kurtosis	-2.042	-1.803	-2.644	-2.117	-0.386	-3.029

In terms of the actual masses lifted, the mean loads lifted to 1.7 and 1.45 m were 57.0 kg (SD 17.5 kg) and 62.8 kg (SD 16.8 kg) respectively. The loads lifted by males were 64.2 kg (SD 13.0 kg) and 69.8 kg (SD 12.5 kg) respectively, and 34.9 kg (SD 8.9 kg) and 41.7 kg (SD 8.5 kg) respectively for females. This gives female : male ratios of 54.4% and 59.7% to 1.7 m and 1.45 m respectively.

Almost all the ILM studies cited in Tables 2.6 and 2.7 are to the slightly higher heights of 1.8 m and 1.5 m which would therefore result in smaller scores. The largest scores to 1.8 m were 64.5 kg (SD 7.5 kg) for males and 28.2 kg (SD 3.8 kg) for females (Ostrom *et al.* 1990, post training). To 1.5 m the largest values were 61.8 kg (SD 11.2 kg) for males (Jacobs *et al.* (1988) and 36.9 kg (SD 7.6 kg) for females (Brock and Legg, 1997, post training). The largest female : male ratio to 1.8 m was 53.2% (Stevenson *et al.*, 1990a), and to 1.5 m was 54.0% (Stevenson *et al.*, 1990b).

Even taking the different target heights into account, the results from this study are high, which reflects the way in which subjects were permitted to keep trying to lift loads until they succeeded in reaching the target height even if they had to hold the load stationary while they changed grip. It is therefore possible that the more constrained protocols of the previous studies magnified the gender differences by restricting the scores females obtained.

Tables 5.28 and 5.29 and Figure 5.10 show the results of the regression using the 1.45 m data for the ILM and the hydrodynamometer. Tables 5.30 and 5.31 show the results for work to 1.7 m. Tables 5.32 and 5.33 and Figure 5.11 show the results of using both gender and hydrodynamometer work to 1.7 m to predict ILM work to 1.7 m. Tables 5.34 and 5.35 show the results of the regression for males only, and Tables 5.36 and 5.37 show the results for females only.

The models for ILM and hydrodynamometer lifts to 1.45 m and 1.7 m had correlation coefficients of 0.823 and 0.844 (Tables 5.29 and 5.31 respectively). These are close to the value of 0.80 found by Rayson *et al.* (1995). The combined model to predict ILM work to 1.7 m from hydrodynamometer work to 1.7 m and gender had an R^2 value of 72.52% (Table 5.32), which, again, was very close to the previous value of 75%. However, when the analysis was subdivided by gender, correlation coefficients of 0.671 for males and 0.558 for females were obtained (Tables 5.35 and 5.37). While the male value is slightly greater than the 0.58 Rayson *et al.* (1995) found, the female correlation is dramatically different. This can be attributed to the very small number of females in the earlier study having resulted in a spuriously small correlation. It can be seen from Figure 5.11 that the fact that the correlation for the combined group is larger than for either gender is due to the gender difference spreading the range over which the correlation is calculated. This is because the females, being weaker, are clustered at the bottom of the graph while the males are spread across the center and top of the graph.

Table 5.28: Regression of work done on the ILM to 1.45 m against work done on the hydrodynamometer to 1.45 m

Parameter	Estimate	Standard error	t value	Probability
Intercept	18.581	30.6182	0.607	0.54449
Slope	1.231	0.0532	23.134	0.00000

Table 5.29: Analysis of variance of the above regression

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Model	6237045.0	1	6237045.0	535	0.00000
Residual	2960136.2	254	11654.1		
Total (Corrected)	9197181.2	255			

Correlation coefficient = 0.823497; $R^2 = 67.81\%$; Standard error of estimate = 107.954

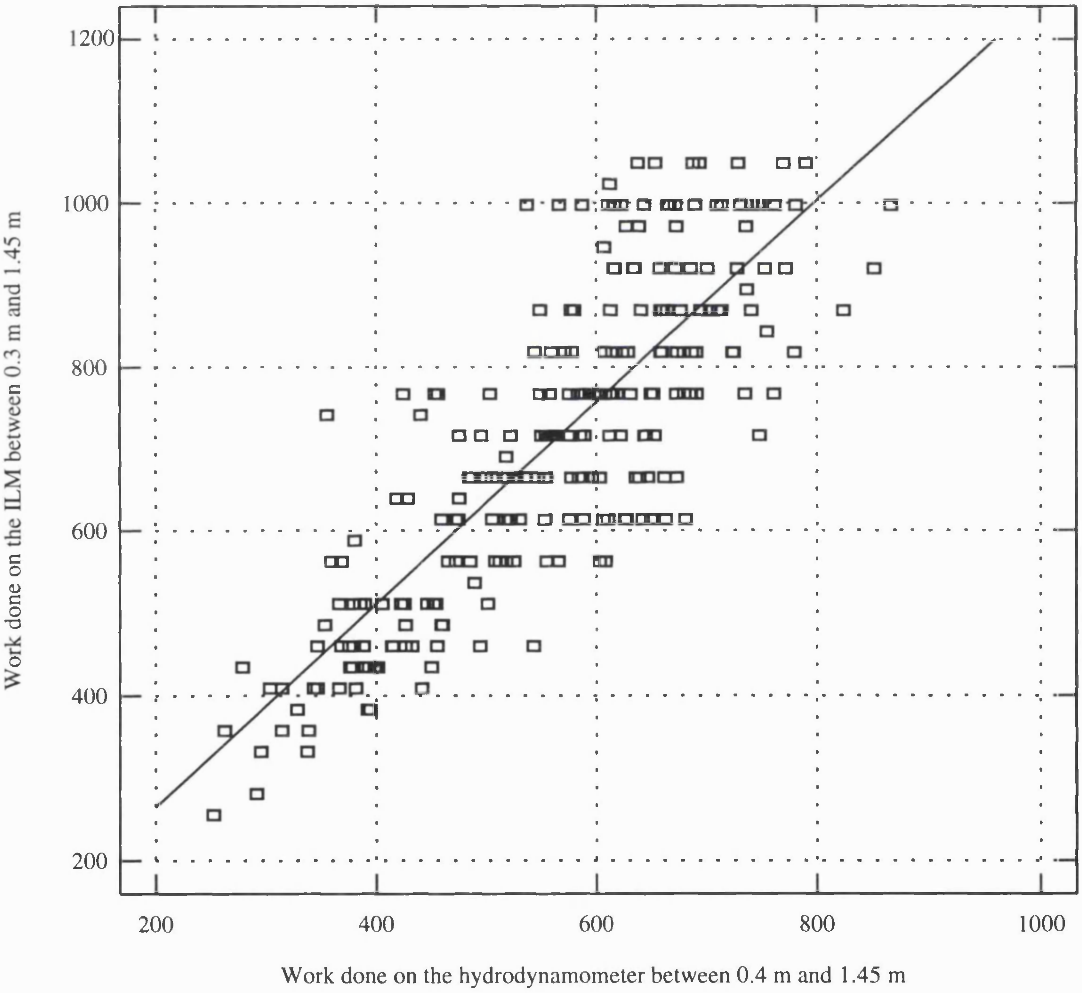


Figure 5.10: Regression of work done on the ILM to 1.45 m on work done on the hydrodynamometer to 1.45 m

Table 5.30: Regression of work done on the ILM to 1.7 m on work done on the hydrodynamometer to 1.7 m

Parameter	Estimate	Standard error	t value	Probability
Intercept	-60.9356	34.6624	-1.75797	0.07996
Slope	1.3134	0.052442	25.0448	0.00000

Table 5.31: Analysis of variance of the above regression model

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Model	10512597	1	10512597	627.2	0.00000
Residual	4257047	254	16760.0		
Total (Corrected)	14769644	255			

Correlation coefficient = 0.843665; $R^2 = 71.18\%$;Standard error of estimate = 129.461

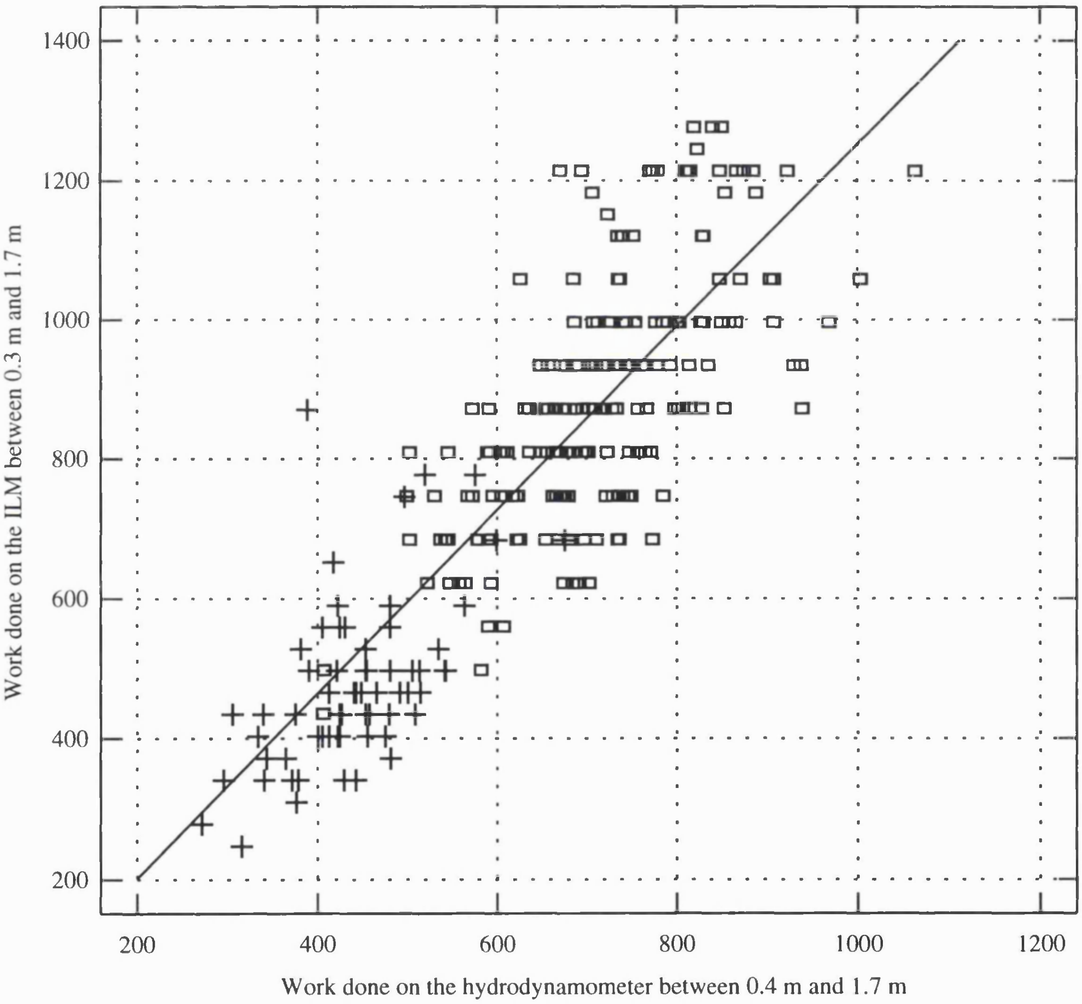


Figure 5.11: Regression of work done on the ILM to 1.7 m on work done on the hydrodynamometer to 1.7 m. □ = males; + = females

Table 5.32: Regression of work done on the ILM to 1.7 m on work done on the hydrodynamometer to 1.7 m, and gender

Predictor	Coefficient	Standard error	t value	Probability
Constant	79.694	40.387	1.973	0.0496
Work from 0.4 - 1.7 m	0.776	0.056	13.811	0.0000
Gender	-76.545	20.119	-3.805	0.0002

Adjusted $R^2 = 72.52\%$; Standard error = 90.113

Table 5.33: Analysis of variance for the above full regression model

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Work from 0.4 - 1.7 m	5363569.9	1	5363569.9	660.52	0.0000
Gender	117535.7	1	117535.7	14.47	0.0002
Model	5481106	2	2740553.0	337.496	0.0000
Error	2054427	253	8120.26		
Total (Corrected)	7535533	255			

Table 5.34: Regression, for males, of work done on the ILM to 1.7 m on work done on the hydrodynamometer to 1.7 m

Parameter	Estimate	Standard error	t value	Probability
Intercept	90.8116	64.0517	1.41779	0.15788
Slope	1.11527	0.089238	12.4978	0.00000

Table 5.35: Analysis of variance for the above regression model

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Model	2761396.5	1	2761396.5	156	0.00000
Residual	3376740.6	191	17679.3		
Total (Corrected)	6138137.1	192			

Correlation coefficient = 0.670727; $R^2 = 44.99\%$; Standard error of estimate = 132.963

Table 5.36: Regression, for females, of work done on the ILM to 1.7 m on work done on the hydrodynamometer to 1.7 m

Parameter	Estimate	Standard error	t value	Probability
Intercept	84.6873	76.1894	1.11154	0.27070
Slope	0.902514	0.171662	5.2575	0.00000

Table 5.37: Analysis of variance for the above regression model

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Model	288249.08	1	288249.08	27.6	0.00000
Residual	636119.28	61	10428.18		
Total (Corrected)	924368.36	62			

Correlation coefficient = 0.55842; $R^2 = 31.18\%$;Standard error of estimate = 102.118

Tables 5.38 and 5.39 and Figure 5.12 show the results of the regression using the data for work on the hydrodynamometer to 1.45 m and during the single lift to 1.45 m. Tables 5.40 and 5.41 and Figure 5.13 show the results for work to 1.7 m for the hydrodynamometer and the single lift.

The correlations between the work on the hydrodynamometer and the single lift to 1.45 m and 1.7 m were of 0.823 and 0.838 (Tables 5.39 and 5.41 respectively). These are very similar to the values of 0.823 and 0.844 obtained for the ILM - hydrodynamometer correlations. In reality, of course, if the single lift data did not have an artificial limit, these correlations would probably be higher. It therefore appears that performance on the hydrodynamometer is related equally well to performance on the ILM and on the single lift.

Table 5.38: Regression of work done to 1.45 m in a maximal box lift against work done on the hydrodynamometer to 1.45 m

Parameter	Estimate	Standard error	t value	Probability
Intercept	66.8613	32.8751	2.0338	0.04296
Slope	1.35347	0.0571085	23.7	0.00000

Table 5.39: Analysis of variance of the above regression

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Model	8233858.2	1	8233858.2	562	0.00000
Residual	3928624.8	268	14659.0		
Total (Corrected)	12162483	269			

Correlation coefficient = 0.822793; $R^2 = 67.70\%$; Standard error of estimate = 121.075

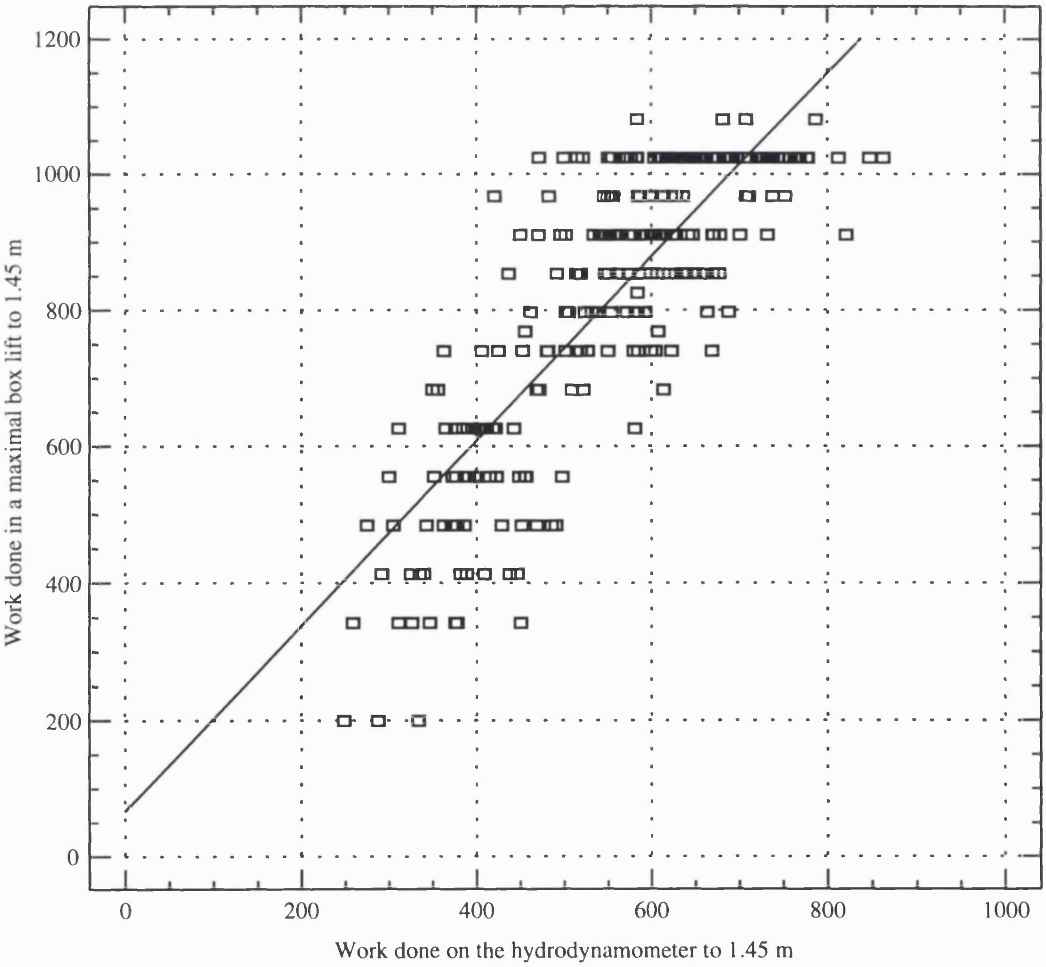


Figure 5.12: Regression of work done in a maximal box lift to 1.45 m on work done on the hydrodynamometer to 1.45 m

Table 5.40: Regression of work done to 1.7 m in a maximal box lift against work done on the hydrodynamometer to 1.7 m

Parameter	Estimate	Standard error	t value	Probability
Intercept	-56.198	36.343	-1.546	0.12321
Slope	1.381	0.055	25.132	0.00000

Table 5.41: Analysis of variance of the above regression

Source	Sum of squares	D.F.	Mean squares	F ratio	Probability
Model	12677563	1	12677563	631.6	0.00000
Residual	5378925.8	268	20070.6		
Total (Corrected)	18056489	269			

Correlation coefficient = 0.837917; $R^2 = 70.21\%$; Standard error of estimate = 141.671

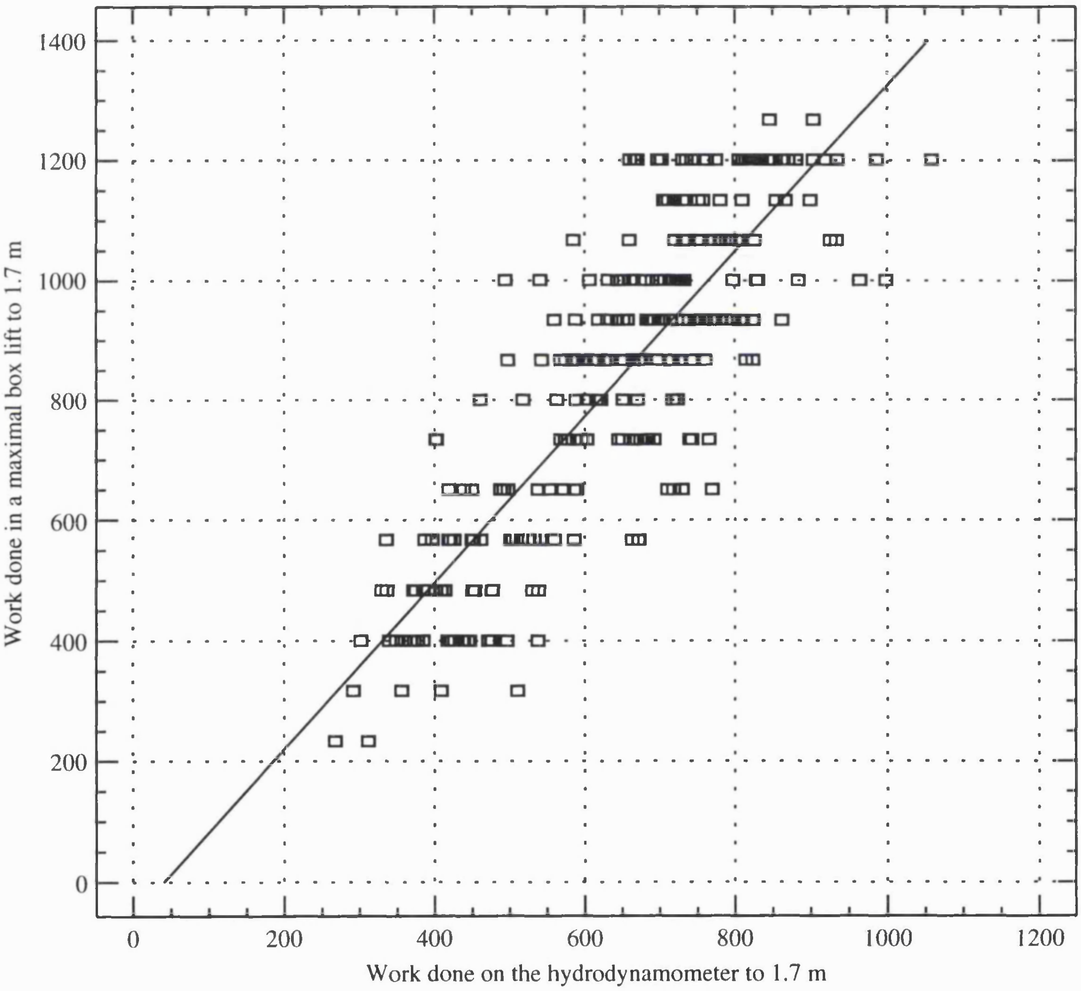


Figure 5.13: Regression of work done in a maximal box lift to 1.7 m on work done on the hydrodynamometer to 1.7 m

5.3.5 *Location of the peak lifting force*

It as previously been reported that static lifting strength varies with both hand height and stature (Sanchez and Grieve, 1992). Pheasant (1986) suggested that maximal lifting strength would occur around knuckle height, which will vary with stature. To investigate the relationship between the height of the peak lifting force and the stature of the subject, a linear regression was carried out. This gave values of $r = 0.4720$, $R^2 = 22.28\%$, $F = 76.81$, 1, 268 df, $p < 0.0001$. The regression equation was:

$$\text{Height of peak force in mm} = -52.787 + 0.419 \times \text{stature in mm}$$

Figure 5.14 shows a scatter plot of the height of the main peak in power against stature, and the associated regression line. It can therefore be concluded that while stature is partly related to the height of peak dynamic lifting force, other factors, which this study is not able to identify, are more important. It may be that knuckle height rather than stature would be a better predictor, but knuckle height was not measured in this study.

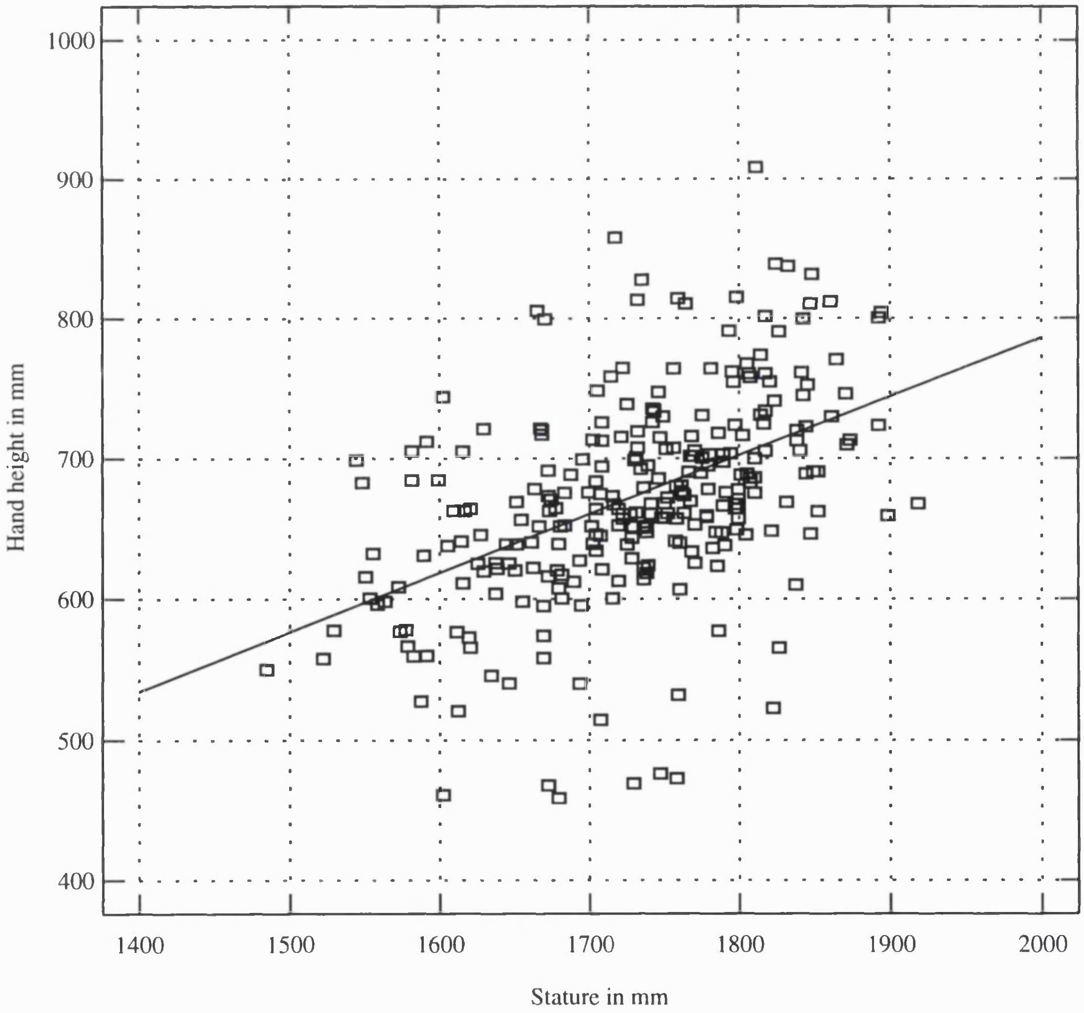


Figure 5.14: Regression of height of main power peak on subject stature

5.3.6 Existence of a double force peak at the start of the lift

As discussed earlier, there were variations in the styles of lifting utilised by the different subjects. Table 5.1 shows that 116 males and 13 females recorded an initial peak force, (Event 5) before the main peak in the force trace (Event 7). Given the proportions of males and females in the group, the expected frequencies for Event 5 are 96.033 males and 32.967 females, giving $\chi^2 = 16.249$ (1 df),with $p = 5.566\times10^{-5}$, i.e. males are significantly more likely than females to record an initial peak in the force trace.

Two-sample t-tests were used to examine the effect of the presence of an initial peak. The peak forces (Event 7) were bigger (920 N vs 826 N) if there was an initial peak first ($t = 4.249$, 268 df, $p = 2.966\times10^{-5}$). The presence or absence of the initial peak did not affect the timing of the peak force (0.405 s vs 0.381 s, $t = 1.863$, 268 df, $p = 0.0636$). However, Event 7 occurred at a greater height when Event 5 existed (701 mm vs 645 mm, $t = 6.684$, 268 df, $p = 1.339\times10^{-10}$) and mean power to 1.7 m was greater (355 W vs 278 W, $t = 5.877$, 268 df, $p = 1.237\times10^{-8}$).

Splitting the genders showed that males with an initial peak reached peak force at a greater height than those that did not (706 mm vs 663 mm, $t = 4.459$, 199 df, $p = 1.390\times10^{-5}$). However, this was not true for females (650 mm vs 617 mm, $t = 1.792$, 67 df, $p = 0.0777$). Mean power to 1.7 m was not significantly different for males (371 W vs 352 W, $t= 1.579$, 199 df, $p = 0.1160$) but was for females (211 W vs 166 W, $t= 2.999$, 67 df, $p = 0.003796$).

The mean values for males of the different parameters at Events 5 - 7 are listed in Table 5.42. This shows that the presence or absence of Event 5 only affected the height of Event 7 and not any of its other characteristics. It is noticeable that Event 5 occurred much earlier in the lift than Event 7 and that Event 6 followed it closely. In fact Event 5 occurred only 0.109 s into the lift and after only 81 mm of movement. The fact that a force of nearly 1 kN and a velocity of 0.8 m·s^{-1} had been attained by this time shows how rapid force development can be in dynamic lifts. The fact that the initial peak (Event 5) occurred at approximately 25% of the displacement of the main peak and that the dip in force occurred at approximately 50% suggests that subjects who exhibited an initial peak adopted a more forceful initial lifting technique than those who did not.

Table 5.42: Effect of initial peak on mean performance by males, with the results of two-sample t-tests showing the effect on the peak force Event

Event	Height	Time	Force	Velocity	Power
Event 5	481 mm	109 ms	935 N	801 mm·s^{-1}	765 W
Event 6	546 mm	196 ms	795 N	731 mm·s^{-1}	591 W
Event 7, after Event 5	706 mm	407 ms	940 N	788 mm·s^{-1}	751 W
Event 7, no Event 5	663 mm	381 ms	945 N	795 mm·s^{-1}	764 W
t-value	4.459	1.770	-0.273	-0.614	-0.477
Probability	1.390×10^{-5}	0.078	0.785	0.540	0.665

Verbal reports from many of the subjects described the initial pull as "like hitting a brick wall". Their perceptions may have been influenced by the presence of the initial peak. Also, the fact that males achieved greater velocities during the lifts (791 $mm \cdot s^{-1}$ by males and 655 $mm \cdot s^{-1}$ by females at Event 7 (Table A1.7)) probably has a bearing on the gender difference in frequency of initial peaks.

The finding of gender differences in the frequency of initial peaks cannot be explained by the measured anthropometric factors: there were no significant differences between males who produced the initial peak and those who did not (Table 5.43). The only significant difference was for female isometric lifting strength at 850 mm, where the difference was only just significant at the 5% level.

Table 5.43: Mean anthropometric characteristics of subjects producing (Ev 5) or not producing (No Ev 5) an initial peak force and results of two-sample t-tests

	Males				Females			
Measure	**Ev 5**	**No Ev 5**	**t**	***p***	**Ev 5**	**No Ev 5**	**t**	***p***
Stature	1766 mm	1752 mm	1.556	0.121	1647 mm	1633 mm	0.729	0.469
Body mass	74.0 kg	74.1 kg	-0.048	0.962	63.8 kg	61.6 kg	0.939	0.351
Fat free mass	60.2 kg	59.5 kg	0.749	0.455	43.6 kg	41.9 kg	1.470	0.146
Iso 850	1506 N	1425 N	1.614	0.108	934 N	771 N	2.203	0.031

Such an initial peak or plateau just before the main peak force in a dynamic exertion can be observed in the graphs reproduced in Chapter 2 from isoinertial exertions on the ILM (Figure 2.6, Stevenson et al., 1996a), exertions on the isokinetic Cybex II (Figures 2.7 2.8 and 2.9, Weisman *et al.*, 1990b, 1992), and exertions on the accommodating resistance Biokinetic Ergometer (Figure 2.14, Garg *et al.*, 1988). It is also consistent with the observation of Grieve (1975) that impulsive forces applied to a load when lifting usually reach a peak within 100ms of lift-off. Therefore it seems that an initial force peak and subsequent main peak is device independent, but none of the studies cited above have commented on the presence of this effect in their diagrams. It is therefore concluded that there is an as yet unidentified biomechanical factor that causes dynamic exertions with a very fast onset rate to reach a plateau or dip slightly before maximum strength is exerted. On this device a gender difference was found which made males more likely than females to exhibit this initial peak in the force trace and for males only, when it is present, the peak force occurs at a higher height.

5.3.7 *Effect of number of grip changes*

It was apparent both from observing subjects performing exertions on the hydrodynamometer and from inspection of the resulting force, velocity and power curves, that some subjects performed a single grip change as was demonstrated to them, but others performed a double grip change. These double grip changes were sometimes associated with changing grip first with one hand and then with the other, but sometimes by changing grip with both hands twice, with the second change being associated with renewed flexion of the knees. No attempt was made to record the postures used in changing grip, so it is not possible to separate out these subjects and the only distinction that can be drawn is between the associated decrements in force and velocity that were recorded.

To examine the differences between subjects who carried out single and double grip changes, the mean power output over the lift to 1.7 m was examined (Table 5.44).

Table 5.44: Power output during lifts from 0.4 to 1.7 m for single and double grip changes

Grip changes	Mean	SD	n
Single	317.9 W	114.8 W	196
Double	306.4 W	112.1 W	74

A two-sample t-test gave t = 0.734, $p = 0.463$; i.e., there was no significant difference in mean power between 0.4 and 1.7 m between subjects who performed a single change of grip and those who performed a double change of grip.

It is more likely that differences due to a second grip change would be apparent in the later part of the lift, so the mean power output after the first grip change was examined (Table 5.45).

Table 5.45: Power output during lifts between the first grip change and 1.7 m for single and double grip changes

Grip changes	Mean	SD	n
Single	172.9 W	90.3 W	193
Double	148.8 W	75.1 W	74

A two-sample t-test gave t = 2.038, $p = 0.0425$, i.e. the difference in mean power was just significant. This means that subjects who performed a double grip change were less powerful between the first change and 1.7 m than subjects who performed only one grip change. This can be attributed to both the carrying out of the second grip change, which will have decreased the mean power, and the fact that subjects found it necessary to carry out a second grip change, meaning that they were running out of strength.

56 males and 18 females performed the second grip change (Table A1.10) and the expected frequencies were 55.089 males and 18.911 females, $\chi^2 = 0.059$ (1 df), $p =$ 0.808, i.e. males and females were equally likely to change grip twice during the lift.

5.3.8 Gender differences during moments of maximal exertion

In order to examine gender differences at instants where subjects were exerting maximally, rather than carrying out changes of grip, values of power obtained at the main peak and at the peaks after the two grip changes were subjected to Anova. Due to reasons explained in Chapter 6, fat-free mass, isometric lifting strength at 850 mm and stature were included as covariates, and Type I sums of squares were used.

Table 5.46: One-way Ancova for power at main peak

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	6897646.2	1	6897646.2	276.581	0.0000	49.372%
Iso strength at 850 mm	189654.8	1	189654.8	7.605	0.0062	1.357%
Stature	203462.2	1	203462.2	8.158	0.0046	1.456%
Main effects						
Gender	71296.5	1	71296.5	2.859	0.0920	0.510%
Residual	6608828.0	265	24939.0			
Total (corrected)	13970888	269				52.693%

Table 5.47: Least squares means (after correction for covariates) for power at main peak

Level	n	Mean (W)	95% confidence intervals	
Grand mean	270	667.952	641.852	694.052
Male	201	699.512	672.843	726.181
Female	69	636.393	578.482	694.304

Tables 5.46 and 5.47 show that once the covariates of fat-free mass, isometric lifting strength at 850 mm and stature have been taken into account, the effect of gender is non-significant, accounting for only 0.5% of the variance. However, the uncorrected means (Table A1.21) show that females produced 42% less power than males.

Table 5.48: One-way Ancova for power at peak after first grip change

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1184681.6	1	1184681.6	64.747	0.0000	19.338%
Iso strength at 850 mm	61326.1	1	61326.1	3.352	0.0683	1.001%
Stature	18869.6	1	18869.6	1.031	0.3108	0.308%
Main effects						
Gender	30795.0	1	30795.0	1.683	0.1957	0.503%
Residual	4830427.0	264	18297.1			
Total (corrected)	6126099.2	268				21.150%

Table 5.49: Least squares means (after correction for covariates) for power at peak after first grip change

Level	n	Mean (W)	95% confidence interval	
Grand mean	269	269.063	246.555	291.571
Male	201	289.823	267.070	312.575
Female	68	248.303	198.485	298.122

Tables 5.48 and 5.49 show a similar pattern. Although the actual difference in means (Table A1.23) between males and females at the peak following the first grip change is

44%, once the covariates have been removed, the difference is non-significant, again accounting for 0.5% of the variance.

Table 5.50: One-way Ancova for power at peak after second change of grip

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	299432.69	1	299432.69	33.280	0.0000	32.428%
Iso strength at 850 mm	120.58	1	120.58	0.013	0.9094	0.013%
Stature	1907.59	1	1907.59	0.212	0.6515	0.207%
Main effects						
Gender	1111.40	1	1111.40	0.124	0.7301	0.120%
Residual	620811.57	69	8997.27			
Total (corrected)	923383.84	73				32.768%

Table 5.51: Least squares means (after correction for covariates) for power at peak after second change of grip

Level	n	Mean (W)	95% Confidence Intervals	
Grand mean	74	170.858	140.293	201.422
Male	56	178.135	148.334	207.935
Female	18	163.581	97.294	229.868

The pattern is repeated in Tables 5.50 and 5.51. The actual difference (Table A1.25) between males and females at the peak following the second grip change has risen to 59% but gender is again insignificant, once the covariates have been accounted for.

5.4 Conclusions

This chapter has examined a number of diverse issues regarding performance on the hydrodynamometer. The following conclusions can be drawn:

1: There is wide variation between individual subjects in performance on the hydrodynamometer. With the selected resistance, lifts to 1.7 m were completed in periods ranging from 1.98 s to 5.22 s. The mean work done was 643 J (SD 157 J) with a mean power output of 315 W (SD 114 W). The mean impulse applied was 1087 N·s (SD 127 N·s). Males performed lifts in a mean of 73% of the time taken by females. Peak power occurred early in the lift (typically within 0.4 s) at 684 mm (SD 73 mm) for males and at 618 mm (SD 62 mm) for females.

2: Peaks in hydrodynamometer velocity typically occurred a few tens of milliseconds or tens of millimetres prior to peaks in force. The converse of a delay between force application and changes in velocity could potentially be expected since any change in velocity is dependent upon force application. The implication is that after velocity has peaked, the additional force is not converted into acceleration of the piston, but is lost in the device. Such loss may be a function of the location or mounting of the force transducer which records force in the rope at some distance from the piston where the water in the tube produces the drag force on the piston.

3: The assumption made by Grieve (1993) that dynamic whole body lifting can be accurately characterised by the mean power output over a part of the most powerful portion of the lifting range is well founded.

4: Lifting performance below chest height is not a good predictor of lifting performance above chest height, i.e. arm strength and back / leg strength are different.

5: The device showed a reverse selection effect had occurred with weaker subjects being found to be employed in military specialisms which are regarded as being more physically demanding than those the stronger subjects were employed in. This appears to be in part an anthropometric effect and may be a function of other aspects of military recruitment policies. This finding also suggests that the subjects tested all had sufficient capacity to carry out all task requirements.

6: The finding of Rayson *et al.* (1995) that there is a correlation of approximately 0.6 for work done by males on the hydrodynamometer and on the Incremental Lifting Machine (ILM) was confirmed. With a much larger sample size the corresponding correlation for females was shown to be in the region of 0.55, not the 0.06 previously reported. When the male and female data were combined correlations of approximately 0.83 were obtained between work done on the hydrodynamometer and both on the ILM and in a single maximal box lift.

7: The height of the peak lifting force was shown to be only weakly related to the stature of the subject.

8: Males were significantly more likely than females to exhibit a preliminary peak in the force trace before the main peak, but subjects that produced the phenomenon did not differ in stature, body weight or fat-free mass from those that did not. Peak forces occurred slightly higher when such initial peaks occurred, but their timing and magnitude were not affected. Such peaks occur on other dynamic lifting devices, and typically occur very early in the lift, implying that they are associated with very rapid force development in the initial jerk applied to the handle.

9: Subjects who performed two grip changes were less powerful than those who only change grip once. This implies that subjects should be trained specifically in how to change grip in order to maximise output above the chest region.

10: Gender differences in power output at the various peaks in the curves ranged between 42% and 59%, but after taking differences in fat-free mass into account, were not statistically significant.

CHAPTER 6

GENDER DIFFERENCES IN PERFORMANCE ON THE HYDRODYNAMOMETER - DO WOMEN HAVE LESS UPPER BODY STRENGTH THAN MEN?

6.1 Introduction

As discussed in the literature review, large gender differences have been identified in strength. Factors believed to cause them are listed in Table 6.1:

Table 6.1: Factors identified as relevant to gender differences in strength

Static / dynamic exertions (The female : male ratio varies between static and dynamic exertions)

Muscle groups involved (women are usually seen as having less upper body strength than men)

Training / habitual activity

Stature (women are smaller than men)

Body mass (women are lighter than men)

Body composition (women have a greater percentage of fat than men)

The purpose of this chapter is to examine the differences in performance on the hydrodynamometer of men and women and to relate it to the widespread perception (see, for example, Laubach, 1976) that women have less upper body strength than men.

6.2 Methods

6.2.1 Data used

The data from the 201 male and 69 female subjects who produced usable records from second pulls were used. Data from second pulls only were used since a warming-up effect is known to occur on this device (Chapter 3.5.4). In order to reduce the amount of data being handled, values of force, velocity, power, work and impulse were extracted at 5% (from 25% to 130%) and 100 mm (from 450 mm to 2150 mm) intervals of stature. A starting value of 450 mm was used because no movement will have occurred at the starting height of 400 mm. Because of variations in stature not all subjects produced data at all of the 5% intervals of stature. The numbers of data points available at each interval of stature are shown in Tables 6.2 and 6.3:

Table 6.2: Number of data points available at 5% intervals of stature

Hand height	Males	Females	Total	% Females
25% stature	198	48	246	19.5%
30% - 100% stature	201	69	270	25.6%
105% stature	200	69	269	25.7%
110% stature	197	69	266	25.9%
115% stature	167	68	235	28.9%
120% stature	113	65	178	36.5%
125% stature	21	30	51	58.8%
130% stature	0	3	3	100.0%

Table 6.3: Number of data points available at 100 mm intervals of stature

Hand height	Males	Females	Total	% Females
450 - 1750 mm	201	69	270	25.56%
1850 mm	201	67	268	25.00%
1950 mm	199	58	257	22.57%
2050 mm	161	30	191	15.71%
2150 mm	55	3	58	5.17%

6.2.2 Analysis of variance and covariance of unbalanced data sets

Analysis of variance (*ANOVA*) allows the partitioning of the *variance* (variability) of a *response* (dependent) variable between the effects of one or more *independent* variables. The *residual* (unexplained) variance is treated as a random source of error and used to calculate an *F ratio*, and hence a probability that the effect associated with different levels of an independent variable is in fact due to chance.

Analysis of covariance (*ANCOVA*) is a variation of this technique which additionally allows the effects of *covariates* to be accounted for. These are variables which were not controlled, but which give additional information about the subjects, and may have caused some of the variability in the response variable.

Anova and Ancova are normally carried out on *balanced* data sets where the number of values in each cell of the design is equal ('equal-*n*'). In an *unbalanced* or *non-orthogonal* design the number of values per cell is not constant ('unequal-*n*'). For a one-way design, this is of minor consequence, but in two-way or higher order designs significant problems are caused in calculation and interpretation. The best ways of handling such situations are still a matter of debate among statisticians (Maxwell and Delaney, 1990, p272).

Orthogonality

The purpose of statistical analysis is to make comparisons or *contrasts* between sets of data. Given *m* groups, *m*-1 *orthogonal* contrasts will partition the between groups sum of squares. However, the sums of squares of non-orthogonal contrasts are not additive, and therefore cannot be used to determine the magnitude of the sum of squares they jointly account for (Maxwell and Delaney, 1990, p158-159).

For equal sample sizes, two contrasts, are orthogonal if their *coefficients, c,* satisfy Equation 4.45 from Maxwell and Delaney (1990), where *j* is the index of the group:

$$\Sigma c_{1j} c_{2j} = 0 \qquad (6.1)$$

In the more general case, without the restriction that sample sizes are equal, Equation 4.46 from Maxwell and Delaney (1990) applies, with n_j being the size of the *j*th group:

$$\Sigma c_{1j} c_{2j} / n_j = 0 \qquad (6.2)$$

There are some unequal-*n* factorial designs which meet this criterion, but in the majority of cases they do not. The usual result, therefore, of unequal-*n*, is that in a two-way design, the contrasts representing the A main effect, the B main effect and the A × B interaction are not orthogonal. This means that hypotheses about main effects and interactions are not independent, their variances overlap, and as a result, their sums of squares are not additive.

Causes of non-orthogonality

An unequal-*n* situation may result from true differences in nature between the populations which are being sampled. However, if it has arisen due to differential loss of subjects in the cells of the design, it is not possible to carry out meaningful analyses if the attrition of subjects has been caused by the treatments *per se*, rather than being random.

6.2.3 The different types of sums of squares

Type I sum of squares are calculated using *weighted marginal means*, i.e. the number of values contributing to each cell in the design are taken into account. What is therefore calculated is a grand mean of all the individual scores. The purpose is to test whether there are differences between levels of a factor irrespective of whether there is an interaction between that factor and another factor. The order in which factors are entered into the model is therefore important.

Type II sums of squares are calculated using a complex formula involving the *harmonic mean* of the cell sizes. This means an average cell size is used when calculating the marginal mean, giving the better estimates of the marginal mean (i.e. those originating from larger sample sizes) more weight. Type II is appropriate when sample sizes reflect the importance of the cells, and there is no interaction between factors, which have equal priority in the model.

Type III sums of squares are calculated using *unweighted marginal means.* In other words, the mean of all the means of the individual cells is calculated, ignoring the number of scores contributing to each mean. Thus the differences between levels of a main effect are calculated within each level of the second factor, and then averaged across the levels of the second factor. This is appropriate where all cells within the experiment are equally important, especially in experiments designed to be equal-*n* which have suffered from random loss of data.

It is important to realise that calculations of interactions between main effects are not affected by the type of sum of squares used because the interaction is a test of differences between cell means, not of differences of averages calculated from groups of cell means. It is also important to note that in an equal-*n* design the three types of sum of squares are identical, because the unweighted and harmonic marginal means are identical to the weighted marginal means.

In orthogonal unequal-n designs, i.e. those which obey Equation 6.2, the relationships between the three types of sums of squares depend upon the precise distribution of cell sizes. Maxwell and Delaney (1990, p280) give the example of a 2 x 2 design with cells of sizes n_{11}, n_{12}, n_{21}, n_{22}. If $n_{11} = n_{12}$ and $n_{21} = n_{22}$, all three types test the same hypothesis and yield identical sums of squares. However, if $n_{11} = n_{21}$ and $n_{12} = n_{22}$, then only Types I and II are identical, with Type III being different. Clearly, in this last case, the difference depends upon which variable is entered first, since changing it would reproduce the first example.

Table 6.4: The three possible ways of testing a main effect in an unbalanced two-way design: (Maxwell and Delaney, 1990, p286)

Type I	Ignore the other main effect and the interaction.
Type II	Allow for the other main effect but ignore the interaction.
Type III	Allow for both the other main effect and the interaction.

6.2.4 Choice of type of sum of squares for unbalanced designs

Maxwell and Delaney (1990, p282-3) recommend analysing unbalanced two-way designs by first testing the interaction, followed, if the interaction is significant, by simple-effect tests of each factor at each level of the other factor. Obviously, these are one-way tests which therefore present no problems of analysis, even when unbalanced. If the interaction is not significant their recommendation is for testing of main effects averaged across all levels of the other factor. It is at this point that a decision must be made as to the type of sums of squares to be used.

6.2.5 Reduction of the data set to a balanced, orthogonal design

In this study it was desired to examine the effects of both gender and hand height, and their interaction on performance on the hydrodynamometer.

The gender main effect

Because the 'gender-free' study was designed to reflect the composition of the British Army, different numbers of men and women were used as subjects. It could therefore be argued that it would be appropriate to use Type I sum of squares because the unbalanced groups of men and women reflect the composition of the whole Army population. However, it could also be argued that generalising the results to the civilian population would require the use of Type III sums of squares.

The hand height main effect

Because women are shorter than men, fewer women than men are able to reach higher absolute heights. In this case, then, differential attrition is caused by gender. The situation regarding relative stature (i.e. normalised to stature) is more complex since, in principle, normalisation will remove the gender difference. However, because women are shorter than men, the 400 mm start height will represent a greater proportion of their height thereby affecting the gender balance at the lowest relative height. Also, the maximum hand height available was 2.2 m, which is less than the overhead reach height of many males, meaning that women will be over-represented at the highest relative hand heights. The actual variations in the proportion of female subjects at the different heights are recorded in Table 6.2 and 6.3.

The gender × hand height interaction

The question of whether there is an interaction between gender and hand height is of major interest because of the suggestion that women have less upper body strength than men (Laubach, 1976). Therefore use of Type II sums of squares would be inappropriate.

Because of the complications of unbalanced designs, and the differential attrition at the extremes of the height distribution revealed in Tables 6.2 and 6.3, the two data sets were reduced by omitting heights where data were not available for all 270 subjects. Data were available from 201 males and 69 females for fourteen hand heights between 450 and 1750 mm, and fifteen hand heights between 30% and 100% of stature. According to Snedecor and Cochran (1989) this situation of a constant proportion between the two levels of one variable and equal-*n* across the other variable is an example of an orthogonal design. Because differences due to hand height were of less interest than overall gender differences, gender was made the first factor (the A main effect) to enter the model, with hand height being the other factor (the B main effect). Because each subject recorded data at all hand heights analysed, but could only be of one gender, two-way split-plot analysis was suitable. Because the available statistical software did not separate the within-groups variance from the residual variance and calculated all F ratios using this residual, there will have been a tendency to underestimate the significance of the gender difference. This problem was partially alleviated by calculating 'R^2', the proportion of the total variance accounted for by each factor, and the total R^2 for the model.

6.3 Results

6.3.1 Effects of using Type I and Type III sums of squares on the reduced data sets

In order to double check how the available software would handle unbalanced data sets (Tabachnick and Fidell, 1996), two-way analyses of variance of the power data collected at absolute hand heights were carried out using both Type I and Type III sums of squares. The results are presented in Tables 6.5 and 6.6.

Table 6.5: Two-way Anova of power measured at absolute hand heights, using Type I sums of squares, with gender entered before height

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	24324601	1	24324601	1315.422	0.0000	10.243%
Height	135696119	13	10438163	564.473	0.0000	57.141%
Interactions						
Gender × Height	8072891.2	13	620991.63	33.582	0.0000	3.399%
Residual	69381454	3752	18491.859			29.216%
Total (Corrected)	237475065.2	3779				99.999%

Table 6.6: Two-way Anova of power measured at absolute hand heights, using Type III sums of squares, with gender entered before height

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	24324601	1	24324601	1315.422	0.0000	10.243%
Height	79933254	13	6148712	332.509	0.0000	33.660%
Interactions						
Gender × Height	8072891.2	13	620991.63	33.582	0.0000	3.399%
Residual	69381454	3752	18491.859			29.216%
Total (Corrected)	237475065.2	3779				76.518%

As can be seen, despite the design being orthogonal, the two methods do not produce identical sums of squares for the height main effect with the Type III method failing to account for nearly 25% of the total variance. However, both methods attribute identical sums of squares to gender.

The effect of sequence of entry of factors was also investigated for both methods, and the results are shown in Tables 6.7 and 6.8.

Table 6.7: Two-way Anova of power measured at 100 mm intervals using Type I sums of squares, with height entered before gender

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Height	135696125	13	10438163	564.473	0.0000	57.141%
Gender	24324601	1	24324601	1315.422	0.0000	10.243%
Interactions						
Gender × Height	8072891.2	13	620991.63	33.582	0.0000	3.399%
Residual	69381454	3752	18491.859			29.216%
Total (Corrected)	237475065.2	3779				99.999%

Table 6.8: Two-way Anova of power measured at 100 mm intervals, using Type III sums of squares, with height entered before gender

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Height	79933254	13	6148712	332.509	0.0000	33.660%
Gender	24324601	1	24324601	1315.422	0.0000	10.243%
Interactions						
Height × Gender	8072891.2	13	620991.63	33.582	0.0000	3.399%
Residual	69381454	3752	18491.859			29.216%
Total (Corrected)	237475065.2	3779				76.518%

From these tables it can be seen that, in this particular case, the sequence of entry of factors does not affect the variance allotted to the different factors for either Type I or Type III sums of squares. It was therefore decided that the use of Type I sums of squares was the most appropriate method, because it accounts for all of the available variance. All other analyses reported in this chapter were therefore performed using Type I sums of squares.

6.3.2 Choice of dependent variables

It is possible to derive a number of parameters to describe a lift from the measurements of force, position and time which were available. It was decided to examine firstly, power, because it reflected instantaneous force and velocity (which are known to be related - see Chapter 3); secondly, work done, because it combined force with the distance the hands had moved; and thirdly, impulse, because it combined force with duration of exertion. It must be realised that work and impulse must be highly correlated because they are both products of force and are both cumulative. Also, because they are cumulative, they will both increase significantly with hand height.

6.3.3 Use of and choice of covariates

It is known that there are pre-existing gender differences in stature, body weight, and body composition, and that the role of gender in both dynamic and isometric strengths is contentious (Stevenson *et al.*, 1996a). Therefore the effects of stature, body mass, fat-free mass and isometric lifting strength at 850 mm were controlled using Ancova to see whether gender differences in hydrodynamometer performance were independent of these known gender differences (Table 6.9, Appendix 3, Tables A3.1 to A3.18). However, where more than one covariate is used, the proportion of variance assigned to each covariate depends upon the relationships (i.e. correlations) between the covariates. Because body mass and fat-free mass are closely related, it is unlikely that using both as covariates at the same time would yield additional information. Therefore comparisons were made to determine which was the more useful covariate.

Table 6.9: Percentages of variance accounted for by the gender main effect in two-way Ancova with the other main effect being either absolute or relative hand height, with a) no covariates; b) covariates of body mass, isometric lifting strength at 850 mm, and stature; c) covariates of fat-free mass, isometric lifting strength at 850 mm, and stature

Analysis	Absolute heights			Height as percentage stature		
	Power	Work	Impulse	Power	Work	Impulse
a) Anova	10.243%	10.236%	2.481%	8.325%	16.295%	6.171%
b) bm Ancova	1.360%	1.612%	0.468%	1.505%	1.625%	0.470%
c) ffm Ancova	0.113%	0.254%	0.117%	0.132%	0.191%	0.097%

A three-way factorial Ancova was carried out to examine the causes of variation in the variance accounted for by gender. This showed (Table 6.10) that the use of different covariates caused significant differences in the amount of variance ascribed to the gender main effect, but that changing the method of measuring hand height or the dependent variable in the analysis did not have a significant effect. Post-hoc analysis of means using the Tukey HSD test showed that the two analyses involving covariates (analyses *b* and *c*) were significantly different from the straight Anova (analysis *a*), but were not different from each other.

Table 6.10: Three way Anova of percentages of variance accounted for by gender

Source	Sum of squares	D.F.	Mean Squares	F Ratio	Probability
Height	3.491	1	3.491	1.214	NS
Dependent variable	35.020	2	17.510	6.089	NS
Analysis	278.465	2	139.233	48.415	0.0016
Height x Dependent variable	5.287	2	2.644	0.919	NS
Height x Analysis	6.735	2	3.367	1.171	NS
Dependent variable x Analysis	46.751	4	11.688	4.064	NS
Error	11.503	4	2.876		
Total	387.251	17			

Because this Anova violated the assumption of homogeneity of variance due to the big variations in variance between the different types of analysis, a two-sample t-test was performed to compare the effects of the Ancova involving body mass with that involving fat-free mass. This showed that the amount of variance allotted to gender was significantly less when using fat-free mass than when using body mass ($t = 4.4969$, 10 df, $p = 0.0011$).

Comparisons were also made using the total variance accounted for in the analyses of variance and covariance described above. The results are shown in Table 6.11.

Table 6.11: Percentages of variance accounted for by two-way analyses with main effects of gender and either absolute or relative hand heights, with a) no covariates; or, b) covariates of body mass, isometric lifting strength at 850 mm, and stature; or, c) covariates of fat-free mass, isometric lifting strength at 850 mm, and stature

Analysis	Absolute height			Height as percentage stature		
	Power	Work	Impulse	Power	Work	Impulse
a) Anova	70.784%	90.070%	97.991%	73.999%	86.175%	95.613%
b) bm Ancova	74.318%	92.950%	98.482%	76.756%	92.218%	98.191%
c) ffm Ancova	74.761%	93.273%	98.560%	77.201%	92.624%	98.292%

A three-way factorial Anova was carried out to examine the causes of variation in total variance accounted for. This also showed (Table 6.12) that the covariates used caused significant differences in the variance accounted for, and also that the differences between the dependent variables were very significant. The interaction between the method of measuring hand height and the dependent variables was significant at the 5% level, but since the hand height main effect was non-significant, this can be seen as spurious due to the massive effects of the dependent variables. Post-hoc analysis of means using the Tukey HSD test showed that all three dependent variables were significantly different from each other. It also showed that the two ancovas (analyses *b* and *c*) were significantly different from the Anova (analysis *a*), but not from each other.

Table 6.12: Three way analysis of the total variance accounted for when different covariates are used

Source	Sum of squares	D.F.	Mean Squares	F ratio	Probability
Height	0.000855	1	0.000855	0.001	NS
Dep variable	1716.180	2	858.091	1219.153	0.0000
Analysis	41.148	2	20.574	29.231	0.0041
Height x Dep variable	16.992	2	8.496	12.071	0.0202
Height x Analysis	2.278	2	1.139	1.618	NS
Dep var x Analysis	6.388	4	1.597	2.269	NS
Error	2.815	4	0.704		
Total	1785.802	17			

From these results, it is clear that while the increase in total amount of variance accounted for when using fat-free mass instead of body mass was not significant, the amount of variance due to gender was less using fat-free mass than when using body-mass. This latter result is not surprising given that females have a greater percentage of body fat than males. Therefore, in order to account for as much variance as possible, and to reduce the effect of gender as much as possible, it was decided to use fat-free mass as a covariate in preference to body mass.

6.3.4 Effect of sequence of entry of covariates

Not only does the proportion of variance assigned to each covariate depend upon the correlations between the covariates, but when Type I sums of squares were used, it also depends upon the sequence of entry of covariates to the analysis. Thus, addition of a single covariate to an anova model will account for all the variance associated with that covariate. Addition of a second, correlated, covariate will increase the variance accounted for by less than the amount the second covariate would account for if it was the only covariate in the model. This is because some of its variance has already been accounted for because it it correlated with the first covariate. Changing the sequence of entry of covariates does not change the total variance accounted for by the covariates, but redistributes it between the covariates.

The sequence of entry of the covariates was systematically varied in order to examine this effect, and to find the relative importance of the covariates. The results are shown in Figures 6.1 and 6.2 for absolute hand heights and in Figures 6.3 and 6.4 for relative hand heights, and in full in Appendix 3, Tables A3.19 to A3.54.

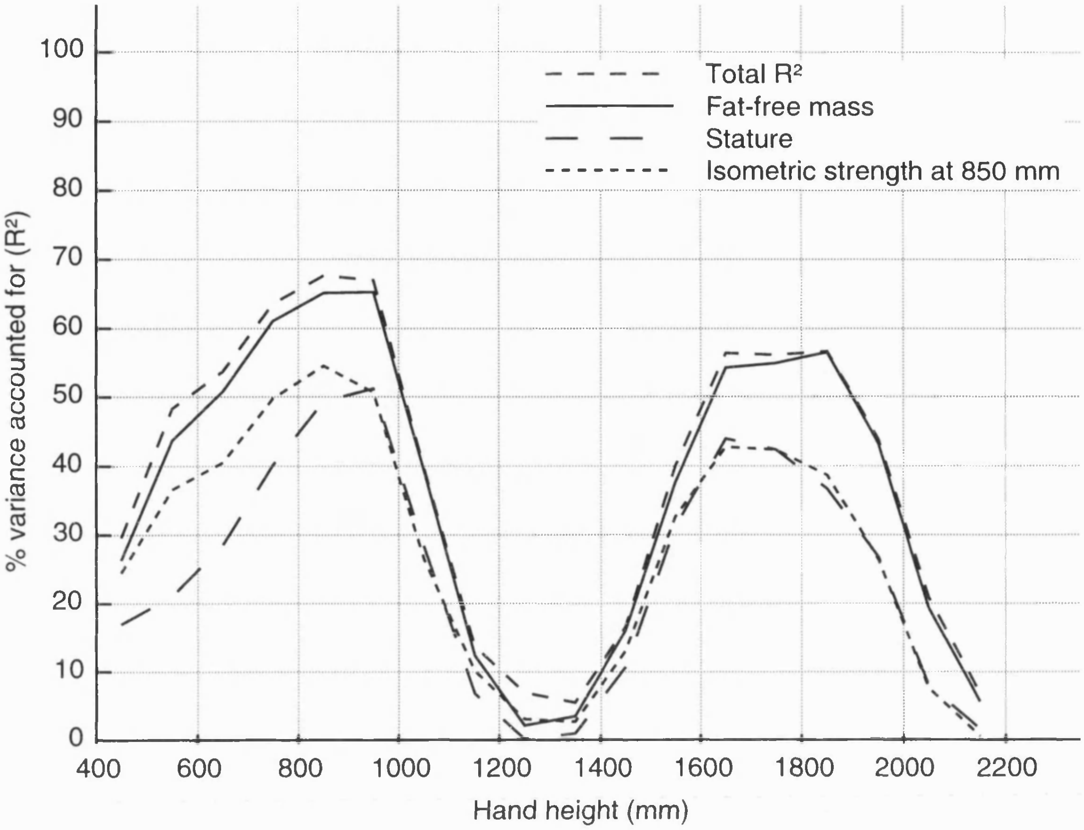


Figure 6.1: Effect of the choice of the first covariate to enter the model, for absolute hand heights

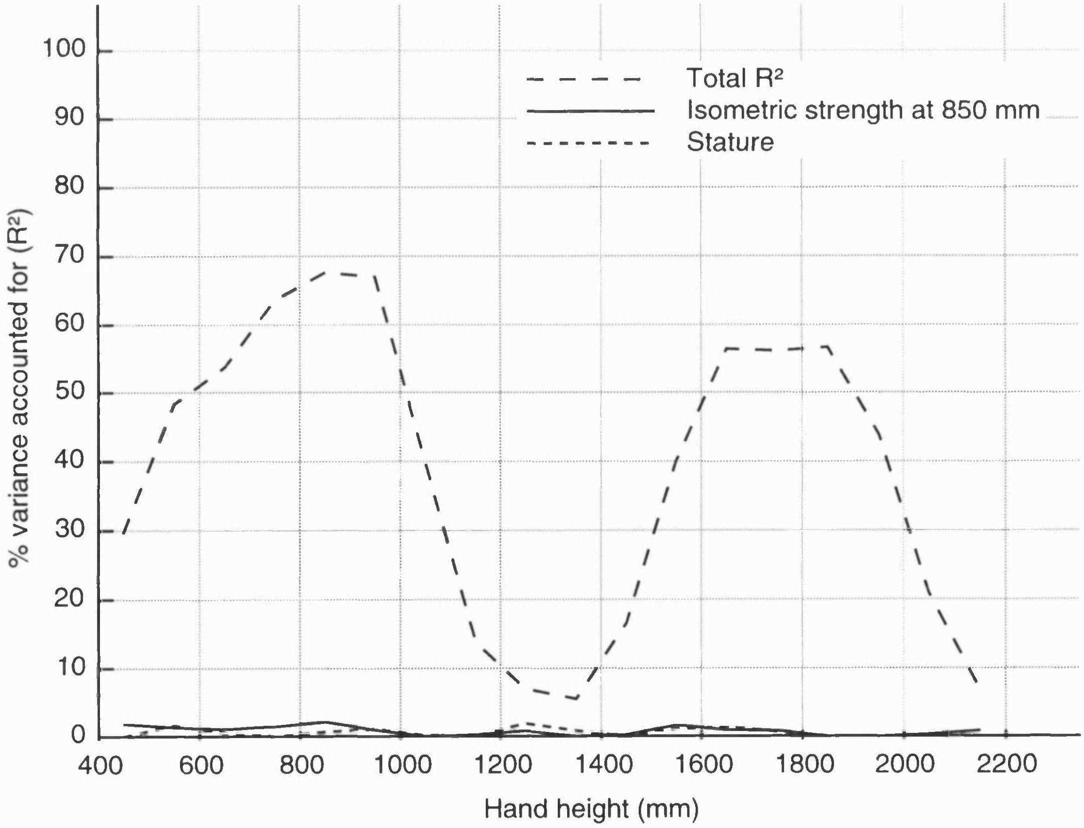


Figure 6.2: Effect of the choice of the second covariate to enter the model, for absolute hand heights

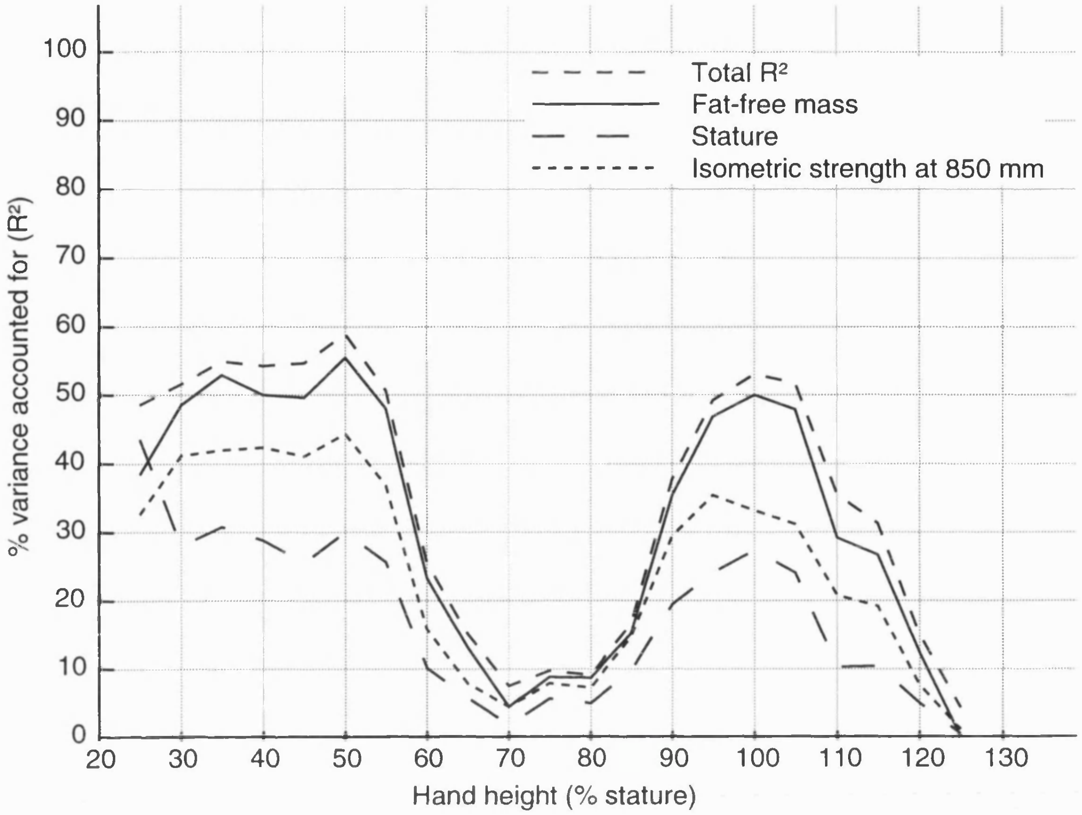


Figure 6.3: Effect of the choice of the first covariate to enter the model, for relative hand heights

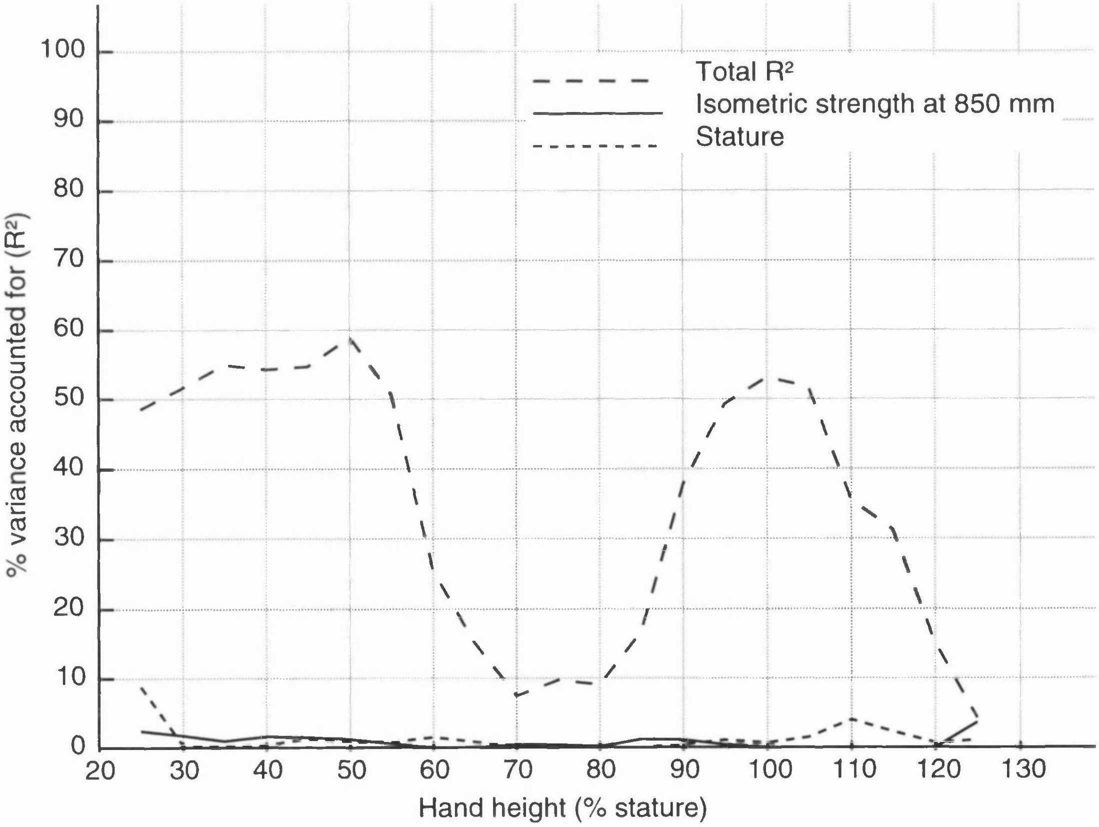


Figure 6.4: Effect of the choice of the second covariate to enter the model for relative hand heights

Figures 6.1 and 6.3 show that fat-free mass was the covariate that on its own accounted for most variance. Use of stature and isometric lifting strength at 850 mm as second and third covariates added only small amounts to the total variance accounted for (Figures 6.2 and 6.4). Whether stature or isometric strength at 850 mm accounted for more variance depended upon hand height. Because isometric lifting strength at 850 mm accounted for more variance at more points than stature, it was decided to use it always as the second covariate, with stature being entered third.

6.3.5 Effect of covariates on the amount of variance accounted for by gender

As is clear from Tables 6.9 to 6.13, inclusion of covariates in an Anova model affects the amount of variance attributed to gender. Therefore, one-way analyses of variance were carried out at hand heights from 450-2150 mm (Figure 6.5, Appendix 4, Tables A4.1 to A4.40) and from 25-125% of stature (Figure 6.6, Appendix 5. Tables A5.1 A5.46) to examine the effect of gender with and without the influence of the three chosen covariates being removed.

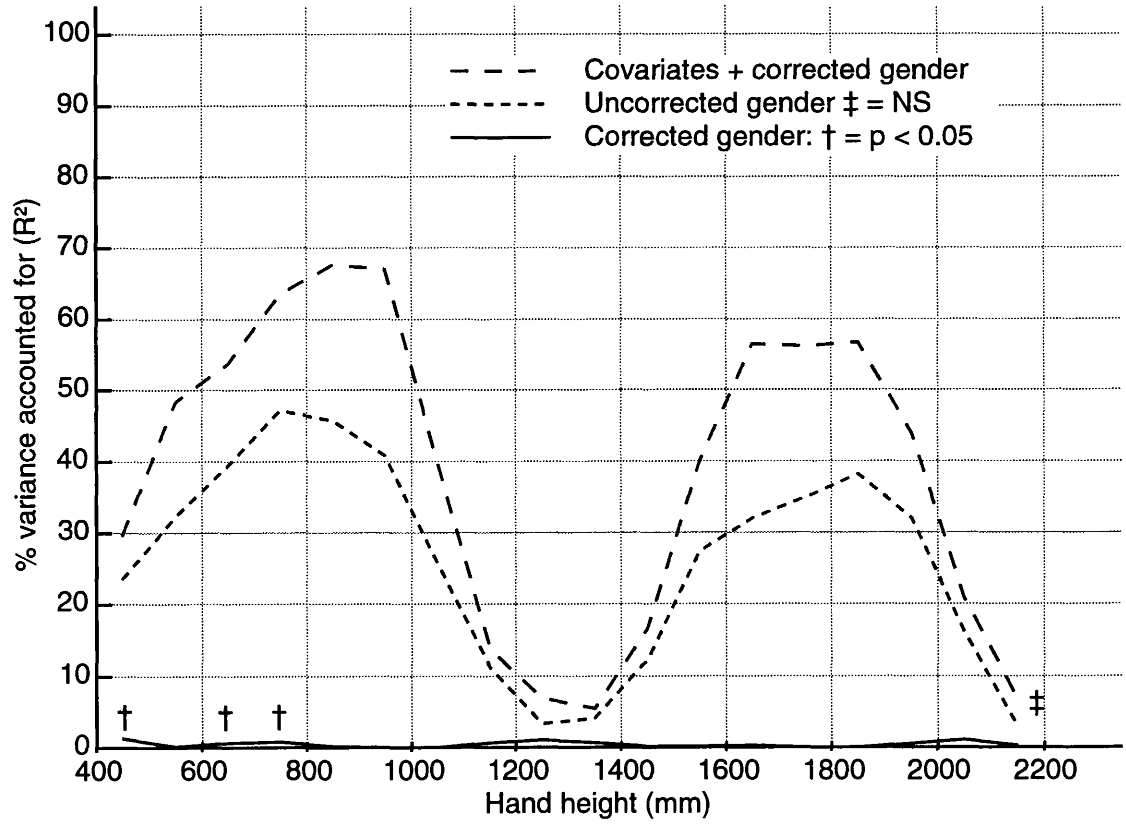


Figure 6.5: Variance in instantaneous power accounted for by gender, with and without the removal of the effects of covariates, for absolute hand heights

These graphs show that while there are very major differences between men and women in performance on the hydrodynamometer, once the differences between the genders in fat-free mass, stature and isometric strength (measured at 850 mm) are accounted for, then the differences almost totally disappear. In fact, the differences are significant at only a few heights, and then only weakly.

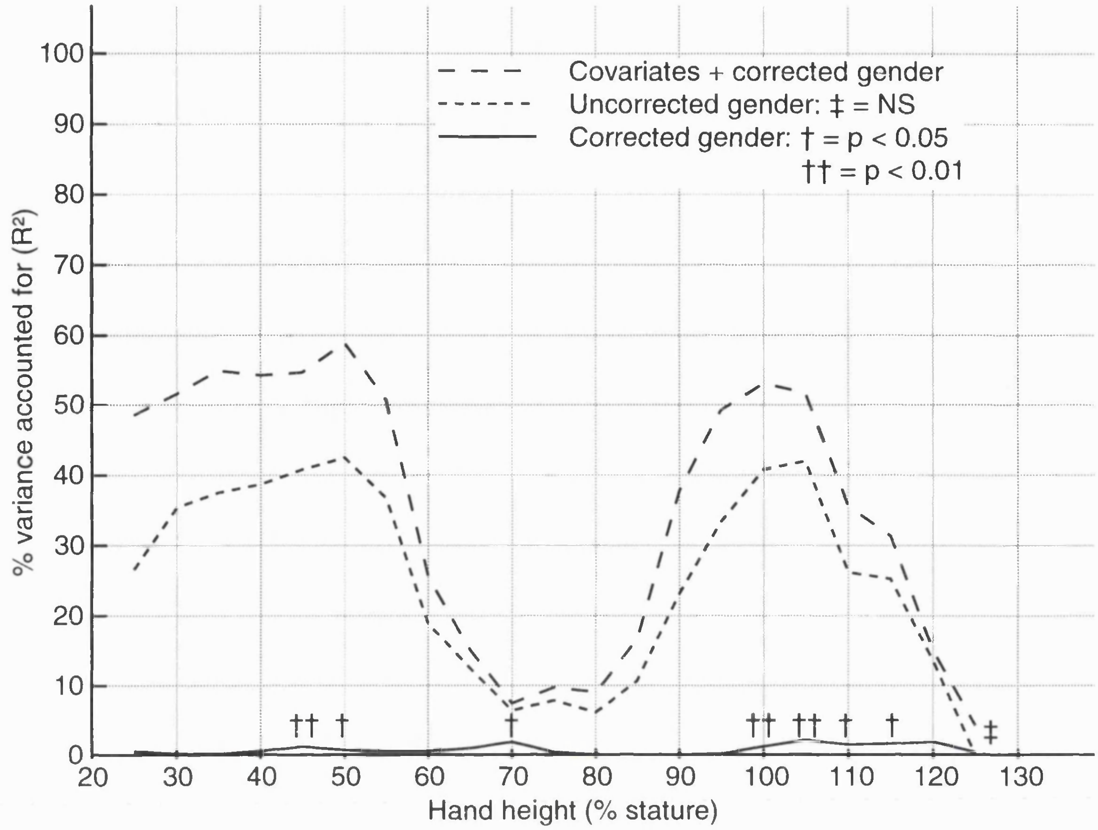


Figure 6.6: Variance in instantaneous power accounted for by gender, with and without the removal of the effects of covariates, for relative hand heights

It can therefore be concluded that the measured gender differences are almost exclusively due to the differences in fat-free mass between males and females. In other words, the aspects of masculinity and femininity that cause gender differences in strength are the differences in fat-free mass. This difference is larger than the difference in total body mass that exists because women are, on average, lighter than men, because women also have a greater percentage of body fat. Any differences in performance that remain after fat-free mass has been taken into account are small enough to be dismissed as either insignificant or trivial. It therefore follows that, in the context of strength, women can be described as small and fat men. Thus weakness is not an inherently female trait, and this study does not support the suggestion that male and female muscles are fundamentally different.

6.3.6 Analysis of measurements of instantaneous forces

Graphs of force against height, for both males and females, are shown in Figures 6.7 and 6.8. These graphs are included for completeness. They are almost identical in form to the graphs of power against height reproduced below. Therefore the discussion of measurements of power should also be applied to force.

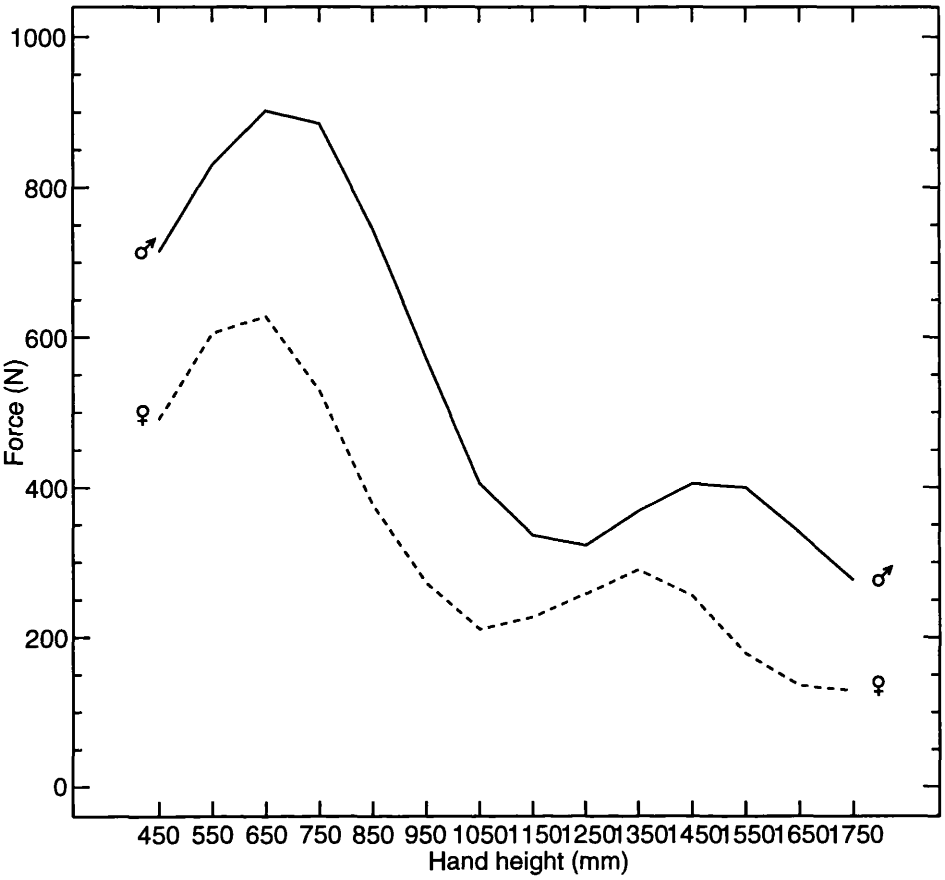


Figure 6.7: Effect of gender and absolute hand height on force produced

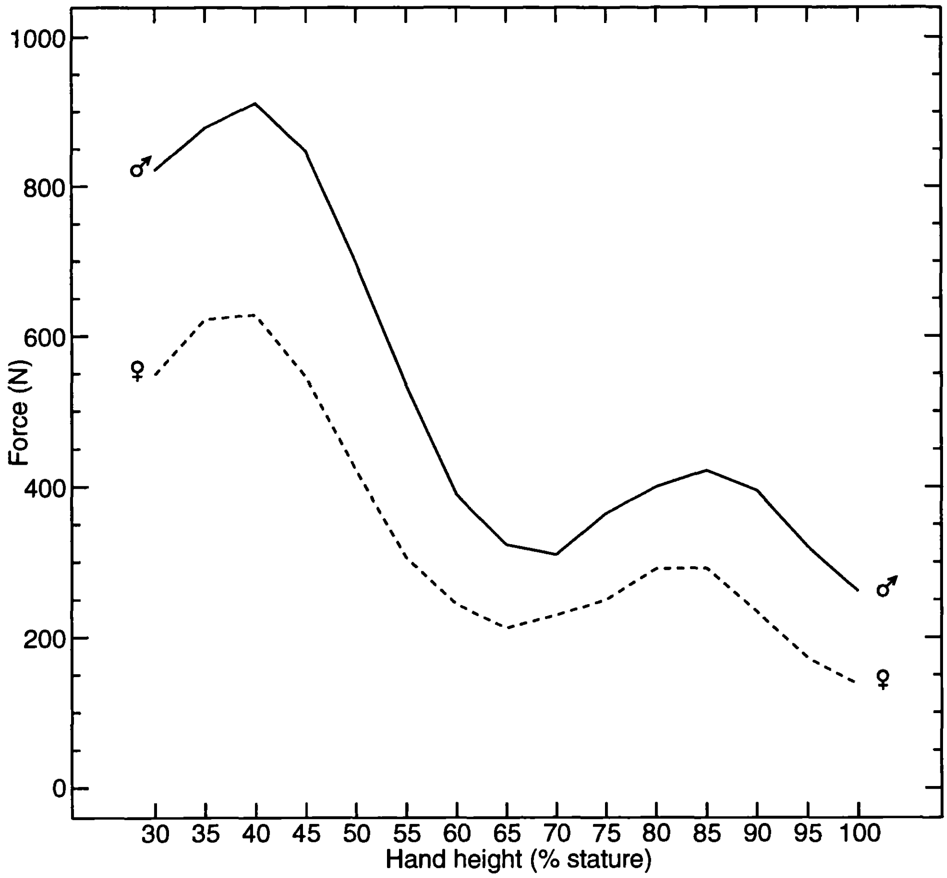


Figure 6.8: Effect of gender and relative hand height on force produced

6.3.7 Analysis of measurements of instantaneous power output

Absolute hand heights

The results of Ancova of power measurements between 450 and 1750 mm are shown in Table 6.13 and Appendix 4, Tables A4.3 to A4.38. Graphs of mean power output (Table A4.39) by males and females are shown in Figure 6.9. The amounts of variance accounted for by gender and by the three covariates are shown in Figure 6.10.

Table 6.13: Two-way Ancova of power measured at 100 mm intervals

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	32512584	1	32512584	2033.634	0.0000	13.691%
Isom strength at 850 mm	910220	1	910220	56.933	0.0000	0.383%
Stature	77989	1	77989	4.878	0.0273	0.033%
Main Effects						
Gender	268369	1	268369	16.786	0.0000	0.113%
Height	135696119	13	10438163	652.898	0.0000	57.141%
Interactions						
Gender x Height	8072891.2	13	620991.63	38.842	0.0000	3.399%
Residual	59936892	3749	15987.44			
Total (Corrected)	237475064	3779				74.761%

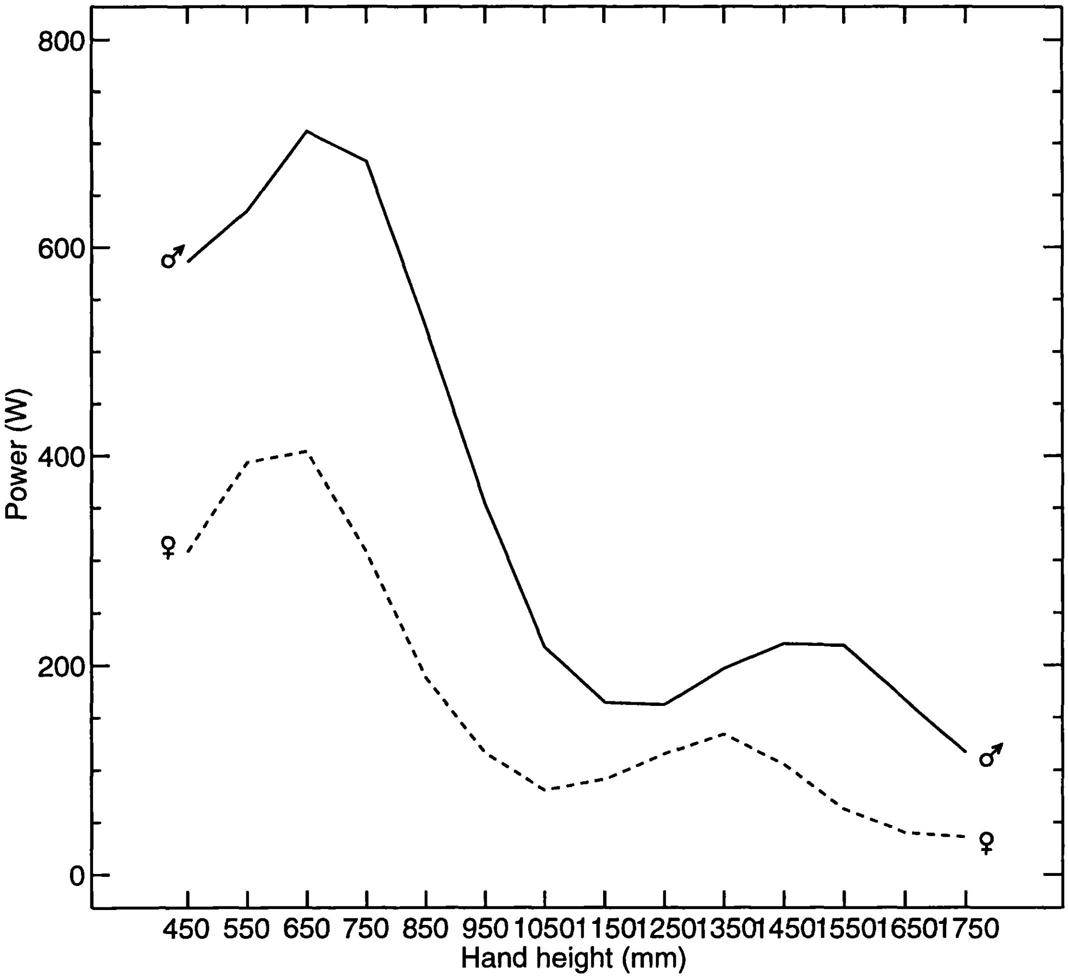


Figure 6.9: Effect of gender and absolute hand height on power produced

These results show that, at any given height, women consistently produce less power than men, and the minimum and subsequent maximum power outputs due to changing grip part way through the lift occur at lower heights than for men. Examination of the gender differences after accounting for the effects of the covariates show that they almost disappear, with the remaining differences occurring at the lowest heights, i.e. the initial pulling phase up to 750 mm (approximately knuckle height). This comparison does not answer the question of whether women have less upper body strength than men because the heights have not been corrected for stature.

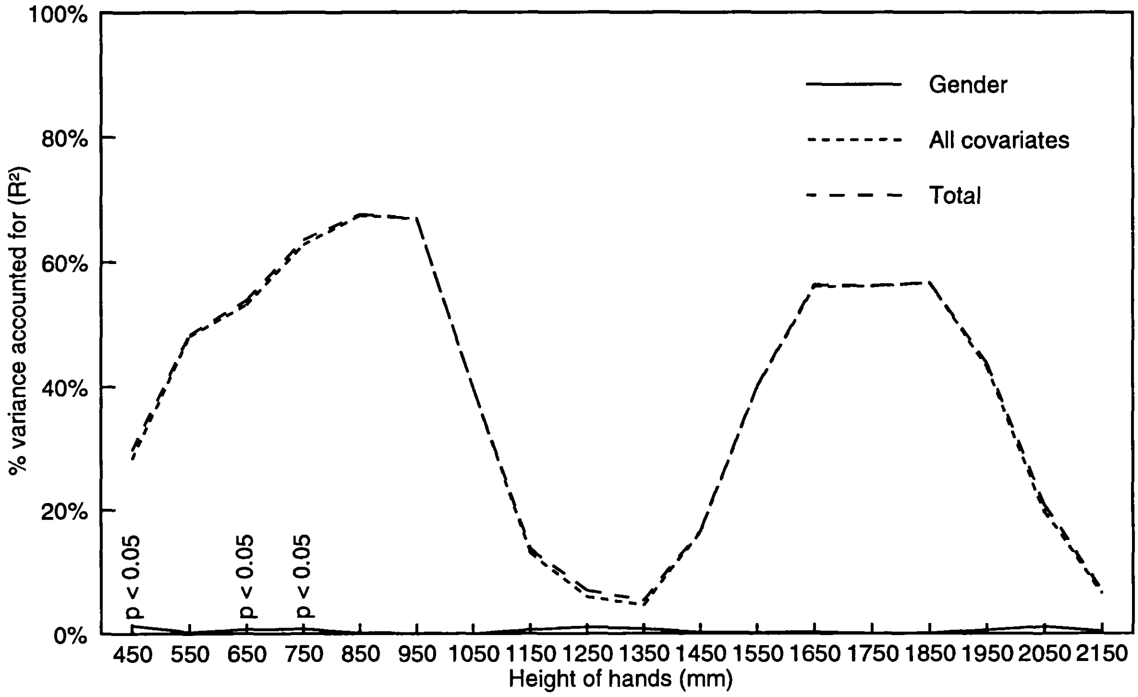


Figure 6.10: Variance of power output accounted for by gender and three covariates at absolute hand heights with significance levels of gender after correction for covariates

Relative hand heights

In a similar manner to the analysis for absolute hand heights, Ancova was used to examine power outputs at 5% intervals of stature. The results are shown in Table 6.14 Appendix 5, Table A5.45 and Figures 6.11 and 6.12 and Tables A5.3 to A5.44.

These results show that normalising hand height to stature increased the total variance and the variance accounted for by hand height by 2.4% and 5.6% respectively. However, the variance accounted for by the covariates decreased by 2.7%. At the same time the variance accounted for by gender increased by 0.019%, but the variance associated with the gender × height interaction was reduced by 0.48%. Normalisation is often seen as a means of removing an effect, but in this case it is acting to enhance the significance of both hand height and gender while reducing the effect of the interaction.

Table 6.14: Two-way Ancova of power measured at 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	25616997	1	25616997	1907.761	0.0000	10.828%
Isom strength at 850 mm	613876	1	613876	45.717	0.0000	0.259%
Stature	728595	1	728595	54.260	0.0000	0.308%
Main Effects						
Gender	311319	1	311319	23.185	0.0000	0.132%
Height	148472492	14	10605178	789.794	0.0000	62.757%
Interactions						
Gender x Height	6900848	14	492917.69	36.709	0.0000	2.917%
Residual	53939403	4017	13427.78			
Total (Corrected)	236583530	4049				77.201%

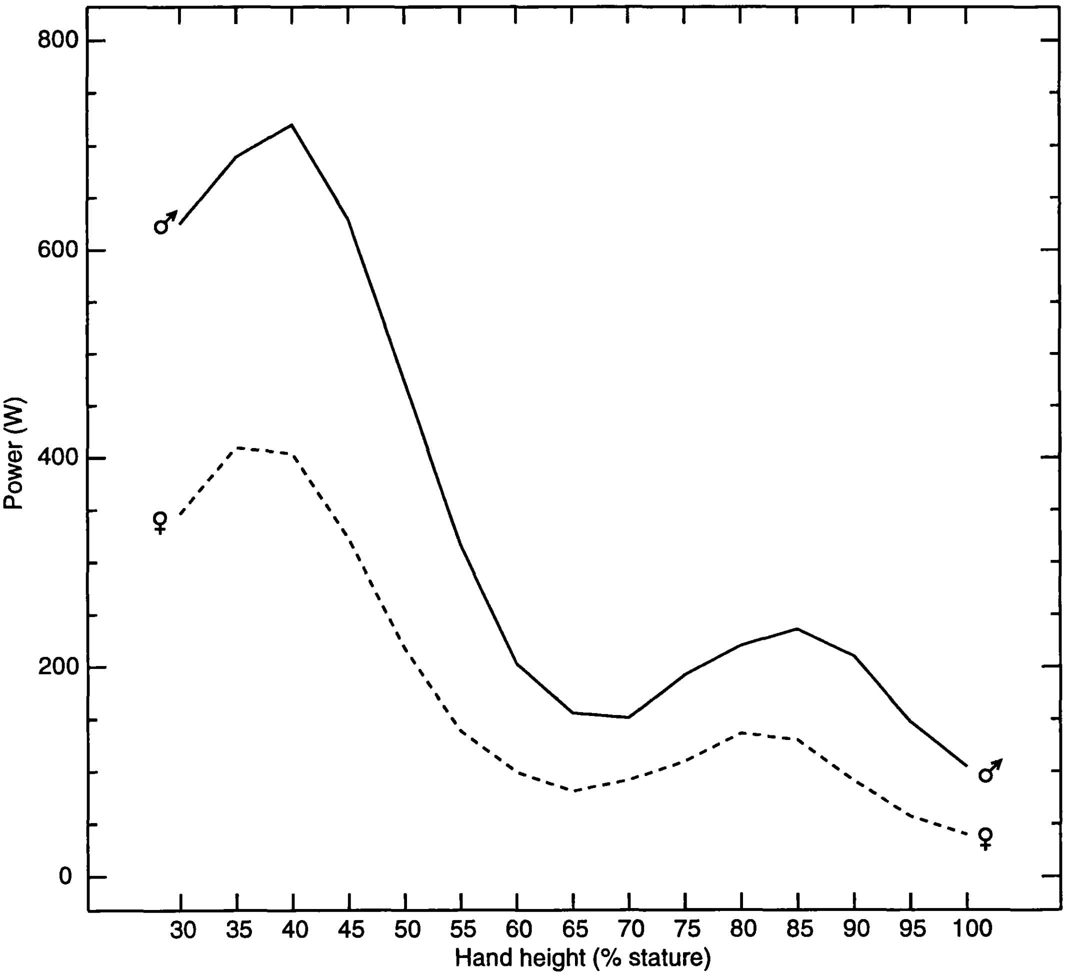


Figure 6.11: Effect of gender and relative hand height on power produced

Figure 6.11 shows that men and women performed the exertions in the same way at the same percentages of stature since the maxima and minima in the normalised curves occurred at almost the same percentages of stature.

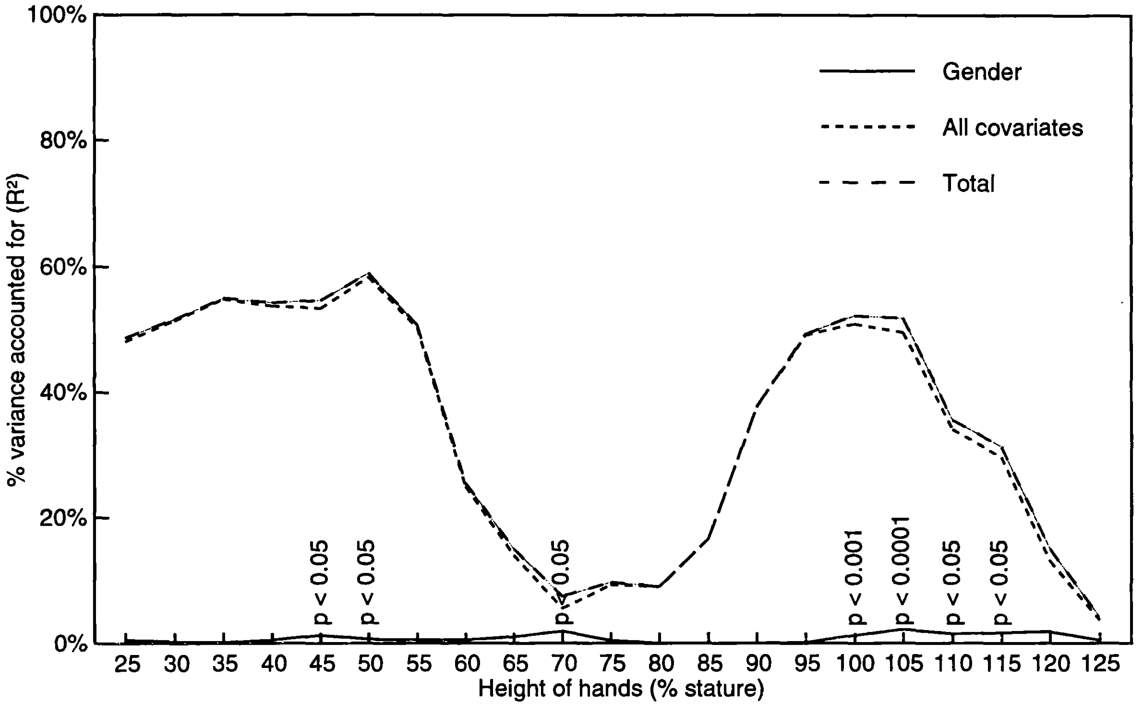


Figure 6.12: Variance of power output accounted for by gender and three covariates at relative hand heights with significance levels of gender after correction for covariates

Figure 6.12 shows that gender differences after correction for covariates occur in three regions of this graph: during the initial impulse, at 45% and 50% of stature, i.e. below hip height, during the weak change of grip at 75% stature, and above head height (100% -125% stature). The early stages of the lift involve leg and back extension, while the later stages almost exclusively involve the upper limbs (Fothergill, 1992). It therefore appears that the major gender difference shown here is that females are less good at producing powerful exertions above the head. This is considerably different to the common hypothesis that women have less upper body strength than men since no gender difference is apparent in the pushing phase largely involving arm strength between 75% and 100% of stature.

6.3.8 Analysis of measurements of work done

Absolute hand heights

The results of Ancova of work done to heights between 450 mm and 1750 mm are shown in Table 6.15. Graphs of work for males and females are shown in Figure 6.13. The amounts of variance accounted for by gender and by the three covariates are shown in Figure 6.14. Means are reported in Appendix 4, Tables A4.79 and A4.80.

This Ancova model accounts for a very high proportion of the variance, i.e. over 93%, with only 0.25% being attributed to gender and 2.84% to the interaction between gender and hand height.

Table 6.15: Two-way Ancova of work done to 100 mm intervals of hand height

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	23549906	1	23549906	7129.024	0.0000	12.792%
Iso strength at 850 mm	671010	1	671010	203.128	0.0000	0.364%
Stature	53659	1	53659	16.244	0.0001	0.029%
Main Effects						
Gender	467811	1	467811	141.616	0.0000	0.254%
Hand height (mm)	141745513	13	10903501	3300.706	0.0000	76.992%
Interactions						
Gender x Height	5233009.2	13	402539.17	121.857	0.0000	2.842%
Residual	12384388	3749	3303.38			
Total (Corrected)	184105297	3779				93.273%

The results show that to any height over the range of the lift, the work done by the males was always significantly greater than that done by the females. Since work is the product of force and distance, i.e. the integral of force with respect to distance, then the work done to any height is a measure of the sum of the forces exerted in reaching that height. The gender difference at any height is therefore a reflection of the gender differences in the forces produced (see Figures 6.7 and 6.8) at all points up to that height. Because of the cumulative nature of the variable, the absolute values of the gender difference will tend to increase with height.

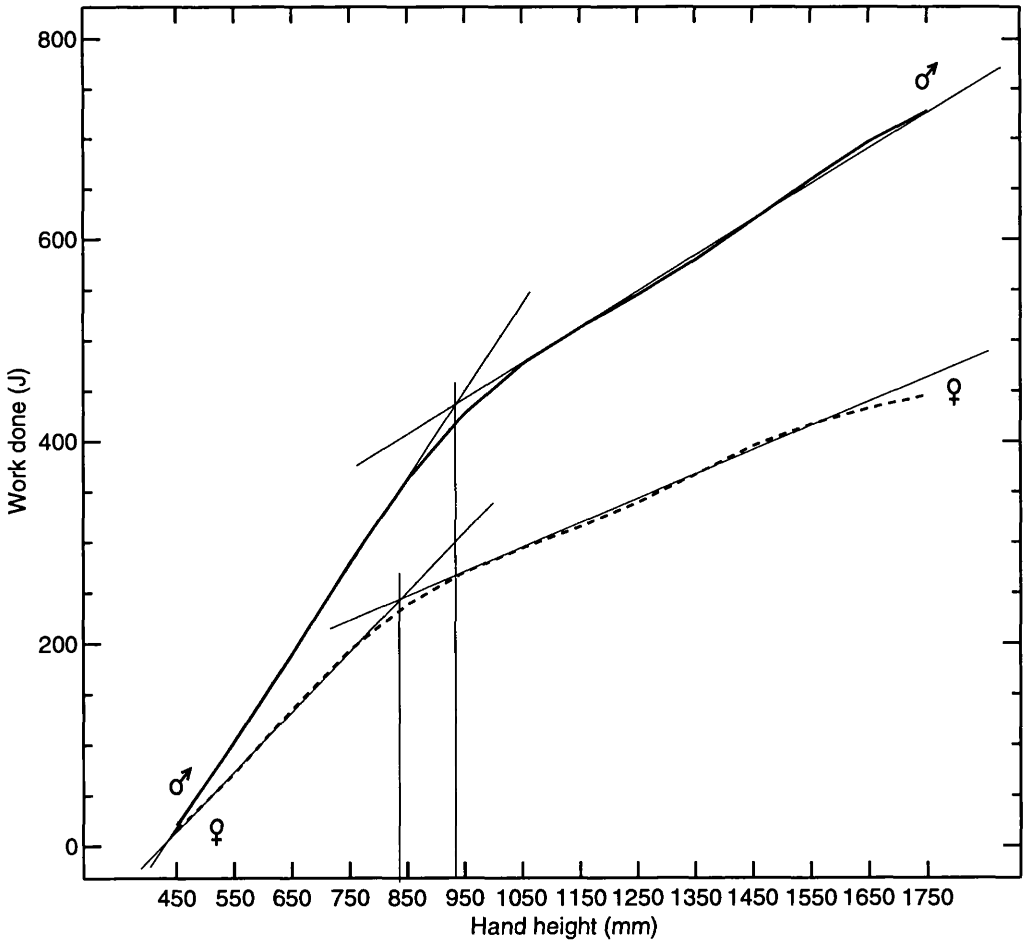


Figure 6.13: Effect of gender and absolute hand height on work done

Each of the plotted male and female work curves can be approximated by two intersecting straight lines. It is therefore possible to find the heights at which these intersections occur. In this case, it occurs at approximately 950 mm for males and 850 mm for females. These are below the heights of 1250 mm and 1050 mm at which the minima in the force and power curves occur for males and females respectively. Due to the interaction of gender and height, one-way analyses of covariance were carried out at each height between 450 mm and 2150 mm. This allows the comparison of the relative importance of gender and the covariates without variations in height affecting each comparison. The results are shown in Appendix 4, Tables A4.41 to A4.80, and are plotted in Figure 6.14.

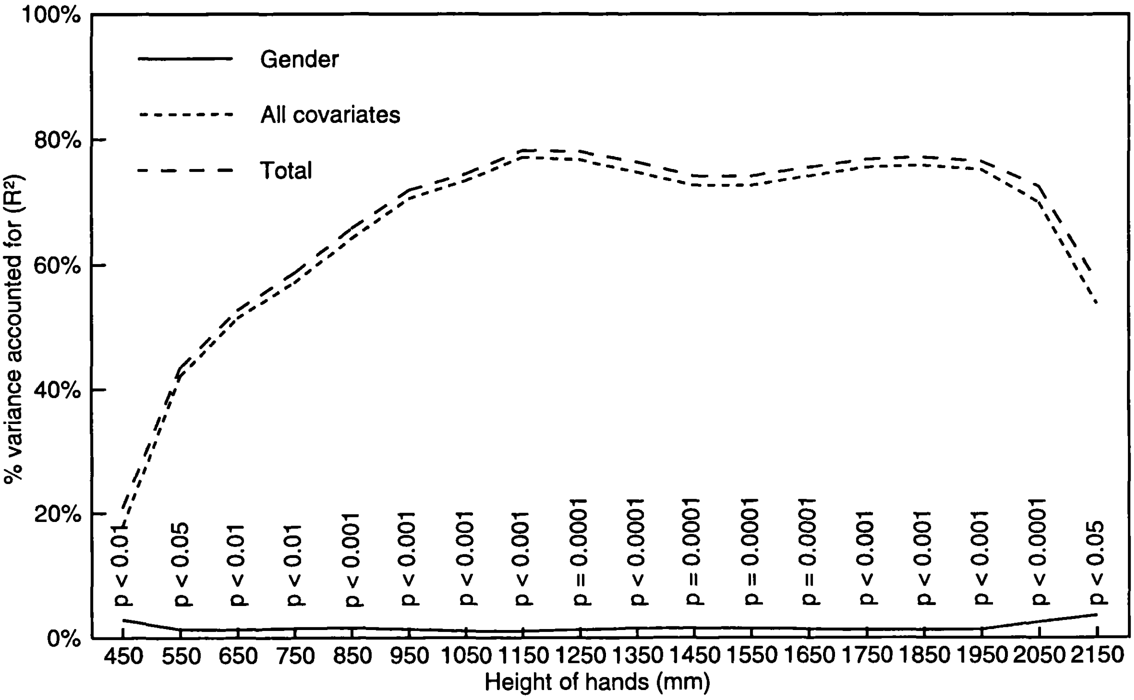


Figure 6.14: Variance in work done accounted for by gender and three covariates for absolute hand heights with significance levels of gender after correction for covariates

It is clear that while the gender differences are largely highly statistically significant, even after correction for the three covariates, the actual percentage of variance accounted for by gender is very small. The way that the variance accounted for at any height varies reflects the effect of height. It is also apparent that the amount of variance accounted for increases up to a height of 1150 mm. After this point, which is approximately where the change of grip occurs, the proportion of variance accounted for is relatively constant at about 80%.

Relative hand heights

The total work done to each 5% interval of stature was analysed using Ancova. The results are shown in Table 6.16, and the means for males and females are plotted in Figure 6.15 and tabulated in Appendix 5, Table 5.91.

Table 6.16: Two-way Ancova of work done made at 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	39250250	1	39250250	11830.90	0.0000	21.724%
Isom strength at 850 mm	1236649	1	1236649	372.754	0.0000	0.684%
Stature	264827	1	264827	79.825	0.0000	0.147%
Main Effects						
Gender	344672	1	344671.7	103.892	0.0000	0.191%
Height	121808130	14	8700580.7	2622.551	0.0000	67.418%
Interactions						
Gender x Height	4443515	14	317393.9	95.67	0.0000	2.459%
Residual	13326809	4017	3317.60			
Total (Corrected)	180674851	4049				92.624%

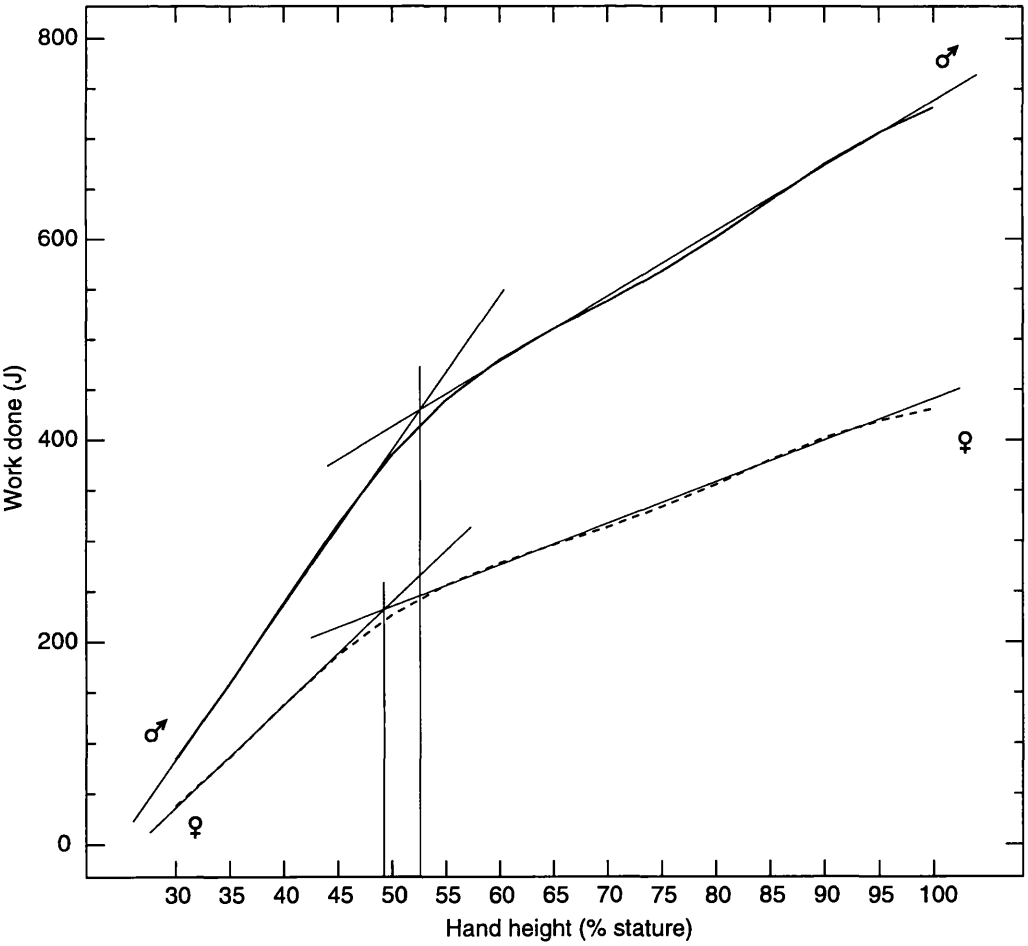


Figure 6.15: Effect of gender and relative hand height on work done

Normalisation to stature kept the proportion of variance accounted for by the model effectively constant, with it decreasing by only 0.65%. The effect of gender was almost unchanged, decreasing by 0.063%, and the hand height x gender interaction decreased by 0.383%. However, the actual work done to each height up to 100% stature was very different for males and females. The effect of hand height decreased by 9.57%, which was almost compensated for by a 9.37% increase in the effect of the covariates, i.e normalisation shifted variance from hand height to fat-free mass. As had been done for absolute hand heights, the curves were approximated by pairs of straight lines. The intersections of the lines, i.e. the points at which the changes in slope occur, were found to be at approximately 52% for males and 49% for females.

As with absolute hand height data, due to the interaction between hand height and gender, one-way analyses of variance were carried out at each 5% of stature between 25% and 125% of stature. The results are shown in Figure 6.16 and Tables A5.47 to A5.92 in Appendix 5.

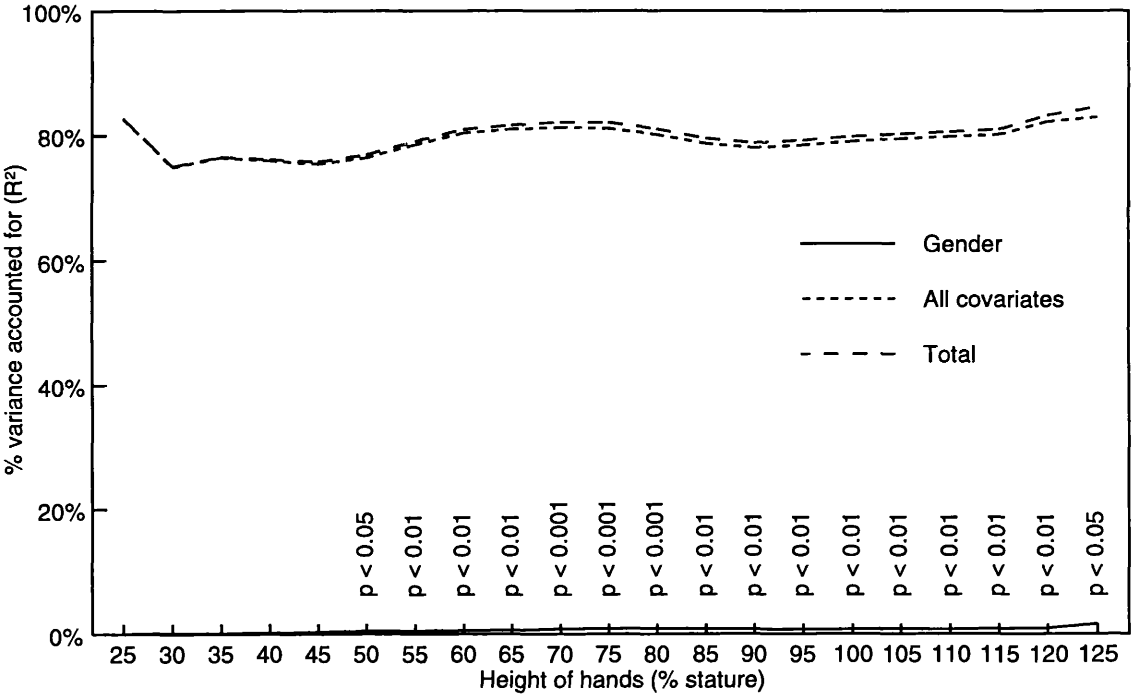


Figure 6.16: Variation in work done accounted for by gender and three covariates for relative hand heights with significance levels of gender after correction for covariates

The effect of normalisation has been to change the shape of the curve dramatically , eliminating the initial increase in variance accounted for. The total variance accounted for remains constant at just below 80%. Gender differences are insignificant in the early portion of the lift, and are reduced in significance throughout the lift. This means that, after correction for covariates, there was no difference between the work that males and females performed up to 50% of stature, i.e. before the change in slope shown in Figure 6.15. Because at heights above 50% stature the upper body is doing the work while the straightened lower limbs are merely providing support, it can be concluded that women have less capacity than men for performing work with the upper body.

6.3.9 Analysis of measurements of impulse

The same procedures that were used for the work data were used for the impulse data. Because impulse is the integral of force with respect to time, while work is the integral of force with respect to distance, it is likely that similar results will be obtained. Impulse is a measure of the magnitude and duration of the force which caused the hands to reach any particular height. Therefore gender differences in impulse will be related to gender differences in force and inversely related to gender differences in velocity.

Absolute hand heights

The results of two-way Ancova of impulse to heights between 450 and 1750 mm are shown in Table 6.17. Graphs of the mean impulses for males and females are shown in Figure 6.17. The variance accounted for by gender and the covariates are shown in Figure 6.18. Underlying data are reported in Appendix 4, Tables A4.81 to A4.120.

Table 6.17: Two-way Ancova of impulse to 100 mm intervals of hand height

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	12866455	1	12866455	7465.128	0.0000	2.867%
Iso strength at 850 mm	291359	1	291359	169.047	0.0000	0.065%
Stature	8113	1	8113	4.707	0.0301	0.002%
Main Effects						
Gender	527358	1	527358	305.974	0.0000	0.117%
Hand height (mm)	424719035	13	32670695	18955.563	0.0000	94.624%
Interactions						
Gender x Height	3976401.9	13	305877.07	177.47	0.0000	0.886%
Residual	6461556.1	3749	1723.54			
Total (Corrected)	448850279	3779				98.560%

These results show that this model accounts for all but 1.4% of the variance in impulse. The vast majority is accounted for by hand height, 2.9% is accounted for by the covariates, and only 0.117% and 0.886% respectively are accounted for by gender and the gender x hand height interaction. This domination of the variance accounted for by hand height is to be expected because of the cumulative nature of the measure.

While the women exerted smaller forces than the men, they exerted them for longer, as can be seen from the times in Table A1.4 for lifts to 1700 mm (3.59 s as opposed to 2.63 s). In the calculation of impulse, these differences will therefore tend to have cancelled each other out and to have minimised the gender difference.

The curves in Figure 6.17 are of the same form as the curves for the work done, again reflecting the cumulative nature of the two measures. As with work, each curve was approximated by two straight lines. Again, as with work (Figure 6.13), the intersection occurs at approximately 950 mm for males and 850 mm for females.

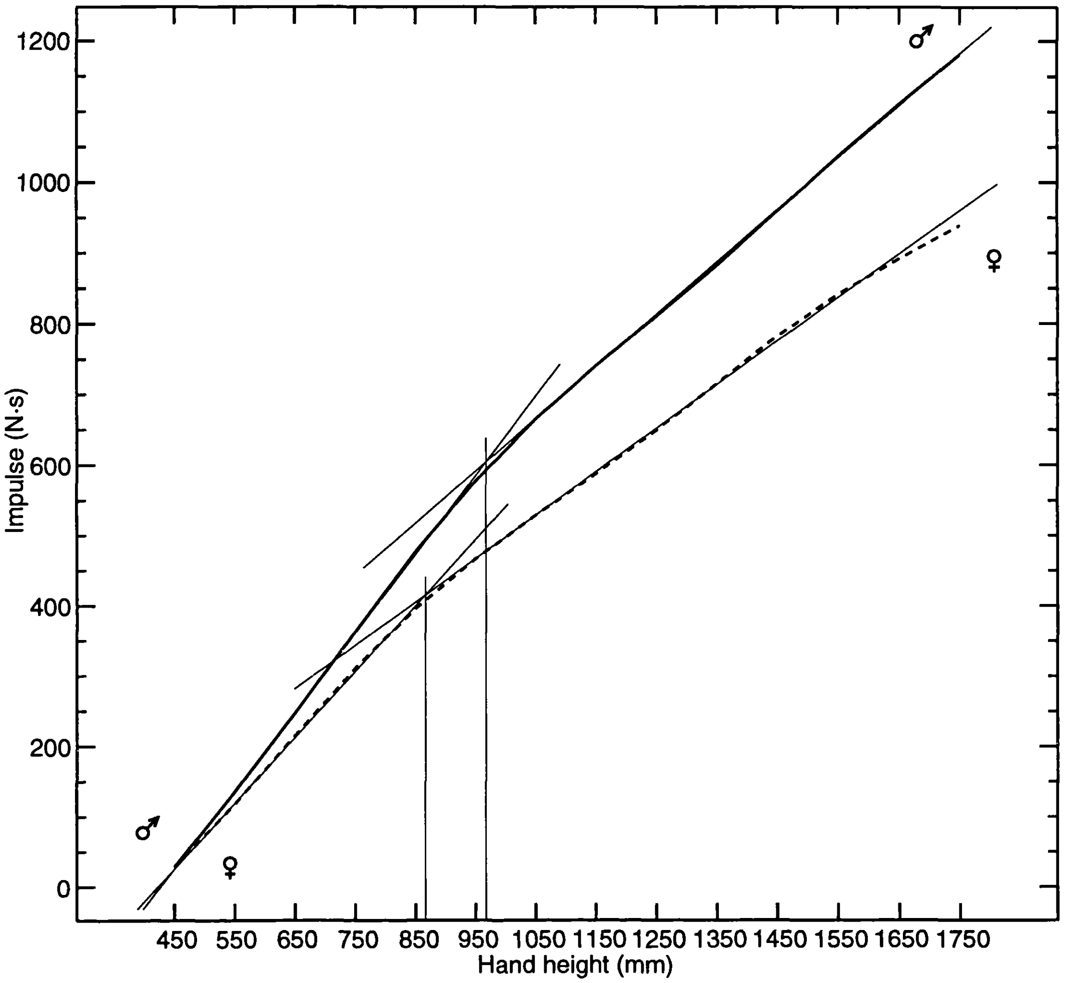


Figure 6.17: Effect of gender and absolute hand height on impulse

Due to the significant interaction between gender and hand height revealed in Table 6.17, one-way analyses of variance were carried out at 100 mm intervals of hand height between 450 and 2150 mm. This allowed comparison of the effects of gender and the covariates when the effect of hand height has been removed. The results are shown in Figure 6.18 and Table A4.83 to A4.120 in Appendix 4.

Figure 6.18 is almost identical in form to the hand height - work graph in Figure 6.14, with an increase in the percentage of variance accounted for up to 1150 mm (the change in grip), and with almost 80% accounted for thereafter. Gender is highly significant at all heights, and the actual percentage of variance accounted for by gender is greater than for work.

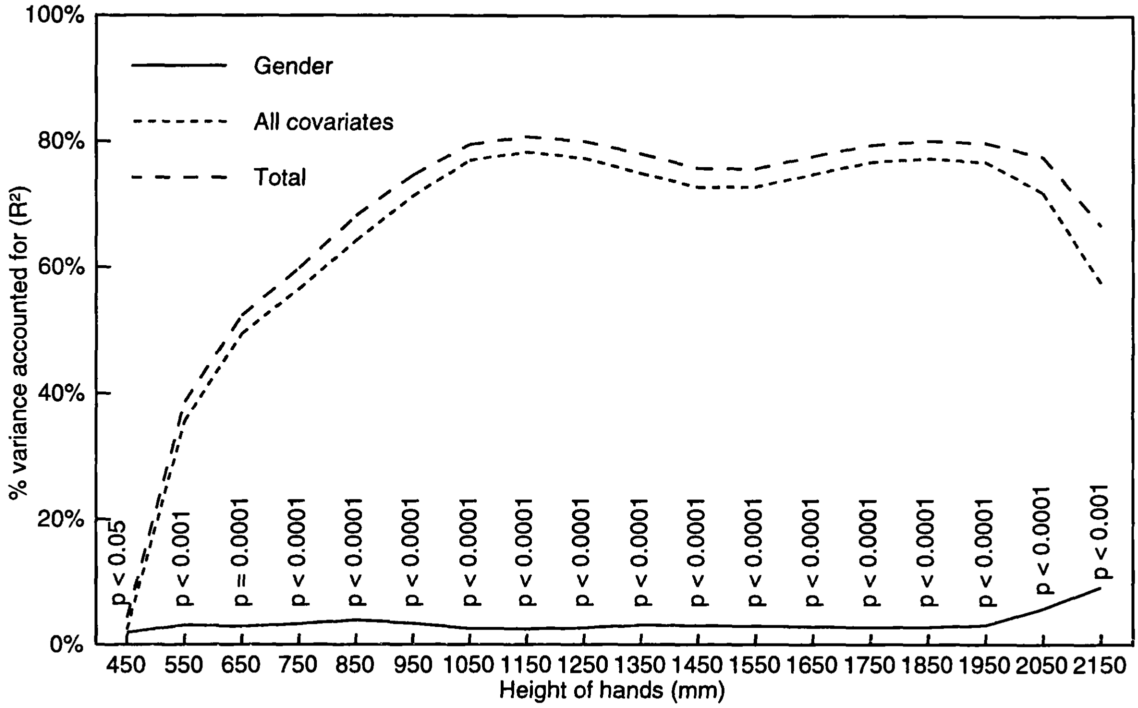


Figure 6.18: Variance in impulse accounted for by gender and three covariates for absolute hand heights with significance levels of gender after correction for covariates

Relative hand heights

As with power and work, impulse to each 5% of stature was analysed using a two-way Ancova. The results are shown in Table 6.18, and the means for males and females are shown in Figure 6.19 and Appendix 5, Table A5.137.

Table 6.18: Two-way Ancova of impulse measured at 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	34844876	1	34844876	18991.14	0.0000	8.072%
Isom strength at 850 mm	1028921	1	1028921	560.782	0.0000	0.238%
Stature	1913837	1	1913837	1043.079	0.0000	0.443%
Main Effects						
Gender	418913	1	418913	228.316	0.0000	0.097%
Height	381500434	14	27250031	14851.8	0.0000	88.376%
Interactions						
Gender x Height	4601553.2	14	328682.37	179.138	0.0000	1.066%
Residual	7370377.8	4017	1834.80			
Total (Corrected)	431678912	4049				98.293%

As with absolute hand heights, the analysis accounted for almost all the variance. Normalisation caused the total sum of squares to decrease by 3.8%, and the proportion of total variance accounted for decreased by 0.27%. Gender accounted for only 0.02% less. The gender × hand height interaction increased by 0.18%. Hand height accounted for 6.25% less, while the effect of the covariates increased by 5.82%.

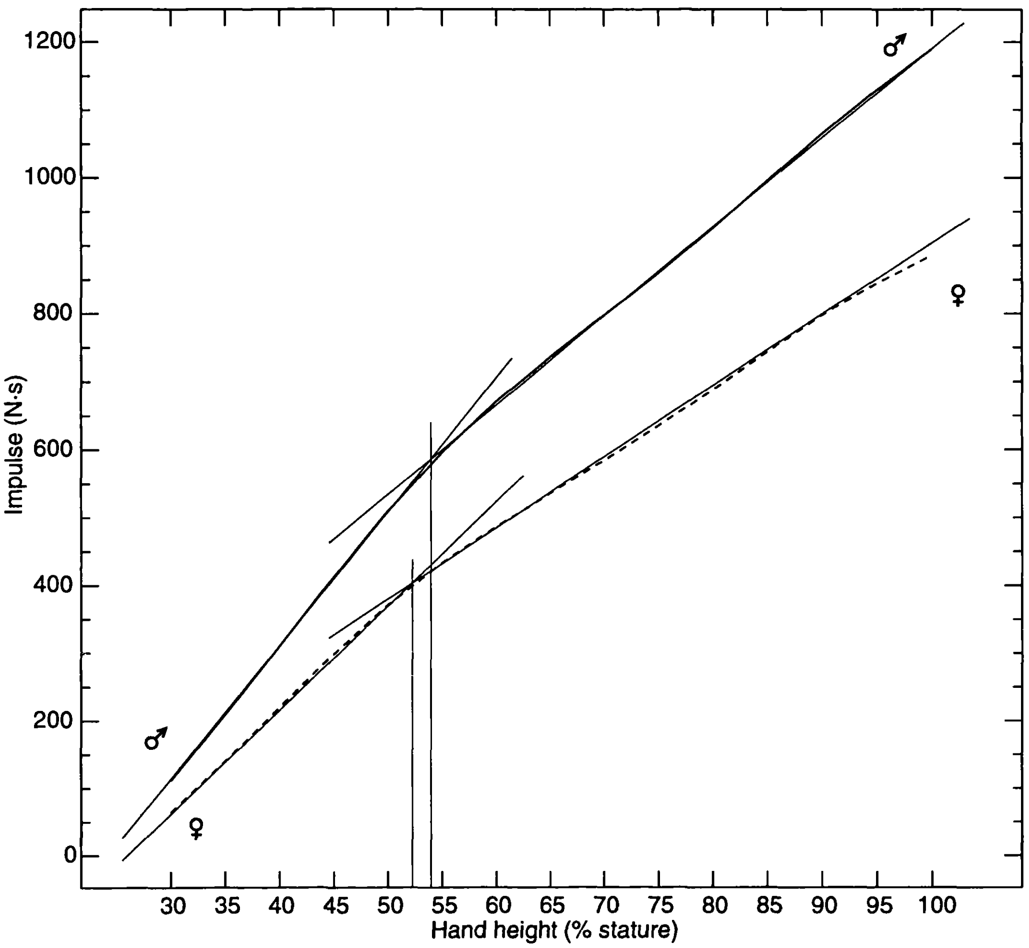


Figure 6.19: Effect of gender and relative hand height on impulse

As with work, the absolute impulse at each height to 100% stature is very different for males and females. Again, as was done for work, the curves were approximated by two straight lines. The intersection of the lines was at approximately 54% stature for males and 52% stature for females. This difference at 2% is smaller than the distance between adjacent points on the curves, which were plotted at 5% intervals of stature, so should be regarded as effectively zero.

Because of the interaction between hand height and gender revealed in Table 6.18, one-way analyses of variance were carried out at each 5% interval of stature to allow the comparison of the gender effect and the covariates without the influence of hand height. The results are shown in Figure 6.20 and Appendix 5, Tables A5.93 to A5.138.

As with the comparable graph for work, normalisation to stature has changed the shape of the early part of the curve, so that approximately 90% of the variance is accounted for throughout the lift instead of 80% in the later stages for the non-normalised data. Again, as with work, there has been a decrease in the significance of the gender difference in the early part of the lift, though in this case it is still significant at all but one height. This similarity between work and impulse extends to when hand height has been expressed as a percentage of stature. The gender differences are greatest above

50% of stature, i.e. in the region where upper limb strength assumes greatest importance. This can partly be attributed to the women performing the lifts more slowly.

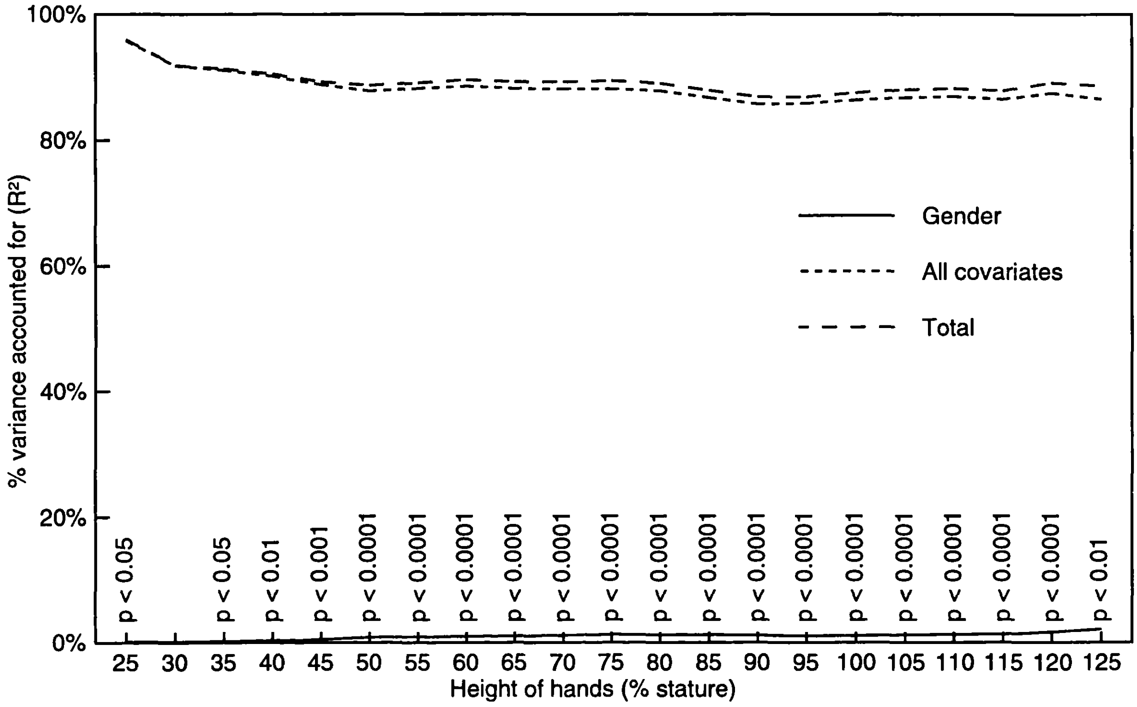


Figure 6.20: Variance in impulse accounted for by gender and three covariates for relative hand heights with significance levels of gender after correction for covariates

6.3.10 Female / male ratios of the various measures

The following graphs show female : male ratios for the measures of force, power, work and impulse before and after correction for the effects of covariates, and at absolute and relative hand heights. For completeness, ratios have been calculated at all heights where data were available, not just at heights where all subjects recorded data. This means that caution should be used when interpreting ratios at heights above 1750 mm and at heights of 25% and 105-125% of stature, especially at 2150 mm and 125% stature which are based on only 3 females and 55 males and 30 females and 21 males respectively.

Corrections for covariates were made using one-way Anova at each height since the interactions found between height and gender made it impossible to apply a single correction factor across all heights.

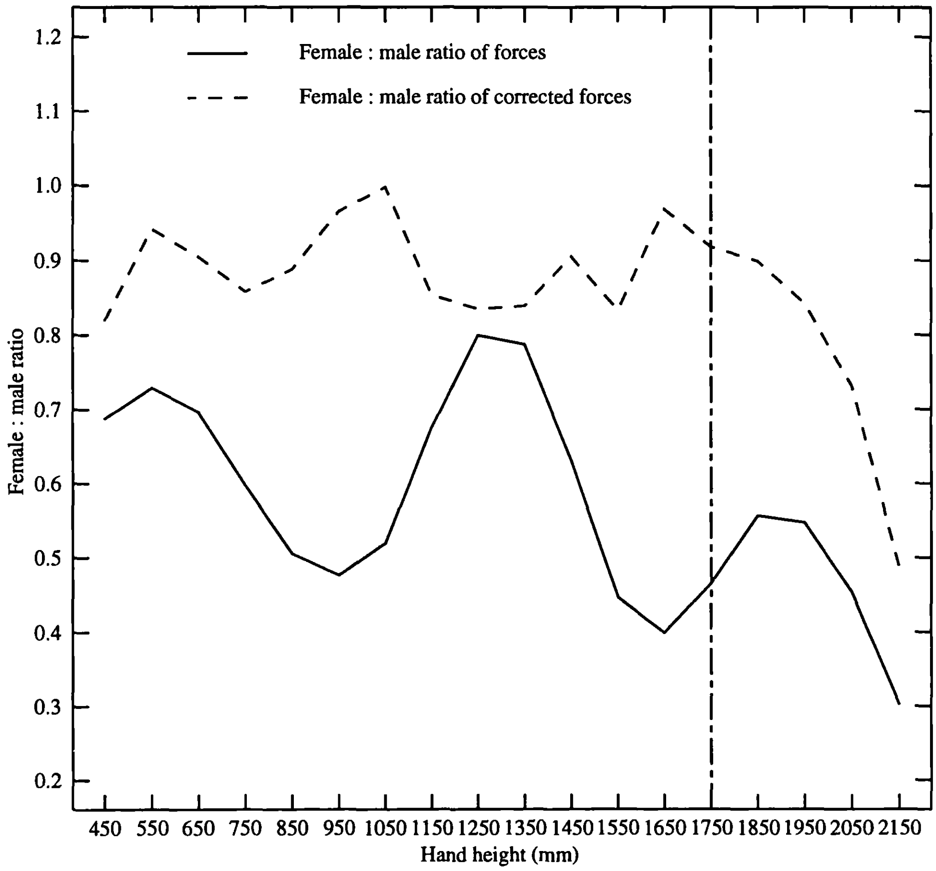


Figure 6.21: Female : male ratios for force at absolute hand heights

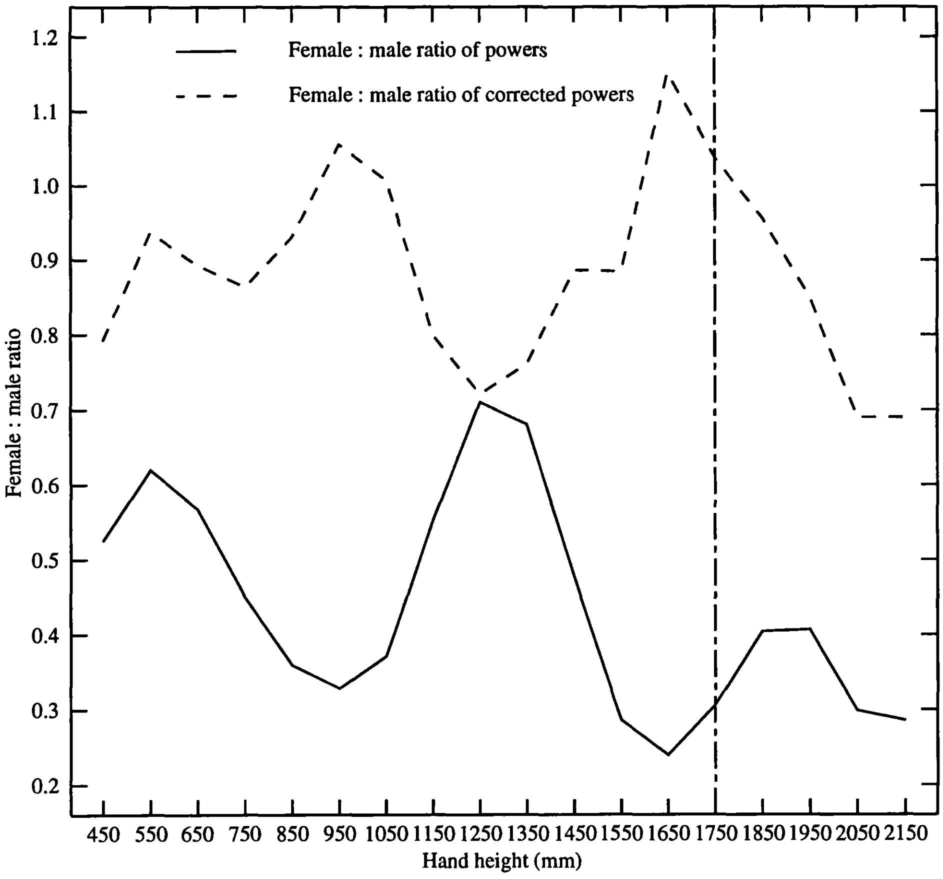


Figure 6.22: Female : male ratios for power at absolute hand heights

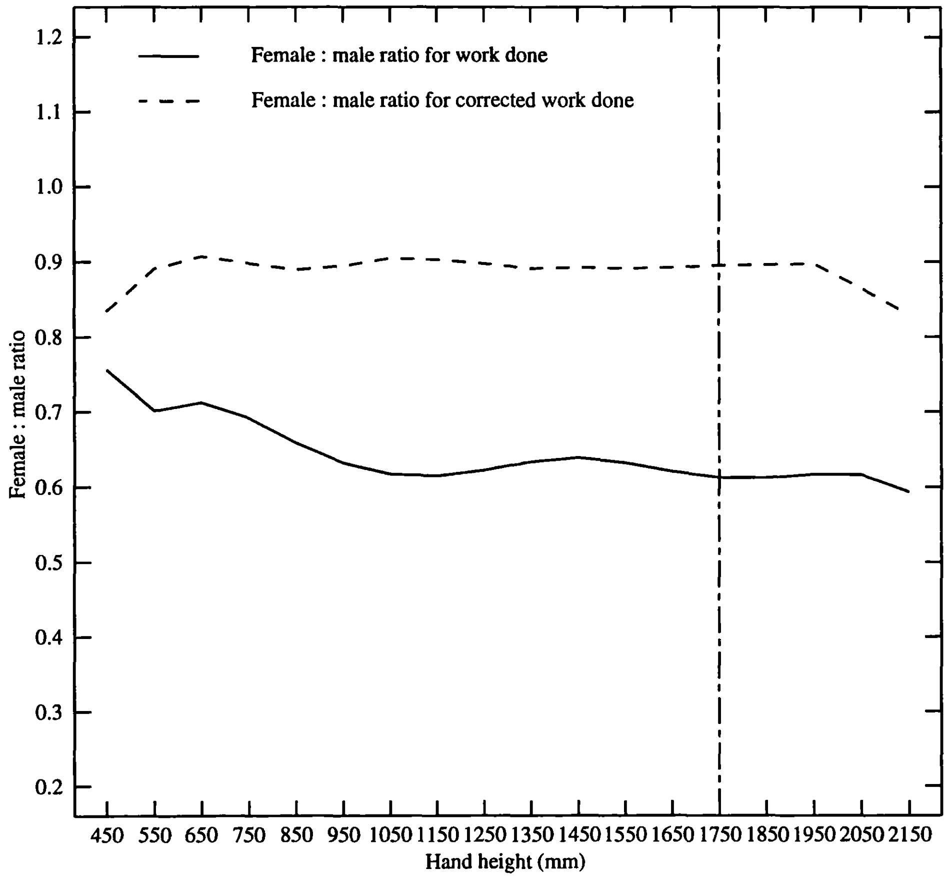


Figure 6.23: Female : male ratios for work done to absolute hand heights

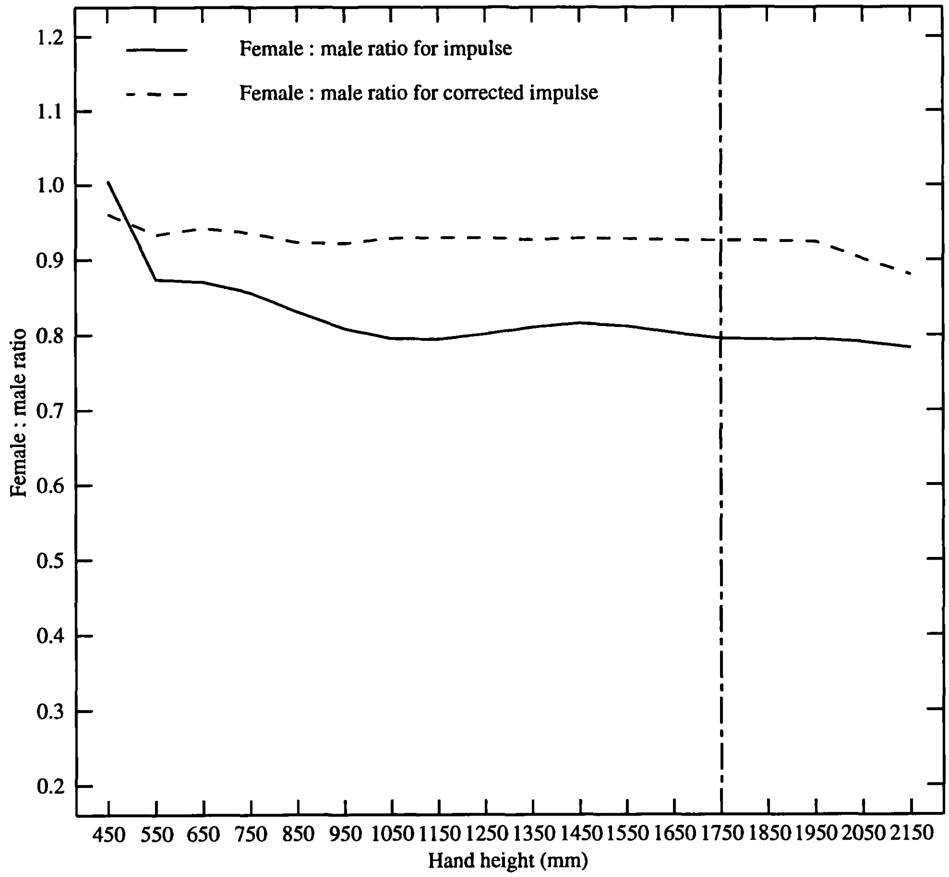


Figure 6.24: Female : male ratios for impulse to absolute hand heights

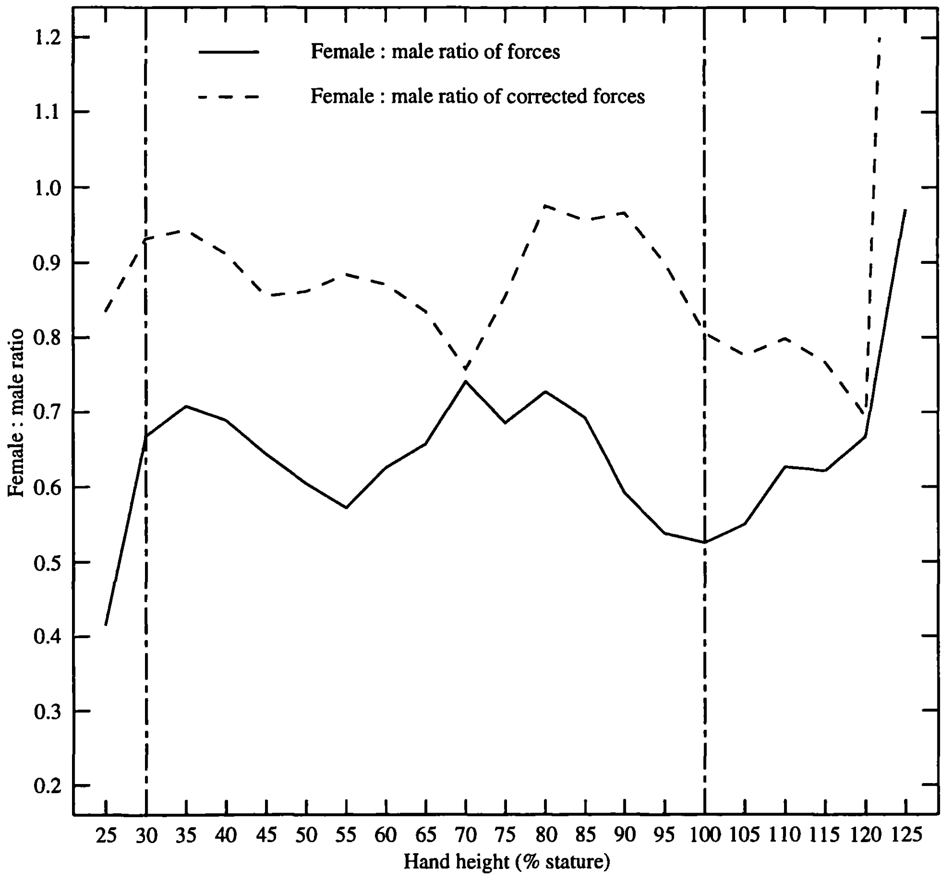


Figure 6.25: Female : male ratios for force at relative hand heights

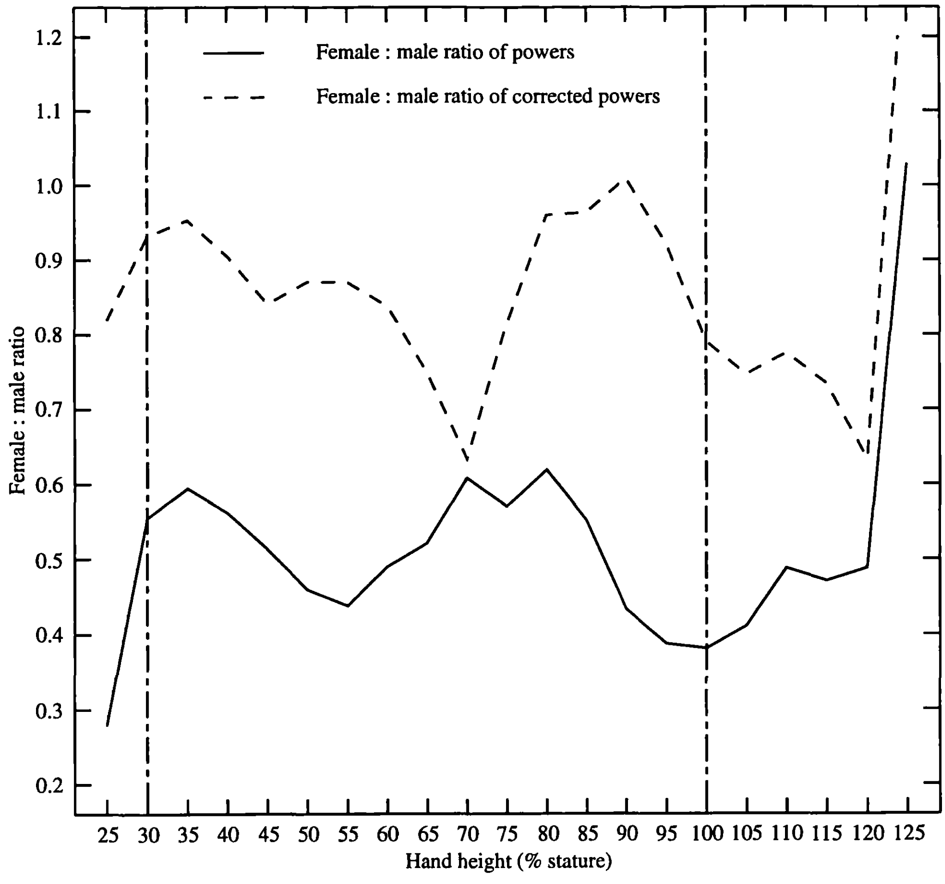


Figure 6.26: Female : male ratios for power at relative hand heights

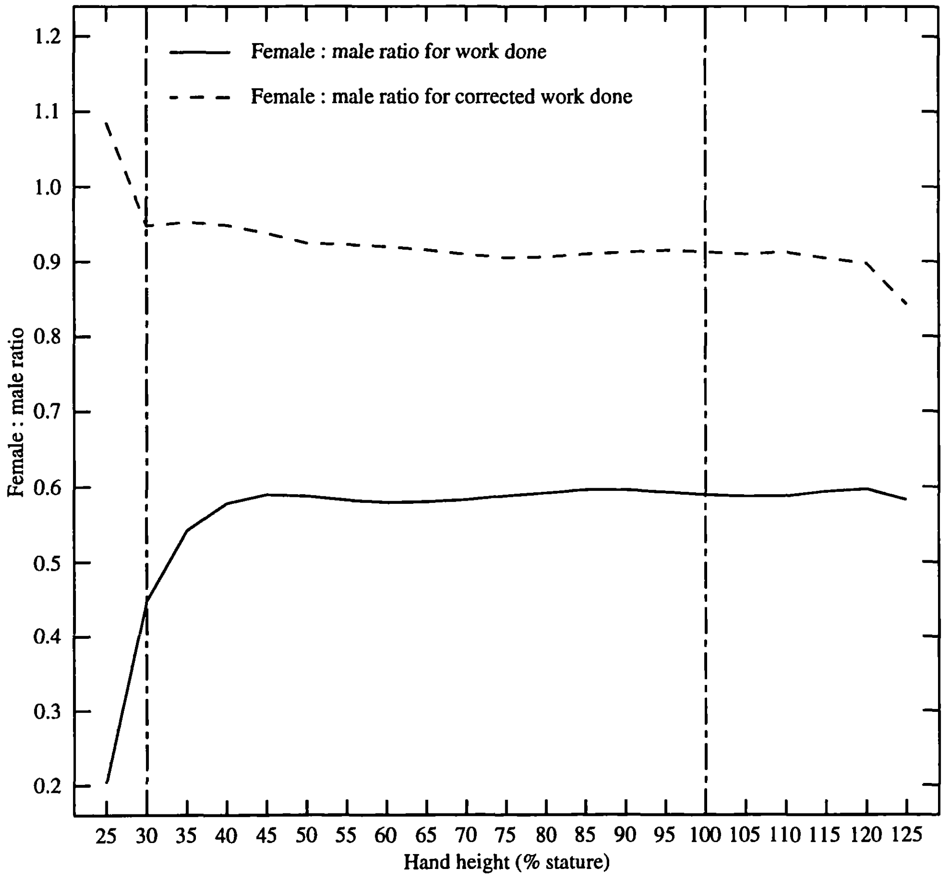


Figure 6.27: Female : male ratios for work done to relative hand heights

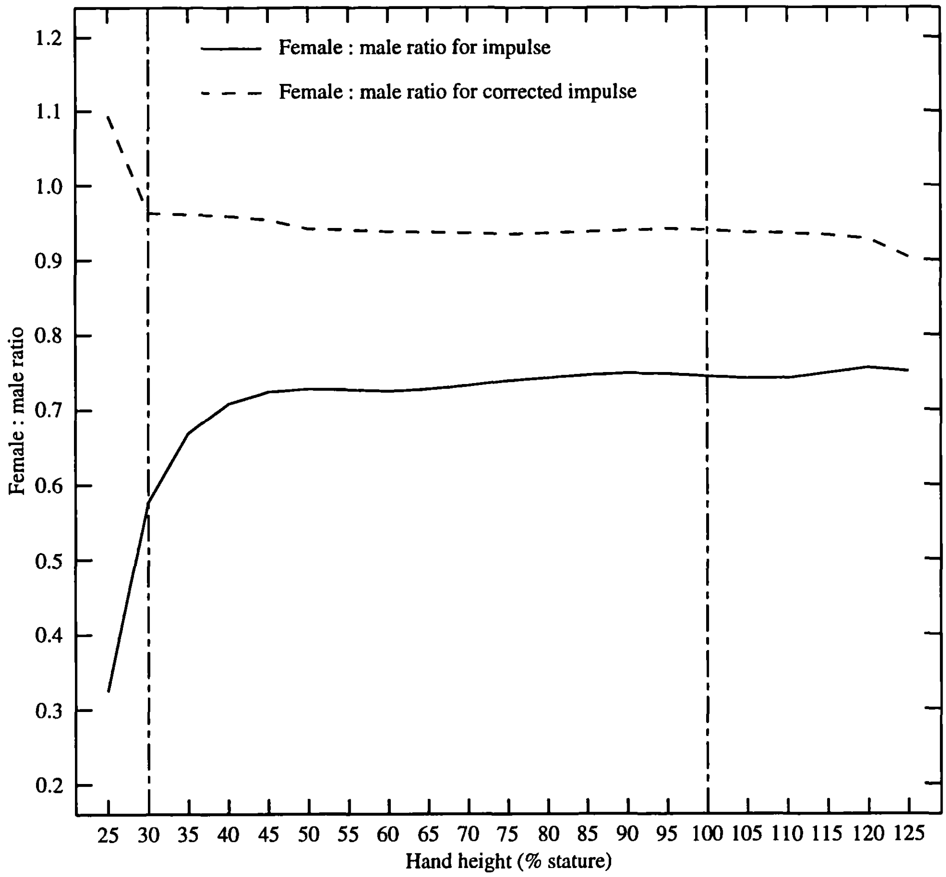


Figure 6.28: Female : male ratios for impulse to relative hand heights

A number of points are immediately apparent from these graphs:

1: Correction for covariates brings all the ratios towards unity. This reflects the finding in Chapter 6.3.3 that addition of covariates to an Anova model reduced the effect of gender from highly significant to largely insignificant.

2: The ratios are height dependent for force and power. Comparison of Figures 6.21 and 6.22 with Figures 6.7 and 6.9 and of Figures 6.25 and 6.26 with Figures 6.8 and 6.11 shows that the ratios are closest to unity at heights where the force and power are greatest, and are least when the values of force and power are least and most variable due to changes of grip occurring.

3: In contrast, the ratios for work and impulse vary very little with height. This is partly due to the cumulative nature of these measures since the figures obtained at any height summate the whole of the exertion up to that point, and therefore will only be influenced very slightly by changes in power or force at higher heights.

4: Normalisation to stature reduces the variability in the ratios.

5: Comparison of the uncorrected force curve in Figure 6.25 with the two-handed curve in Fig. 4 of Fothergill *et al.* (1996) shows that the female : male ratios of the two studies are reasonably consistent, ranging between approximately 0.5 and 0.7.

6: The fact that the impulse ratios are generally greater than the work ratios reflects the fact that women lifted more slowly than the males, and therefore exerted their smaller forces for longer over the same distance.

6.3.11 Prediction of performance from hand height

Polynomial regression was used to fit equations to the curves of performance against absolute and relative hand heights. This allows the prediction of power from hand height and the prediction of work and impulse from the distance travelled by the hands. In these equations a trade-off had to be made between number of terms used, and accuracy of fit between the original and predicted curves. A criterion of a minimum R^2 value of 98% was used which led to the use of hexic equations for predicting power, and quadratic equations for prediction of work and impulse. The equations are listed in Tables 6.19 and 6.20.

These equations can be used to predict, from hand height alone, lifting performance at any hand height between 450 and 1750 mm or between 30% and 100% of stature. Like the equations for predicting static lifting strengths developed by Sanchez & Grieve (1992), these equations have the advantage of only requiring hand position, gender and stature as the input. The equations of Kumar (1995b) for predicting static and isokinetic strengths, while using the basic anthropometric measures of height and weight, are complex linear functions of several measures of isometric and isokinetic strength in different postures. In the vast majority of the 108 equations generated, between 70%

and 99% of the variance was accounted for, whereas the hydrodynamometer equations account for almost all variance. If, in future, measurements were to be made in asymmetric postures and at greater horizontal reaches, these predictions of dynamic lifting strength could like those of Sanchez and Grieve (1992) and Kumar (1995b) cover the complete zone of exertion.

Table 6.19: Prediction of dynamic lifting performance from hand height (x mm)

Mean male power output	(Figure 6.9)	$R^2 = 99.56\%$
$= 13562 - 97.56x + 0.2848x^2 - 4.11\times10^{-4}x^3 + 3.117\times10^{-7}x^4 - 1.187\times10^{-10}x^5 + 1.792\times10^{-14}x^6$		
Mean female power output	(Figure 6.9)	$R^2 = 98.70\%$
$= -3579 + 16.04x - 1.427\times10^{-2}x^2 - 1.7\times10^{-5}x^3 + 3.563\times10^{-8}x^4 - 2.064\times10^{-11}x^5 + 4.023\times10^{-15}x^6$		
Mean male work	(Figure 6.13)	$R^2 = 99.43\%$
$= -435 + 1.157x - 2.88\times10^{-4}x^2$		
Mean female work	(Figure 6.13)	$R^2 = 99.26\%$
$= -261.7 + 0.7249x - 1.86\times10^{-4}x^2$		
Mean male impulse	(Figure 6.17)	$R^2 = 99.88\%$
$= -546.4 + 1.384x - 2.32\times10^{-4}x^2$		
Mean female impulse	(Figure 6.17)	$R^2 = 99.88\%$
$= -422.6 + 1.102x - 1.86\times10^{-4}x^2$		

Table 6.20: Prediction of dynamic lifting performance from hand height (x% stature)

Mean male power output	(Figure 6.11)	$R^2 = 99.69\%$
$= 9660 - 1356x + 73.79x^2 - 1.946x^3 + 2.655\times10^{-2}x^4 - 1.81\times10^{-4}x^5 + 4.846\times10^{-7}x^6$		
Mean female power output	(Figure 6.11)	$R^2 = 99.69\%$
$= -3771 + 212.8x + 1.379x^2 - 0.2576x^3 + 5.552\times10^{-3}x^4 - 4.8\times10^{-5}x^5 + 1.48\times10^{-7}x^6$		
Mean male work	(Figure 6.15)	$R^2 = 99.19\%$
$= -418.7 + 19.88x - 8.569\times10^{-2}x^2$		
Mean female work	(Figure 6.15)	$R^2 = 99.09\%$
$= -264.3 + 12.07x - 5.212\times10^{-2}x^2$		
Mean male impulse	(Figure 6.19)	$R^2 = 99.83\%$
$= -543 + 24.25x - 7.075\times10^{-2}x^2$		
Mean female impulse	(Figure 6.19)	$R^2 = 99.83\%$
$= -424.2 + 18.14x - 5.108\times10^{-2}x^2$		

6.4 Discussion

The purpose of this chapter was to examine gender differences in performance on the hydrodynamometer, and in particular to see whether the data collected supported the widespread perception that women have less upper body strength than men.

6.4.1 Covariates

It is not surprising that the amount of variance attributed to gender was significantly less for each measure of exertion when using fat-free mass rather than when using body mass as a covariate since females have a greater percentage of body fat than males. This change in covariates did not significantly change the total variance but transferred variance from gender to fat-free mass. That stature and isometric lifting strength at 850 mm added only slightly to the total variance accounted for by fat-free mass implies that the major determinant of dynamic strength is the fat-free mass and that, once this has been taken account of, stature considerations, in particular, can be ignored.

6.4.2 Normalisation

Using stature to normalise the different measures of exertion reduced the differences between males and females by matching the curves. This shows that men and women were performing similar actions at similar percentages of stature. This process also served to enhance the significance of both hand height and gender by decreasing the importance of the gender × height interaction. In the case of both work and impulse, normalisation to stature removed the tendency for variance accounted for to increase as hand height increased to 1150 mm.

6.4.3 Power

The finding that correcting for differences in body composition by using fat-free mass as a covariate makes the gender differences in power output negligible has important implications. It shows that the real differences between men and women, where, at any given height, women consistently produced less power than men, are solely due to their differences in body size and composition, i.e. their differences in fat-free mass. This means that women are weaker than men, not because they are women, but because they are smaller and have a greater proportion of their body mass as fat. Other than in these two ways, having two X chromosomes instead of an X and a Y chromosome does not cause gender differences in strength. Thus, there is no need to postulate differences between the genders in muscle composition or structure, or in motivation and effort.

The significance of the finding that after correction for covariates remaining gender differences occurred below 750 mm, and at 45%, 50%, 75%, and above 100% of stature is probably not great as the percentages of variance accounted for at each of these levels are small and the significance levels are at the 5% level for five of the seven heights. The finding that the major gender difference observed is that females do not produce as powerful exertions as males above the head suggests that women may be less effective than men in the combination of elbow extension and shoulder flexion required to push upwards above the head. Conversely, this implies that there are no significant differences in the abilities of males and females to produce the combination of shoulder flexion and shoulder adduction required to push upwards toward head height.

6.4.4 Work

The finding that the Ancova model accounted for a very high proportion of the variance in work reflects the fact that work is a cumulative variable which increases as hand height increases. The finding that the absolute work done by males was always significantly greater than that done by the females is a reflection of the gender differences in the forces produced at all points up to that height.

The fact that gender differences, while statistically significant, account for very little variance shows that the most important determinant of work done is the distance travelled by the hands. Normalisation of hand height to stature caused the gender differences to became insignificant below 50% of stature, and to be reduced in significance in later stages. This effect was small and does not imply that women have less capacity than men for performing work with the upper body because in reaching 100% stature women will have performed less work because they are smaller.

6.4.5 Impulse

The dominance of hand height in determining impulse shown for both absolute and relative hand heights reflects the cumulative nature of the measure, since impulse must increase as the duration of the exertion increases and hence as the hands travel further. It is therefore not surprising that the height-impulse curve is almost identical in form to the height-work curve.

Similarly to the finding for work done, the absolute impulse at each height up to 100% stature was very different for males and females. Despite the women having exerted their smaller forces for longer than the men the actual percentage of variance accounted for by gender is greater than for work. As with work, the gender differences were greatest above 50% of stature, i.e. in the arm strength area. This can partly be attributed to the women performing the lifts more slowly.

6.4.6 Male : female strength ratios

Fothergill *et al.* (1996) reported female : male ratios for nine males and nine females who performed maximal exertions on this hydrodynamometer when it was instrumented with other transducers. Given the much larger samples measured, and the more accurate instrumentation used, the findings of this study can be taken to be more accurate estimates of female : male ratios over the range of the dynamic lifts studied. The finding that correction for covariates and normalisation to stature both bring all the ratios towards unity again emphasises the lack of significant differences once fat-free mass is taken into account.

Also, the finding that ratios are height dependent for force and power but not for work and impulse means that it is necessary to consider both the measure being used and the hand height. The finding that the ratios were furthest from unity when force and power were least and most variable due to grip changes emphasises the importance of technique in such actions and submaximal exertions in general.

6.5 Conclusion

This chapter has extended the discussion of gender differences beyond simple numerical ratios of upper body or lower body strength to show that gender differences in lifting strength are not constant but depend crucially upon the hand height at which the exertion occurs. Fothergill *et al.* (1996) had also found this result with small sample sizes (nine males and nine females) and that the female : male ratio depended upon whether the exertion was one- or two-handed. Fothergill *et al.* (1991) showed that female : male strength ratios at fixed hand heights vary as the direction of static exertion moves around the sagittal plane. Grieve (1979a,b) and Grieve and Pheasant (1982) had shown the ways in which posture sets limitations upon the static forces that can be exerted. Grieve and Pheasant (1981) showed that subjects naturally exert in strong directions with the aim of producing a component force in a direction that is greater than if the force was solely in that direction. Pinder *et al.* (1995) extended the measurement of force to include lateral components, showing that static strength is dependent upon the precise direction in which the force is exerted in in all planes, and that the strong directions vary dramatically with hand height. It is therefore highly likely that female : male strength ratios in both static and dynamic whole-body manual exertions will vary as a function of the three-dimensional direction of exertion, the numbers of hands used, and their location.

It is therefore concluded that it is extremely unwise to quote a single figure for the 'average' or 'typical' female : male strength ratio, as it will almost certainly not apply to the exertion under consideration. This reinforces the statement of Laubach (1976), who reviewed what was then a far less extensive literature, and concluded that:

> *"the emphasis should be re-focussed on the broad* ***range*** *from 35 to 86% of mean percentage differences [between male and female strengths] that were found to exist rather than on a single mean figure".*

The findings of this chapter imply that males and females matched for fat-free mass would, on average, produce similar power outputs at similar relative hand heights on the hydrodynamometer. In terms of their total body mass, of course, the matched females would tend to be heavier than the males because of their greater proportion of body fat.

However, it does appear that females did less work and produced smaller impulses in the regions of the lift where upper body strength was the determining factor of performance. This may be related to the characteristics of the device, but may also be related to the fact that women tended to lift more slowly than men.

This study provides little support for the contention, largely based upon static strength measurements that women have less upper body strength than men (Laubach, 1976; McArdle *et al.*, 1991). It should be noted that McArdle *et al.* (1991) acknowledged that contrary opinions had been advanced on gender differences in strength and suggested that a more complete answer awaited further research. It is hoped that this present work has helped to clarify the issues.

CHAPTER 7

PRINCIPAL COMPONENTS ANALYSIS OF DYNAMIC LIFTING

7.1 Introduction

As mentioned earlier, Bryant *et al.* (1990) and Stevenson *et al.* (1995) used Principal Components Analysis (Tabachnick and Fidell, 1996) to describe dynamic lifts performed on an Incremental Lift Machine (ILM). The purpose of this chapter is to apply the same techniques to the data obtained from the hydrodynamometer in order to examine the structure of factors underlying events in hydrodynamometer lifting, and thus to attempt to demonstrate or deny the generalizability, from an isoinertial device to a hydraulic resistance device, of the factor structure developed by Bryant *et al.* (1990) and validated by Stevenson *et al.* (1995).

7.2 Definitions / concepts used in Principal Components Analysis

7.2.1 Factor Analysis

Factor Analysis (FA) is a statistical technique used to separate a set of variables into coherent and independent subsets ('factors') of correlated variables. Factors are thought to reflect underlying processes that have created the correlations among variables (Tabachnick and Fidell, 1996). It can be used to summarise patterns of correlations between observed variables, to reduce a large number of variables to a smaller number of factors, to provide a regression equation for an underlying process by using observed variables, or to test a theory about the nature of underlying processes. Factor Analysis attempts to estimate and eliminate variance due to error, and variance that is unique to any variable, by only analysing the variance shared between variables (the covariance).

7.2.2 Principal Components Analysis

Principal Components Analysis (PCA) is a variant of Factor Analysis and is used to extract maximum variance from a data set with each component by analysing all the variance instead of just the covariance. The first principal component is the linear combination of observed variables that maximally separates subjects by maximising the variance of the component scores. Subsequent components are formed from residual correlations and are the linear combinations that extract maximum variability uncorrelated with (orthogonal to) previously extracted components.

7.2.3 Steps in PCA

The process of carrying out PCA involves selecting and measuring a suitable set of variables, creating a correlation matrix of the variables, extracting a set of factors from the correlation matrix, determining the number of factors to be used, rotating the factors to increase interpretability, and interpreting and naming the obtained factors. 'A good PCA or FA "makes sense"; a bad one does not.' (Tabachnick and Fidell, 1996)

Rotation does not change the underlying properties of an extracted solution. It can be interpreted as a geometric rotation of the factor axes about the origin. Orthogonal rotation ensures that the factors remain uncorrelated with each other; oblique rotation causes the factors to become correlated and increases the level of complexity involved in interpretation. Both types of rotation produce a matrix of factor-score coefficients, which can be used in regression like equations to predict scores on factors from scores on observed variables.

Interpretation and naming of factors depend on the meaning of the combination of observed variables that correlate with each factor. A factor is more easily interpreted when several observed variables correlate highly with it but not with other factors. Once interpretation is adequate the factor structure should be verified by establishing the construct validity of the factors. This involves showing that scores on the factors co-vary with scores on other variables, or that scores on factors change with experimental conditions as predicted by theory.

7.2.4 Limitations of PCA

No external criterion exists against which the extracted solution can be tested in the way that the goodness of a regression can be examined using the closeness of the observed and predicted values of the dependent variable.

An extracted solution can be rotated in an infinite number of ways, which all account for the same amount of variance in the original data. Rotation has the effect of changing how the factors are defined. The final choice is a matter of judgement as to the interpretability and utility of the obtained solution.

Factor analysis has a reputation for often being used to 'rescue' poorly designed research when it is discovered that no other form of analysis is applicable.

7.2.5 Exploratory and Confirmatory Factor Analysis

Exploratory FA seeks to describe and summarise data by grouping correlated variables. These may or may not have been chosen with potential underlying processes in mind. Confirmatory FA is a more sophisticated technique used to test a theory about latent processes. Variables are carefully and specifically chosen to reveal underlying processes.

7.2.6 Varimax Rotation

The most common form of rotation is Varimax (*vari*ance *max*imising), which is an orthogonal rotation which maximises the variance of factor loadings by making the higher loadings higher and the low ones lower for each factor. This makes the factors easier to interpret. Varimax also tends to redistribute variance from the first factors extracted to the later ones.

7.2.7 Selection of number of factors to be extracted

The maximum number of factors that can be extracted from a data set is equal to the number of variables entered. A coherent set of factors will normally be much smaller and will account for a large proportion of the variance. In PCA an initial estimate of the number of factors to be extracted can be obtained as the number of factors with eigenvalues greater than 1.0. (The eigenvalue of a factor is a measure of the variance associated with it; each standardised factor contributes 1.0 to the sum of eigenvalues and therefore factors with eigenvalues greater than 1.0 have more variability associated with them than would be expected by chance). The number of eigenvalues greater than 1.0 is usually between one-fifth and one-third of the total number of variables.

A second criterion is the scree test developed by Cattell. This is a plot of eigenvalues in descending order against factors (Tabachnick and Fidell, 1996). The cut-off below which factors are not extracted is identified visually as the point at which a line drawn through the points on the curve changes slope. This test has a subjective element but even when samples are small, correlations are low, and only a few variables load highly on each factor, it is usually accurate to within one or two factors.

7.3 Previous work

Stevenson *et al.* (1990a) had identified a series of eight Events relating to clearly identifiable points (maxima and minima) in the ILM displacement, velocity, force/ acceleration, and power curves. They derived values for velocity, displacement, force/ acceleration and power at each Event, and also calculated mean velocity, acceleration, force and power. They used a total of 37 parameters to describe a lift on the ILM to 1.83 m. Bryant *et al.* (1990) reduced the number of parameters from 37 to 32 (Table 7.1) by not using means or the time at the target height, which was the only parameter representing the Event identified as the maximum displacement.

Table 7.1: Possible parameters for describing ILM lifts. Question marks identify those not listed by Stevenson *et al.* (1990a). Parameters not used by Bryant *et al.* (1990) for PCA of ILM lifts are bracketed

Event	Time	Displacement	Velocity	Acceleration	Force	Power
0 Target height	(TMAX)	(trivial)	(?)	(?)	(?)	(?)
1 Maximum velocity	T1	D1	V1	A1	F1	P1
2 Minimum velocity	(?)	(?)	V2	(?)	(?)	(?)
3 Maximum acceleration/force	T3	D3	V3	A3	F3	P3
4 Minimum acceleration/force	T4	D4	V4	A4	F4	P4
5 Second max acceleration	T5	D5	V5	A5	F5	P5
6 Maximum power	T6	D6	V6	A6	F6	P6
7 Minimum power	(?)	(?)	(?)	(?)	(?)	P7
Average	(trivial)	(trivial)	(AVVEL)	(ACC)	(FORCE)	(POWER)

Bryant *et al.* (1990) sought to 1) develop an empirical description of dynamic factors involved in an ILM test; 2) conduct gender analyses of the factor structures; and 3) test the stability of the structures with repeated sampling. They used an initial group of 79 females and 96 males to develop the factor structures, and a group of 33 females and 99 males to confirm them. They converted all individual scores on the lift parameters to z-scores within gender because of the large differences in performance between genders and the different numbers of males and females in the groups. PCA was carried out on the whole sample and on the separate male and female groups. Coefficients of congruence were used to compare the solutions obtained with the initial and confirmatory data.

After a trial PCA they eliminated the measures of acceleration and velocity because they showed instability. A scree test at this point suggested four to seven factors would be optimal. They then further reduced the number of variables, and carried out a scree test on the remaining 13 variables. This indicated that a four factor solution was optimal. The factor structures for males and females were similar but different variables entered in some of the factors. They concluded that the underlying factor structure was essentially the same for both genders.

To confirm this structure they used data from the second group of subjects from the 13 variables identified in the exploratory analysis. The scree test suggested that four factors were optimal, accounting for 77.4% of variance, The solution obtained was very similar to the one produced for the initial group. Coefficients of congruence between 0.92 and 0.97 were obtained, suggesting that the initial factor structures were successfully replicated. They "could find no evidence to suggest that this stability in structure could be accounted for by the methods adopted for deriving the parameters." They therefore considered the factor structures extremely robust.

Stevenson *et al.* (1995) used ILM factor score and variable models to predict maximum box-lifting performance. 25 females and 23 males (sample F in Stevenson *et al.*, 1990b) completed the free-style and ILM protocols described by Stevenson *et al.* (1990b). ILM data were subjected to PCA in the manner described by Bryant *et al.* (1990) except that, the first deletion criterion was raised to 0.40 for combined analyses and 0.50 for genders. A four factor solution based on ten variables accounted for 89.2% of the variance. This structure differed from Bryant *et al.* (1990)'s structure in the predictive power of the first two factors.

7.4 Methods

7.4.1 Definition of Event and Range variables

The 25 'Events' that occur during a dynamic lift were defined in Tables 4.5 and 4.6. For each of the *n* Events, the time, ti*n*, height, ht*n*, force, frc*n*, velocity, vel*n*, and power, pow*n*, variables were obtained. Because ht1 - ht4 were fixed heights, they were eliminated, leaving a total of 25x5-4, i.e. 121 variables. The 70 variables listed in Table

4.6 which had been defined from the 14 Ranges of handle movement created from the seven distinct Event heights were labelled Range26 to Range95.

7.4.2 Data integrity / usability issues

PCA is very sensitive to the size of correlations between variables and therefore it is essential that reliable data is used. Problems can be caused by outlying data points, missing data, and poorly distributed variables.

7.4.3 Sample size and missing data

The experimental protocol required subjects to carry out a slow speed practice exertion on the hydrodynamometer, followed by two maximal lifts which were recorded. On a later occasion, a subset of subjects was retested using the same protocol. The numbers of usable data sets obtained from each of these exertions are shown in Table 7.2.

Table 7.2: Usable data obtained from subjects

Occasion	Code	Males	Females	Total
First lift	T1	203	69	272
Second lift	T2	201	69	270
Repeat first lift	T3	11	10	21
Repeat second lift	T4	11	10	21
TOTAL		426	158	584

In order to ensure that correlations between variables are reliably estimated, Tabachnick and Fidell (1996, Section 13.3.2.1), recommend as a general rule of thumb that there should be data from at least 300 cases entered into the analysis. Since there were a total of 121 variables defined from momentary Events it was decided to carry out the initial PCA using all 584 data sets, giving a mean of 4.8 cases per variable. However, since Tabachnick and Fidell (1996) urge caution when using data from measures repeated in time, it was decided to rerun the analysis using just the T1 and just the T2 values. It was also decided to rerun the analysis splitting the data into male and female groups to test the stability of solutions found across genders and to allow comparison with the finding of Bryant *et al.* (1990) that on an ILM the underlying factor structure of the lift parameters was essentially the same for both genders.

Because the Range data were completely different in nature to the Event data it is questionable whether, for the purposes of PCA, the two types can validly be combined. It was also considered doubtful whether PCA was appropriate for variables which covered overlapping Ranges and therefore would be inevitably highly related. Therefore PCA was carried out separately on the instantaneous Event data and on the Range data. As a final check PCA was carried out on the combined data sets.

Because subjects performed differing numbers of grip changes, data did not exist for all Events for every subject, and therefore not for all Ranges. In other words, data were missing from certain variables in a systematic fashion. Therefore no attempts were made to delete variables containing missing data or to estimate values, but pairwise deletion of cases was specified, allowing the software to use all non-missing values for each variable whenever possible. Tabachnick and Fidell (1996, Section 4.1.3.3), warn that this results in different correlations being based on different numbers and subsets of cases, resulting in different reliabilities of estimates of the correlations. They warn that it can also result in negative eigenvalues being obtained. Because eigenvalues represent variance, positive eigenvalues are inflated in size by the total of negative eigenvalues leading to overestimates of the variance accounted for by the extracted factors. They conclude that pairwise deletion "should be used cautiously with a wary eye to negative eigenvalues", but do not indicate limits that should be set before accepting solutions with negative values, either in terms of the proportion of negative values or the proportion of variance affected. In fact, the software used (Statgraphics Plus v5.22) calculates the percentage variance accounted for as a percentage of the sum of positive eigenvalues, ignoring negative eigenvalues.

7.4.4 Normality

Tabachnick and Fidell (1996, Section 13.3.2.2) point out that if PCA is only used as a convenient descriptive method for summarising the relationships between a large set of observed variables then no assumptions are made about the normality or otherwise of variables. It was noted that the force and power values obtained tended to be positively skewed. It was therefore decided to run analyses with untransformed data and rerun them after transforming variables with either the standardised skewness or standardised kurtosis outside the 99.9% confidence limit for normality (Tabachnick and Fidell, 1996, p73). However, underestimates of variance due to kurtosis disappear when more than 200 cases are used, so only minor differences should be expected in these circumstances. A variety of methods of transformation were used (Tabachnick and Fidell, 1996, p81-84) until standardised skewness and kurtosis values within the 99.9% limit were obtained. Negatively skewed variables were first reflected by subtracting each value from the largest value plus 1 to create positive skew. Distributions with negative values were then shifted by addition of a constant to ensure that all values were positive before transformations were applied. Square root transformations were tried first, followed where necessary by logarithmic transformations, then reciprocal transformations. Where a satisfactory transformation could not be obtained the variable was left untransformed.

7.4.5 Linearity

Underlying PCA is the assumption of multivariate normality, i.e. that relationships between all pairs of variables are linear, since correlation measures linear relationships (Tabachnick and Fidell, 1996, Section 13.3.2.3). Non-random non-linear relationships (e.g. curvilinear) cause misleading correlation coefficients to be calculated. Tabachnick and Fidell (1996) therefore recommend the inspection of bivariate scatter plots for non-linearity, but suggest restricting this to likely cases where variables are known to be significantly skew or where there is a theoretical reason to suspect non-linearity. However, because of the number of variables to be used it was decided that this would only be carried out if it became clear that transforming the data to ensure normality had significantly affected the results of the PCA.

7.4.6 Outliers among cases

Outliers are defined as cases with such extreme values on one or more variables that they distort descriptive statistics and statistical tests (Tabachnick and Fidell, 1996, Section 4.1.4). They can result in both Type I and Type II errors. Possible causes are incorrect data entry or coding, incorrect sampling and non-normal distributions of data.

Careful design of sampling strategies and checking of data coding and entry will increase the likelihood of valid data being used. Transformation of data to ensure normality will reduce the influence of outliers but make variables harder to interpret.

7.4.7 Multicollinearity & Singularity

Multicollinearity occurs when variables have very high correlations. Singularity occurs when a variable is a combination of two or more other variables (Tabachnick and Fidell, 1996, Section 4.1.7). This means that not all the variables are needed in the same analysis. Also, both of these can cause problems when correlations of 0.9 or higher occur in statistical procedures that require matrix inversion. However, in the case of PCA, this is not a problem since matrix inversion is not required.

Both multicollinearity and singularity are to be expected in this analysis because of measurements being taken from the same variables at different times, and also because of the fixed relationships between some of the variables. It is to be expected that deletion of variables as the PCA proceeds will help considerably. However, it must be remembered that the whole purpose of PCA is to determine relationships between variables and therefore variables cannot be eliminated prior to PCA except on theoretical grounds.

7.4.8 Factorability

A requirement of PCA is that correlations between variables must be sufficiently large for meaningful factors to be extracted. Tabachnick and Fidell (1996, Section 13.3.2.6), suggest that if no correlations between variables exceed 0.30, then the use of factor analytic techniques should be reconsidered. In the circumstances of this study with a data set with clearly inter-related variables, this is highly unlikely to be a problem.

7.4.9 Outliers among variables

According to Tabachnick and Fidell (1996, Section 13.3.2.7), variables that are unrelated to others in the set can be identified as not correlating with the first few factors, though they may correlate with factors extracted later. They are usually unreliable because they account for very little variance and are defined by only one or two variables. In these circumstances reliability can be judged by whether the variables correlate highly with each other and not with other variables.

7.4.10 Selection of deletion criteria

It was decided to use the first two deletion criteria specified by Bryant *et al.* (1990) (Table 7.3) to reduce the number of variables in the data sets and to continue running PCA analyses until the number of factors and variables became constant. The third deletion criterion of Bryant *et al.* (1990) was not used because the description given was not sufficiently precise to guarantee accurate replication.

Table 7.3: Deletion criteria used by Bryant *et al.* (1990)

1:	Deletion of variables loading less than 0.3 on all factors
2:	Deletion of variables loading more than 0.3 on more than one factor
3:	Deletion of highly redundant (i.e. highly correlated) variables by selecting from each group of correlated variables the variable with the lowest correlations with the others.

7.4.11 Software and data processing choices

The Factor Analysis option within Statgraphics Plus v5.22 was used. Pairwise deletion of missing values was specified, as was the Standardize option. The defaults of Varimax rotation, a Convergence Criterion of 0.00001, and a maximum of 100 iterations were chosen. After the system had calculated correlations and communalities, the diagonals of the correlation matrices were not replaced with the communalities, i.e. PCA was specified, not FA.

7.4.12 Confirmatory Factor Analysis

To examine the stability of the factor structures obtained for the different genders, and for the initial and second pulls, confirmatory factor analysis was undertaken in a manner similar to that adopted by Bryant *et al.* (1990). Thus, for the factor structure obtained from females, the variables in the male data set which matched the variables remaining in the female data set when a stable factor solution had been achieved were selected. These were then subjected to PCA using exactly the same methods and deletion criteria until a stable solution was achieved. Similar processes of selection were used for the male data and for the initial and second pulls data. Bryant *et al.* (1990) had chosen to omit applying deletion criteria in this phase of their analysis, but it was felt that it was necessary to do so in this analysis to ensure that stable solutions were being compared.

7.5 Results

7.5.1 Analysis of screened Event data

The set of 121 Event variables was subjected to data screening (Tabachnick and Fidell, 1996) to eliminate outliers due to transcription errors etc. The cleaned data were subjected to PCA. After an initial PCA 14 eigenvalues were > 1.0. A scree test (see Chapter 7.2.7) identified ten factors which were extracted and rotated. 60 variables were eliminated which loaded > 0.3 on more than one factor. Three more cycles of PCA, extraction, rotation and deletion (Table A7.1) were carried out before a stable solution was obtained using 57 variables. This had six factors accounting for 93.4% of the variance (Table 7.4). The variables retained and their loadings on the factors are listed in Table A7.2.

Table 7.4: Factors obtained from PCA of Event data after data screening

Factor	Factor name	R^2
1	Exertion before first grip change	42.5%
2	Exertion at second grip change	16.3%
3	Exertion at first grip change	15.7%
4	Time and height of main peak exertion	7.3%
5	Time of initial peak exertion & height of initial peak velocity	6.7%
6	Height of first grip change	4.8%
Total		93.4%

7.5.2 Re-analysis of Event data after deletion of related variables

In order to examine the effects of multi-collinearity and singularity in the data set, the analysis was rerun after removing all velocity and power variables and Events 12-25. This left a total of 29 variables. Four cycles of PCA (Table A7.3) reduced the data set to a stable solution (Table A7.4, Table 7.5) of nine variables and two factors which accounted for 81.6% of the variance.

Table 7.5: Factors obtained from PCA of Event data after deletion of correlated variables

Factor	Factor name	R^2
1	Slowness of whole exertion, i.e. duration of exertion	64.4%
2	Timing of initial peak force and subsequent dip	17.2%
Total		81.6%

Because only nine variables remained and only two factors, which bore little relation to the factors obtained from the first analysis, were obtained, it was concluded that it was necessary to retain the correlated variables in the analysis. All further analyses of Event data therefore started using all 121 Event variables.

7.5.3 Analysis of transformed Event data

The screened data were transformed to maximise the number of variables which were normal. Normality was defined as both standardised skewness and standardised kurtosis < ± 3.09, i.e. within the 99.9% confidence limit for normality (Tabachnick and Fidell, 1996). This was not achieved for 13 variables which were left untransformed. Three cycles of PCA (Table A7.5) reduced the 121 variables to 53 variables described by seven factors accounting for 95.1% of the variance. After extraction and rotation no variables met the deletion criteria. This solution was therefore considered stable. Seven of the 13 untransformable variables were not deleted by this process. After examination of bivariate plots involving these variables, five were deleted due to non-normality / .heteroscedascity (Tabachnick and Fidell, 1996) Two more cycles of PCA (Table A7.5) produced a stable solution (Table A7.6, Table 7.6) with seven factors accounting for 95.9% of the variance of 47 variables.

Table 7.6: Factors obtained from PCA of transformed Event data

Factor	Factor name	R^2
1	Exertion before first grip change	40.1%
2	Exertion at second grip change	17.1%
3	Exertion at first grip change	15.2%
4	Height of first grip change	8.8%
5	Time of initial peak exertion	6.0%
6	Time of main peak exertion	5.5%
7	Time of dip after initial peak exertion	2.4%
Total		95.1%

The first three factors obtained ~~from~~ were common to both the transformed and untransformed data. A fourth variable was also common, and there was overlap with the remaining two variables in the untransformed analysis. The common variables accounted for 81.2% and 79.3% of the variance in the transformed and untransformed data sets respectively. It was therefore concluded that there was no benefit to be gained from transforming data, and therefore all subsequent analyses were carried out using untransformed data.

7.5.4 Analysis of female Event data

PCA of the 158 cases of data obtained from females was carried out on all 121 Event variables. Three cycles of PCA (Table A7.7) produced a stable six factor solution (Table A7.8, Table 7.7) using 41 variables and accounting for 92.1% of the variance.

Table 7.7: Factors obtained from PCA of female Event data

Factor	Factor name	R^2
1	Exertion at initial peak / subsequent dip (before main peak)	32.8%
2	Exertion at first grip change	21.3%
3	Exertion at peak exertion after second grip change	14.0%
4	Heights of first grip change and subsequent peak exertion	12.0%
5	Height of main peak exertion	7.4%
6	Exertion at 1.45 m	4.6%
Total		92.1%

7.5.5 Confirmation of female Events factor structure using male data

Confirmatory PCA was carried out using 41 variables in the male data set which matched the variables in the factor solution obtained from the female Event data. After three cycles of PCA (Table A7.9) 28 variables remained and resulted in a stable five factor solution (Table A7.10, Table 7.8) which accounted for 91.4% of the variance.

Table 7.8: Factors obtained from PCA of male Event data carried out to confirm the female Events factor structure

Factor	Factor name	R^2
1	Exertion at first grip change	31.5%
2	Exertion below first grip change	22.4%
3	Heights of first grip change and subsequent peak	19.7%
4	Height of main peak	10.4%
5	Exertion at 1.45 m	7.3%
Total		93.8%

7.5.6 Analysis of male Event data

PCA of the 121 Event variables of the 426 cases obtained from males led, after three cycles (Table A7.11) to a seven factor solution accounting for 93.8% of the variance of 56 variables. The seventh factor was found to load less than 0.3 on all variables. Therefore the PCA was repeated with the extraction of only six factors (Table A7.12, Table 7.9), accounting for 92.5% of the variance.

Table 7.9: Factors obtained from PCA of male Event data

Factor	Factor name	R^2
1	Exertion before first grip change	37.5%
2	Time and height of second grip change and subsequent peak	19.4%
3	Exertion at second grip change	15.6%
4	Exertion at first grip change	11.9%
5	Exertion at 1.0 m	5.0%
6	Time of dip after initial peak exertion	3.0%
Total		92.5%

7.5.7 Confirmation of male Events factor structure using female data

Confirmatory factor analysis of the structure obtained for males was carried out by subjecting to PCA 56 variables in the female data set which matched the variables remaining in the male data set when a stable factor solution had been achieved for the male data. After four PCAs (Table A7.13) 17 variables remained and three factors accounted for 93.8% of the variance. The solution (Table A7.14, Table 7.10) was stable.

Table 7.10: Factors obtained from PCA of female Event data carried out to confirm the male Events factor structure

Factor	Factor name	R^2
1	Exertion before first grip change	57.8%
2	Exertion at second grip change	23.9%
3	Exertion at first grip change	12.1%
Total		93.8%

7.5.8 Analysis of initial pulls Event data

To examine the effect of warming up or learning on the factor structure obtained, the data from initial and second pulls (T1, T2) were examined separately. PCA was carried out on the 121 Events using the 272 cases from initial pulls. After three cycles of PCA (Table A7.15) a stable seven factor solution (Table A7.16, Table 7.11) was extracted from the remaining 60 variables.

Table 7.11: Factors obtained from PCA of initial pulls Event data

Factor	Factor name	R^2
1	Exertion before first grip change	36.7%
2	Exertion at first grip change	15.5%
3	Exertion at second grip change	14.7%
4	Height of second grip change and subsequent peak exertion	10.2%
5	Time and height of main peak exertion	8.4%
6	Time of initial peak exertion & height of peak velocity at initial peak exertion	4.8%
7	Height of first grip change	4.2%
Total		94.4%

7.5.9 Confirmation of initial pull Events factor structure using second pull data

The 60 variables ~~which~~ remaining after PCA of the initial pulls data were selected from the second pulls data and subjected to confirmatory PCA. Three cycles of PCA (Table A7.17) reduced the data set to 53 variables with a stable six factor solution (Table A7.18, Table 7.12), accounting for 94.7% of the variance.

Table 7.12: Factors obtained from PCA of data from second pulls carried out to confirm the initial pulls Events factor structure

Factor	Factor name	R^2
1	Exertion before first grip change	40.6%
2	Exertion at second grip change	18.0%
3	Exertion at first grip change	15.1%
4	Height of second grip change and subsequent peak	10.2%
5	Time of main peak exertion and height of main peak velocity	6.1%
6	Height of first grip change	4.8%
Total		94.7%

7.5.10 Analysis of second pulls Event data

PCA was also carried out on the 121 Events using the data from 270 cases of second pulls. Four PCAs (Table A7.19) produced a stable five factor solution (Table A7.20, Table 7.13) from 45 variables These accounted for 94.2% of the variance.

Table 7.13: Factors obtained from PCA of second pulls Event data

Factor	Factor name	R^2
1	Exertion before first grip change	42.9%
2	Exertion at second grip change	19.3%
3	Exertion at first grip change	17.0%
4	Time of main peak exertion and height of main peak velocity	8.6%
5	Height of first grip change	6.4%
Total		94.2%

7.5.11 Confirmation of second pull Events factor structure using initial pull data

The factor solution obtained from PCA of the second pulls Event data used 45 Event variables. Therefore these variables were selected from the initial pulls Event data and subjected to confirmatory PCA. After a single PCA (Table A7.21), a stable five factor solution (Table A7.22, Table 7.14) accounting for 94.5% of the variance was obtained.

Table 7.14: Factors obtained from PCA of initial pull Event data carried out to confirm the second pull Events factor structure

Factor	Factor name	R^2
1	Exertion before first grip change	42.9%
2	Exertion at first grip change	19.4%
3	Exertion at second grip change	18.1%
4	Time of main peak exertion and height of main peak velocity	7.8%
5	Height of first grip change	6.3%
Total		94.5%

7.5.12 Analysis of all Range data

Because of the way that Events had been defined, 14 Ranges had been defined using them as end points. Data were available from a total of 70 Range variables since five measures had been used (mean force, mean velocity, mean power, mean work, and mean impulse). The untransformed Range data from all 584 cases were subjected to PCA. The fourth PCA (Table A7.23) confirmed three factors accounting for 96.4% of the variance as the optimal solution (Table A7.24, Table 7.15) for the remaining 36 variables.

Table 7.15: Factors obtained from PCA of all Range data

Factor	Factor name	R^2
1	Exertion before first grip change.	79.9%
2	Exertion between second grip change and 1.45 m.	10.8%
3	Work and impulse between first grip change and 1.45 m.	5.8%
Total		96.4%

7.5.13 Analysis of transformed Range data

27 out of the 70 Range variables were found to be non-normal. 26 of these were transformed using square root transformations. A log transform was used for the last one. Three PCAs (Table A7.25) confirmed that three factors existed and that the solution (Table A7.26, Table 7.16) accounted for 95.5% of the variance and was stable.

Table 7.16: Factors obtained from PCA of transformed Range data

Factor	Factor name	R^2
1	Exertion before first grip change.	78.4%
2	Exertion between second grip change and 1.45 m.	10.2%
3	Work and impulse between first grip change and 1.7 m.	6.9%
Total		95.5%

Because the three factors obtained were almost identical to those obtained from the untransformed data and because there were only minor changes in the variables which loaded on each factor and in the percentages in variance accounted for, it was decided, that, as with the Event data, the benefits to be gained from transformation were so small that they did not outweigh the losses in interpretability which would result. All the remaining analyses of Range data were therefore carried out using untransformed data.

7.5.14 Analysis of female Range data

The 70 Range variables were subjected to PCA using the 158 cases obtained from females. Four cycles of PCA (Table A7.27) led to the extraction of three factors (Table A7.28, Table 7.17) accounting for 95.7% of the variance of the remaining 27 variables.

Table 7.17: Factors obtained from PCA of female Range data

Factor	Factor name	R^2
1	Exertion before first grip change.	77.4%
2	Exertion between second grip change and 1.45 m.	12.2%
3	Impulse between first grip change and 1.7 m	6.1%
Total		95.7%

7.5.15 Confirmation of female Ranges factor structure using male data

The 27 variables which remained in the factor structure obtained from Range data from female subjects were selected from the male Range data and used for confirmatory PCA. Three factors, accounting for 94.2% of the variance were extracted (Table A7.29) and gave a stable solution (Table A7.30, Table 7.18).

Table 7.18: Factors obtained from PCA of male Range data carried out to confirm the female Ranges factor structure

Factor	Factor name	R^2
1	Exertion before first grip change	76.2%
2	Exertion between second grip change and 1.45 m	11.5%
3	Impulse between first grip change and 1.7 m	6.6%
Total		94.2%

7.5.16 Analysis of male Range data

Analysis of the 70 Range variables was carried out using the 426 cases obtained from males. Four PCA cycles (Table A7.31) produced a stable three-factor solution (Table A7.32, Table 7.19) from 37 variables, accounting for 91.8% of the variance.

Table 7.19: Factors obtained from PCA of male Range data

Factor	Factor name	R^2
1	Exertion before first grip change.	69.4%
2	Exertion above first grip change.	12.4%
3	Exertion above second grip change.	9.5%
Total		91.8%

7.5.17 Confirmation of male Ranges factor structure using female data

The 37 variables which had been left in the factor structure obtained from Range data obtained from male subjects were selected from the female Range data and subjected to confirmatory PCA. Two PCA cycles (Table A7.33) reduced the number of variables to eight, with three factors, accounting for 99.0% of the variance and giving a stable solution (Table A7.34, Table 7.20).

Table 7.20: Factors obtained from PCA of female Range data carried out to confirm the male Ranges factor structure

Factor	Factor name	R^2
1	Exertion between 0.7 and 1.0 m.	49.7%
2	Exertion between second change of grip and 1.45 m.	31.3%
3	Work done above first change of grip.	18.0%
Total		99.0%

7.5.18 Analysis of initial pulls Range data

PCA was carried out of the 70 Range variables for the 272 cases obtained from initial pulls. Four PCA cycles (Table A7.35) produced a stable two factor solution (Table A7.36, Table 7.21) accounting for 95.1% of the variance of 40 variables.

Table 7.21: Factors obtained from PCA of initial pulls Range data

Factor	Factor name	R^2
1	Exertion before first grip change.	85.4%
2	Exertion between first grip change and 1.45 m.	9.7%
Total		95.1%

7.5.19 Confirmation of initial pulls Ranges factor structure using second pulls data

40 variables which matched those in the factor structure obtained from initial pulls Range data were selected from the second pulls Range data for confirmatory PCA. After three PCA cycles (Table A7.37) two stable factors (Table A7.38, Table 7.22) were extracted from 36 variables and accounted for 95.1% of the variance. ~~This solution.~~

Table 7.22: Factors obtained from PCA of second pulls Range data carried out to confirm the initial pulls Ranges factor structure

Factor	Factor name	R^2
1	Exertion below first grip change	88.7%
2	Work / Impulse above first grip change	6.3%
Total		95.1%

7.5.20 Analysis of second pulls Range data

Three cycles of PCA (Table A7.39) of the 70 Range variables using the 270 cases obtained from second pulls resulted in the extraction of three factors (Table A7.40, Table 7.23) from 41 variables and 95.2% of the variance was accounted.for.

Table 7.23: Factors obtained from PCA of second pulls Range data

Factor	Factor name	R^2
1	Exertion before first grip change.	77.8%
2	Exertion between second grip change and 1.45 m.	11.9%
3	Work and impulse between first grip change and 1.7 m.	5.5%
Total		95.2%

7.5.21 Confirmation of second pulls Ranges factor structure using initial pulls data

41 variables matching those in the factor structure obtained from second pulls Range data were selected from the initial pulls Range data for confirmatory PCA. 96.2% of the variance was associated with the three factors extracted (Table A7.41, Table A7.42, Table 7.24).

Table 7.24: Factors obtained from PCA of initial pulls Range data carried out to confirm the second pulls Ranges factor structure

Factor	Factor name	R^2
1	Exertion below first grip change.	79.9%
2	Exertion between second grip change and 1.45 m.	10.6%
3	Impulse above first grip change.	5.6%
Total		96.2%

7.5.22 Analysis of combined Event and Range data

Despite the reservations expressed above about the validity of combining Event and Range data, it was decided to do so in order to examine the resulting factor structure. This was done for all 584 cases for the total of 191 variables. The scree test, performed after the initial PCA, was ambiguous, possibly identifying seven factors or four factors. A conservative approach was adopted and seven factors were extracted. By the fifth PCA 74 variables remained and produced seven factors, associated with 95.0% of the variance. After extraction and rotation, no variables met the criteria for deletion, but no variables loaded > 0.3 on the seventh factor extracted. The extraction and rotation were therefore repeated with only six factors. This resulted in seven variables meeting the deletion criteria. A seventh PCA (Table A7.43) produced a stable six factor solution (Table A7.44, Table 7.25), accounting for 92.9% of the variance.

Table 7.25: Six factor solution obtained from PCA of all Event and Range data

Factor	Factor name	R^2
1	Exertion before first grip change.	54.1%
2	Exertion at first grip change.	12.1%
3	Exertion at second grip change.	11.3%
4	Height of first grip change / subsequent drop in work & impulse	7.3%
5	Time of initial peak exertion and height of initial peak velocity	5.3%
6	Work and impulse between second grip change and 1.7 m	2.9%
Total		92.9%

Because of the ambiguity of the initial scree test, it was decided to examine the effect of extracting four factors at that stage. The resulting sixth PCA cycle (Table A7.45) produced a stable five factor solution (Table A7.46, Table 7.26). which accounted for 90.8% of the variance of the remaining 81 variables.

Table 7.26: Five factor solution obtained from PCA of all Event and Range data

Factor	Factor name	R²
1	Exertion before first grip change.	61.9%
2	Exertion at first grip change.	10.8%
3	Exertion at second grip change.	9.5%
4	Time of initial peak and height of initial peak velocity	5.2%
5	Time of main peak exertion	3.5%
Total		90.8%

The two solutions were identical for the first three factors, accounting for 77.5% and 82.2% of the variance respectively. The fourth factor of the five factor solution was identical to the fifth factor of the six factor solution, but the remaining factors were unrelated. The five factor solution was judged to be preferable because it was more parsimonious, i.e. it produced one less factor, and used a greater number of variables while accounting for only 2.1% less variance.

7.6 Discussion

7.6.1 Factors extracted from Event and Range data

The results of the main PCAs are summarised in Table 7.27. The most important factor extracted from the Event data related to the level of exertion during the pulling phase before the first grip change. The next two factors related almost equally to the level of exertion at each of the two changes of grip. In interpreting this it must be remembered that, on the second pull, 269 of the 270 subjects changed grip once, but only 74 subjects changed grip a second time (Table ~~4.4~~ A1.10). (On the first pull only 66/272 subjects changed grip a second time). Also, the changes of grip were characterised by low levels of exertion (mean forces of 33 N and 43 N at the first and second grip changes), though the distributions were wide and highly skewed, with coefficients of variation > 100% and maxima of 239 and 171 N (Tables A1.8 and A1.10). These first three factors accounted for almost 75% of the variance.

The fourth and fifth factors related to the elapsed time and height reached for the main peak and preliminary peak respectively. Again, differences in lifting technique must be remembered since only 130 of the 270 subjects produced an initial peak force, and a significantly greater proportion of males did so than females did (see Chapter 5.3.6). The sixth factor related to the height at which the first grip change occurred, but accounted for less than 5% of the variance. The fact that two of the factors related to features of the lift produced by under 50% of the subjects may be an artefact of the unequal numbers of values contributing to the different correlations, but is more likely to show that these features were important sources of variability, and that the remainder of the lift was predictable from the other factors extracted.

While six factors had been obtained from the Event data, only three were obtained from the Range data, but the first factor was common to both analyses. This one factor accounted for almost 80% of the variance of the Range data. The second factor was the amount of exertion (mean force, mean velocity, mean power) between the second grip change and 1.45 m, and accounted for 10.8% of the variance. Again, it must be remembered that the second grip change was carried out by only 74 of the 270 subjects (Table A1.10), and the mean height of the first grip change was actually greater than 1.45 m at 1.489 m, so the number of cases where there was a second grip change below 1.45 m was even smaller at 27 (Table A1.38). The third factor was the mean work and impulse between the first grip change and 1.45 m.

The fact that the first factor extracted massively dominates the Range data suggests that due to the averaged nature of the Range data in general and these Range variables in particular, these data do not describe the inherent variability of the data and hence are not well suited to Principal Components Analysis.

7.6.2 Validity of combining Range and Event data

Table 7.27: Comparison of factors obtained from PCA of separate Event and Range data with the five factor solution obtained from combined Event and Range data

Factor name	Events	R^2	Range	R^2	All	R^2
Exertion before first grip change	E1	42.5%	R1	79.9%	ER1	61.9%
Exertion at second grip change	E2	16.3%			ER3	9.5%
Exertion between second grip change and 1.45 m			R2	10.8%		
Exertion at first grip change	E3	15.7%			ER2	10.8%
Time and height of main peak exertion	E4	7.3%				
Time of main peak					ER5	3.5%
Time of initial peak & height of initial peak velocity	E5	6.7%			ER4	5.2%
Work and impulse bet. 1st grip change and 1.45 m			R3	5.8%		
Height of first grip change	E6	4.8%				
Total		93.4%		96.4%		90.8%

Given the limited number of factors extracted from the Range data, the fact that the first factor, which predominates, is common to both data sets, and in the light of the conclusion that the Range data are not suitable for PCA, it is not surprising that the factors extracted from the combined set of Event and Range data match very closely the factor structure extracted from the Event data, and, apart from the first factor, do not match the structure extracted from the Range data. Combining the data sets increased the dominance of the first factor, the exertion before the first grip change. It also reduced the total number of factors from six to five. The levels of exertion at the two grip changes remained comparable as factors, even though the order of the factors changed. This was also true of the factors relating to height and timing of the two peaks in exertion below the first change in grip.

It is clear that combining the two data sets for PCA is not a useful exercise, and these findings confirm the conclusion that Principal Components Analysis of the Range data is unjustified *per se* and does not provide insights into the data.

7.6.3 Meaning of factors extracted from the Event data

The most important factor extracted from the Event data was related to the level of exertion during the pulling phase of the lift which occurred before the first grip change. The next two factors related almost equally to the level of exertion at each of the two changes of grip. The fourth and fifth factors related to the elapsed time and height reached for the main peak and preliminary peak respectively. The sixth factor related to the height at which the first grip change occurred.

7.6.4 Comparison of factors obtained with those obtained by Bryant et al. (1990)

Table 7.28 compares the factors obtained from this study with those obtained by Bryant *et al.* (1990) from the ILM. While there are similarities, the factor structures are different. Thus, there is no hydrodynamometer equivalent of the first, *Mid-Body Coordination,* factor on the ILM. This is due to the different physical principles which govern the two devices ensuring that the peaks in force and velocity coincide on the hydrodynamometer but are separate on the ILM where peak velocity occurs at zero force / acceleration. *Maximum Strength* is the second ILM factor and accounts for 22.5% of the variance, but on the hydrodynamometer maximal exertion is the main factor and accounts for 42.5%. On the hydrodynamometer the levels of exertion at the two grip changes together account for 32.0% of the variance, but the equivalent *Minimum Strength* factor on the ILM accounts for only 17.2%. Two factors on the hydrodynamometer describe the timing and displacement of the main and initial peaks in exertion, and together account for 14.0% of the variance, which is very close to the 14.4% accounted for by the *Lower Body Coordination* factor on the ILM. The last factor on the hydrodynamometer, the height of the first grip change, has no ILM equivalent.

Table 7.28: Comparison of hydrodynamometer and ILM factor structures

	Hydrodynamometer	R^2	ILM (Bryant *et al.*, 1990)	R^2
1	Exertion before first grip change (Initial and main peak in force, velocity and power)	42.5%	Mid-Body Coordination (Timing and displacement of maximum velocity and power, occurring at chest and waist height prior to wrist changeover).	24.7%
2	Exertion at second grip change (Second minimum in exertion)	16.3%	Maximum Strength (Maximum power, force at maximum velocity, power at maximum and second maximum force).	22.5%
3	Exertion at first grip change (First minimum in exertion)	15.7%	Minimum Strength (Minimum force, minimum power, and power at minimum force).	17.2%
4	Time and height of main exertion	7.3%	Lower Body Coordination (Displacement and timing of maximum force).	14.4%
5	Time of initial peak exertion and height of initial peak velocity	6.7%		
6	Height of first grip change	4.8%		

It is clear from these results that the factor structure underlying the lifting action utilised on the hydrodynamometer is different to that underlying the lifting action on the ILM because of the different physical principles governing the two devices and because some subjects exhibited two grip changes on the hydrodynamometer, whereas only single grip changes were identified by Bryant *et al.* (1990) on the ILM.

7.6.5 Comparison of male and female Events factors

Table 7.29 compares the factor structure. obtained from the full set of Event data with those obtained from the separate male and female data sets.

Table 7.29: Comparison of factors obtained from PCA of all and of separate male and female Event data

Factor name	All	R^2	Male	R^2	Female	R^2
Exertion before first grip change	1	42.5%	1	37.5%		
Exertion at initial peak and subsequent dip					1	32.8%
Times and heights of 2nd grip change and next peak			2	19.4%		
Exertion at second grip change	2	16.3%	3	15.6%		
Exertion at first grip change	3	15.7%	4	11.9%	2	21.3%
Peak exertion after second grip change					3	14.0%
Heights of first grip change and next peak					4	12.0%
Height of main peak exertion					5	7.4%
Time and height of main peak exertion	4	7.3%				
Time of initial peak & height of initial. peak velocity	5	6.7%				
Exertion at 1.0 m			5	5.0%		
Height of first grip change	6	4.8%				
Exertion at 1.45 m					6	4.6%
Time of dip after initial peak exertion			6	3.0%		
Total		93.4%		92.5%		92.1%

While three common factors were obtained from the whole group and the male subset, only one factor (exertion at first grip change) is common to the group data, and to the male and female data. However, there is overlap between some of the other factors, and in particular the first factors obtained, since initial exertion is part of the exertion below the first grip change. This lack of agreement may reflect the disparity in the number of cases obtained from males (426) and females (158). (Bryant *et al.* (1990) had used approximately equal groups of males (96) and females (79) to generate their initial factor structure, and found almost identical structures for males and females). However, this lack of common factors is more likely to reflect genuine gender differences in lifting on this device, since, for example, it was shown (Chapter 5) that women were less likely to have an initial peak than males. The similarity of the mean curves obtained, especially when normalised to stature (Chapter 6), counts against this interpretation.

Table 7.30: Comparison of factors obtained from PCA of female Event data and from confirmatory PCA using male Event data

Factor name	Female	R^2	Male	R^2
Exertion at initial peak / subsequent dip (before main peak).	1	32.8%		
Exertion below first grip change.			2	22.4%
Exertion at first grip change.	2	21.3%	1	31.5%
Exertion at peak exertion after second grip change.	3	14.0%		
Heights of first grip change and subsequent peak exertion.	4	12.0%	3	19.7%
Height of main peak exertion.	5	7.4%	4	10.4%
Exertion at 1.45 m.	6	4.6%	5	7.3%
Total		92.1%		93.8%

There is reasonable overlap (Table 7.30) between the results of the female analysis and the male confirmatory analysis using the same variables except that the first two factors are reversed in order and amounts of variance, and there are fewer variables loading on the first female factor than on the second male factor.

Table 7.31: Comparison of factors obtained from PCA of male Event data and from confirmatory PCA using female Event data

Factor name	Male	R^2	Female	R^2
Exertion before first grip change.	1	37.5%	1	57.8%
Time and height of second grip change and subsequent peak.	2	19.4%		
Exertion at second grip change.	3	15.6%	2	23.9%
Exertion at first grip change.	4	11.9%	3	12.1%
Exertion at 1.0 m.	5	5.0%		
Time of dip after initial peak exertion.	6	3.0%		
Total		92.5%		93.8%

The attempt to use female data to confirm the male factor structure failed since only three factors were obtained of the six obtained from the male data (Table 7.31). Also, while the first factor is common, in the confirmatory PCA it has increased in importance by over 50%. This failure to match factor structures may be partly due to the disparity in numbers of males and females since the larger male group will make extraction of less important factors easier. It may also reflect genuine gender differences.

7.6.6 Comparison of male and female Ranges factors

The factor structures obtained from all Range data and from the male and female subsets are compared in Table 7.32. Again, only the first factor is common, but it is completely dominant and again there is overlap between the remaining factors.

Table 7.32: Comparison of factors obtained from PCA of Range data from all subjects and of separate male and female Range data

Factor name	All	R^2	Male	R^2	Female	R^2
Exertion before first grip change	1	79.9%	1	69.4%	1	77.4%
Exertion above first grip change			2	12.4%		
Exertion above second grip change			3	9.5%		
Exertion between second grip change and 1.45 m	2	10.8%			2	12.2%
Impulse between first grip change and 1.7 m					3	6.1%
Work and impulse bet. first grip change and 1.45 m	3	5.8%				
Total		96.4%		91.8%		95.7%

Table 7.33 shows that the attempt to confirm the female factor structure using male data was successful. There are 27 variables in each factor structure, which contain the same factors, and the proportions of variance obtained are very similar.

Table 7.33: Comparison of factors obtained from PCA of female Range data and from confirmatory PCA of male Range data

Factor name	Female	R^2	Male	R^2
Exertion before first grip change.	1	77.4%	1	76.2%
Exertion between second grip change and 1.45 m.	2	12.2%	2	11.5%
Impulse between first grip change and 1.7 m.	3	6.1%	3	6.6%
Total		95.7%		94.2%

Table 7.34 shows that, unlike the reverse process, the attempt to use the female data to confirm the structure obtained from the male data has been poor because only eight variables remained in the analysis. This meant that almost all the variables which had represented the first factor, the exertion below the first grip change, had been deleted. This failure to confirm the structure can be partly attributed to the relatively small number of female cases, and to the 3:1 ratio of cases from male and female subjects.

Table 7.34: Comparison of factors obtained from PCA of male Range data and from confirmatory PCA of female Range data

Factor name	Male	R^2	Female	R^2
Exertion before first grip change	1	69.4%		
Exertion between 0.7 and 1.0 m.			1	49.7%
Exertion above first grip change	2	12.4%		
Exertion between second change of grip and 1.45 m			2	31.3%
Exertion above second grip change	3	9.5%		
Work done above first change of grip			3	18.0%
Total		91.3%		99.0%

The differences in the factors obtained for the males and females show that the factor structures are not constant across gender despite the confirmations of the male structures using female data. This is contrary to the findings of Bryant *et al.* (1990) regarding the ILM and implies that factor structure is affected by the interaction of device and gender, i.e. the way that men and women perform manual exertions depends upon the nature of the device and hence the exertion. This finding will need further evaluation.

7.6.7 Comparison of initial and second pulls Events factors

Table 7.35: Comparison of factors obtained from PCA of all Event data and of initial and second pulls Event data

Factor name	All	R^2	T1	R^2	T2	R^2
Exertion before first grip change	1	42.5%	1	36.7%	1	42.9%
Exertion at second grip change	2	16.3%	3	14.7%	2	19.3%
Exertion at first grip change	3	15.7%	2	15.5%	3	17.0%
Height of second grip change and subsequent peak			4	10.2%		
Time of main peak and height of main peak velocity					4	8.6%
Time and height of main exertion peak	4	7.3%	5	8.4%		
Time of initial peak & height of initial peak velocity	5	6.7%	6	4.8%		
Height of first grip change	6	4.8%	7	4.2%	5	6.4%
Total		93.4%		94.4%		94.2%

Table 7.35 shows that there are very great similarities between the three sets of factors obtained from all Event data and from initial and second pulls. Though the sequence is altered slightly, the first three factors are common and account for 74.5%, 66.9% and 79.2% of the overall variance and in T1 and T2 respectively. The last factor is common, and the fourth factor in T2 overlaps with a factor in T1. The difference between the two pulls appears to be that the variability in T2 has decreased leading to the elimination of two factors and an increase in the dominance of the first three factors. This suggests that the warming up effect found in Chapter 3 leads not only to a more powerful. but also a more consistent exertion.

Table 7.36: Comparison of factors from PCA of initial pulls Event data and from confirmatory PCA of second pulls Event data

Factor name	T1	R^2	T2	R^2
Exertion before first grip change	1	36.7%	1	40.6%
Exertion at first grip change	2	15.5%	3	15.1%
Exertion at second grip change	3	14.7%	2	18.0%
Height of second grip change and subsequent peak	4	10.2%	4	10.2%
Time and height of main peak exertion	5	8.4%		
Time of main peak and height of main peak velocity			5	6.1%
Time of initial peak & height of initial peak velocity	6	4.8%		
Height of first grip change.	7	4.2%	6	4.8%
Total		94.4%		94.7%

Table 7.36 shows that the high degree of matching between the factors obtained confirms the structure obtained from the initial pulls and again demonstrates the tendency of the second pulls to have fewer factors and to increase the loading on the first three factors.

Table 7.37: Comparison of factors from PCA of second pulls Event data and from confirmatory PCA of initial pulls Event data

Factor name	T2	R^2	T1	R^2
Exertion before first grip change.	1	42.9%	1	42.9%
Exertion at second grip change.	2	19.3%	3	18.1%
Exertion at first grip change.	3	17.0%	2	19.4%
Time of main peak exertion and height of main peak velocity	4	8.6%	4	7.8%
Height of first grip change.	5	6.4%	5	6.3%
Total		94.2%		94.5%

Table 7.37 shows that a very good match has also been obtained between the initial and confirmatory PCAs. The only difference is a slight redistribution of variance leading to the second and third factors swapping places. This again demonstrates that the second pull is a less variable replica of the initial pull.

It is clear from these comparisons that with only minor differences, the same factor structure was obtained from initial and second pulls. This confirms the repeatability of measurements made on this device. The fact that fewer factors were obtained from the second pulls and that the first variable in particular accounted for a greater percentage of the variation suggests that the previously shown warming-up effect made the second pulls less variable than the initial pulls. This confirms that when taking measurements on the device, data from second or later exertions should be used, as was in fact done in the analyses reported in Chapters 5 and 6.

7.6.8 Comparison of factor structures of initial and second pulls Range data

Table 7.38: Comparison of factors obtained from PCA of all Range data and initial and second pulls Events data

Factor name	All	R^2	T1	R^2	T2	R^2
Exertion before first grip change	1	79.9%	1	85.4%	1	77.8%
Exertion between second grip change and 1.45 m	2	10.8%			2	11.9%
Exertion between first grip change and 1.45 m			2	9.7%		
Work & impulse bet. first grip change and 1.45 m	3	5.8%				
Work & impulse between first grip change and 1.7 m					3	5.5%
Total		96.4%		95.1%		95.2%

The comparison in Table 7.38 shows that the exertion below the first grip change continues to dominate the Range data. While three factors were obtained from the combined data set, only two were found for the initial pull. There was better matching of the combined data set by the second pulls than by the initial pulls, and as with the Event data, less variance was attributed to the exertion before the first grip change. This may imply that in the second pull subjects were more effective at exerting after changing grip than in the initial pull.

Table 7.39: Comparison of factors from PCA of initial pulls Range data and from confirmatory PCA of second pulls Range data

Factor name	T1	R^2	T2	R^2
Exertion before first grip change.	1	85.4%	1	88.7%
Exertion between first grip change and 1.45 m.	2	9.7%		
Work & impulse above first grip change			2	6.3%
Total		95.1%		95.1%

Table 7.39 shows that the attempt to verify the factor structure of the initial pulls confirmed the dominance of the first factor but failed to confirm the second factor.

Table 7.40: Comparison of factors from PCA of second pulls Range data and from confirmatory PCA of initial pulls Range data

Factor name	T2	R^2	T1	R^2
Exertion before first grip change.	1	77.8%	1	79.9%
Exertion between second grip change and 1.45 m.	2	11.9%	2	10.6%
Work and impulse between first grip change and 1.7 m.	3	5.5%		
Impulse above first grip change.			3	5.6%
Total		95.2%		96.2%

Table 7.40 shows that the attempt to confirm the factor structure of the second pulls was more successful because the first two factors were matched with almost exactly the same variance, and there was overlap between the third factors extracted.

The domination in these factor structures of the exertion before the first grip change means that the commonality between the initial and confirmatory PCAs is very high. Despite this, there are differences in the second and third factors extracted, though they do all relate to aspects of the lift after the first grip change.

7.7 Conclusions

This chapter has produced a number of important findings relating to the use of Principal Components Analysis to examine the characteristics of dynamic lifting exertions.

While queries could have been raised about the utility of analysing the relationships between the defined parameters when the different measures used are all derived from one original set of force / displacement / time measurements, PCA has been shown to be a useful method for analysing dynamic lifting exertions on a hydrodynamometer. By reducing the large number of parameters available to describe the characteristics of a dynamic lift to a small number of factors, it has proved possible to identify the features of the lift that contribute to its variability. This information could be of use in both qualitative and quantitative descriptions of dynamic lifts and in predictive models of dynamic lifting capacity.

The most important factor underlying exertion on the hydrodynamometer has been shown to be the level of exertion during the pulling phase before the first grip change. Grieve (1970) had noted that if a sufficiently large impulse was applied to an inertial load at the start of a lift then it could be allowed to reach the target height under its own momentum. This study has shown that, even on this device which, unlike the ILM, requires continuous exertion through the Range of lift, the level of exertion in the early stages of the lift has the largest influence on the total exertion. This tends to confirm the use by Grieve (1993) of the mean power between 0.7 and 1.0 m to characterise a lift on the device.

The factors of second and third importance related to the grip changes, which showed that they were important sources of variability in the lift, even though the second change was only performed by 24% and 27% of subjects on the first and second pulls respectively. This highlights the importance of the need to change grip as a limiting factor when performing lifts that pass through the shoulder region and implies that assessment tools such as the NIOSH lifting equations (NIOSH, 1981; Waters et al., 1993, 1994) should be revised to take account of this fact. Also, should it prove possible to develop a dynamic predictive model of lifting strength, this aspect will need explicit consideration.

This chapter has shown clearly that it is easier to characterise a dynamic lift using instantaneous Event data rather than data averaged over a Range of the lifts since such Range data appeared not to describe well the inherent variability of the data. However, the fact that the first factor obtained from the Range data was identical to the first factor obtained from the Event data implies that it is legitimate to characterise the early stage of the lift before the grip changes by a range mean, such as the mean power over the 0.7 to 1.0 m Range. This further reinforces the finding of Chapter 5 that Grieve (1993) was justified in his previous characterisation of dynamic lifting capacity by the mean power exerted over the 0.7 m - 1.0 m range.

This chapter has shown that the factor structure identified by Bryant *et al.* (1990) for dynamic lifts on the ILM is specific to isoinertial lifts and cannot be generalised to dynamic lifting on all devices. The fact that a different factor structure was obtained from a hydraulic resistance lifting dynamometer showed that the factor structure obtained on any device is dependent on the physical principles governing that device. This means that different devices measure different aspects of dynamic lifting and implies that tests used to predict dynamic lifting capacity should be as similar as possible to the situation being modelled. The suggestion by Mital *et al.* (1986a) that they did not expect the different operating characteristics (hydraulic and mechanical) of the Cybex and Min-Gym devices is therefore almost certainly profoundly mistaken.

This chapter has shown that there appears to be a gender-device interaction in factor structures. Different, though partly overlapping, structures were found for males and females on the hydrodynamometer. Bryant *et al.* (1990) had found essentially the same structure for males and females and had suggested that there was no evidence that the stability of factor structures they observed was due to the methods adopted for deriving the parameters. The finding that PCA of instantaneous Event data and averaged Range data from the same exertions produced significantly different factor structures means that the form of the input data significantly affects the results of PCA, and thus it seems reasonable to suggest that if Bryant *et al.* (1990) had used different methods of deriving parameters they would have obtained different factor structures.

Despite the failure to find a common factor structure for males and females, this chapter showed that the factor structures obtained for initial and second pulls by the subjects were virtually identical, showing that performances on the hydrodynamometer are highly repeatable, even in naive subjects. The slight differences in factor structure that were observed showed that the second pulls were less variable replications of the initial pulls with increased performance after the change of grip. This tends to confirm the finding (Chapter 3) of a warming-up effect on the device.

CHAPTER 8

SUMMARY AND CONCLUSIONS

The purpose of this thesis has been to examine dynamic lifting strength exhibited by a large group of fit individuals when performing exertions on a hydraulic, accommodating resistance, dynamometer. Such devices have been used previously, but the majority of work appears to have been carried out using isoinertial and isokinetic devices.

Review of previous studies of dynamic lifting showed that many authors have not considered the length-tension, force-velocity and power-velocity curves that describe the properties of muscle. Proper understanding of dynamic lifting depends upon the understanding of both the characteristics of the musculoskeletal system and the physical principles underlying the measurement device in use. As Timm (1988) pointed out, lifting is a multi-joint, multisegment, multi-muscle activity. Further work remains to be done in linking the biomechanics of the musculoskeletal system to the dynamics of lifting actions.

This thesis describes in detail the fluid mechanics of the hydrodynamometer used in this study. This instrument is robust, mobile, and unlike the ILM, fail-safe in that it does not require the presence of 'safety spotters' to prevent loss of control of the load. However, it has the disadvantage that it has to be filled with water before use and drained after use. Also, it requires a computer link-up to collect the data.

Weisman *et al.* (1990b) showed that dynamic lifts starting at different heights follow closely the force-displacement curves of full range lifts. A similar finding was obtained by Fothergill (1992). This implies that in maximal lifting it is the postural and muscular constrains at any instant which determine force output, not the force exerted in a previous part of the lift.

Studies of dynamic lifting strength have often employed low sampling rates, which lead to low resolutions. This study and the studies reviewed have clearly shown that very rapid build-ups of force occur in dynamic lifting. Thus there is a need for a minimum sampling rate or resolution to be adopted in future studies of dynamic lifting to ensure that the normal phenomena of such lifts are observed. This study employed a sampling rate for force of 12.5 kHz and measured displacement at intervals of 0.278 mm.

Weisman *et al.* (1990a) found that isokinetic lifting strength of a group of five males was not affected by repeatability considerations, and Newton *et al.* (1993) did not find significant learning effects on isokinetic devices measuring low back and lifting strength in both 120 low back pain patients and 70 normal subjects. However, Russell *et al.* (1992) showed a learning effect for upper body strength of 32 novice subjects on a hydraulic dynamometer. This study succeeded in showing that the hydrodynamometer produces repeatable results when testing the same subjects on separate days, but did demonstrate a warming-up effect on each day. It is imperative that any procedure for measuring dynamic strength takes in to account repeatability, learning effects and warming up effects.

The conclusion of Weisman *et al.* (1990b) that because force generated varies throughout a person's range of motion, it is impossible to describe strength with a single value should act as a warning to all ergonomists and biomechanists when discussing human strength. This study examined the utility of a number of different measures of dynamic lifting performance. It emerged that the work done, i.e. an integrated measure over the range of the lift, appears to be a useful parameter which allows comparison with performance on other devices using other physical principles.

In this thesis particular attention has been paid to examining features of the lifts that reflected differences in lifting technique, especially methods of changing from an overarm upward pull to an under arm upward thrust.

This study has addressed the thorny issue of gender differences in strength, particularly in relation to differences in upper body strength. It is a common assertion that women have less upper body strength than men. This study has shown that gender differences in whole body dynamic lifting performance can be almost exclusively attributed to differences in lean body (fat-free) mass. This tends to confirm similar findings for bench and leg press (Hosler and Morrow, 1982), isokinetic knee and elbow flexion and extension (Falkel *et al.*, 1985), bench press and elbow curls (Bishop *et al.*, 1987, 1989), and isometric elbow flexion and extension (Castro *et al.*, 1995). It therefore follows that upper body strength differences are due to gender-related differences in lean body mass not to gender *per se*.

This study has confirmed that complex statistical techniques such as Principal Components Analysis can usefully be applied to data characterising maxima and minima of dynamic exertions since it allows links to be made between data from different instants during a dynamic lift. The study has also shown that the factor structures obtained are dependent upon the physical principles underlying the operation of the device. Therefore some of the criticisms of the Canadian studies of the ILM (such as Stevenson *et al.*, 1996a) expressed by McDaniel (1996) are unjustified.

In the wider context, when selection tests are devised for physically demanding occupations they must provide a more rational basis than opinions based on simple observation, rules of thumb or the average worker (Ayoub *et al.*, 1979). Developing such tests raises issues of test objectivity, validity, and reliability and job relevance and the costs of implementing the programme (Sharp *et al.*, 1980).

The effect of absolute gender differences in strength is that if a job demands strength then more men than women will be capable of performing the job. This means that if it is desired to allow women and men equal access to any such job then the job must be redesigned to remove the need for strength. If selection tests based on strength are used, more women than men will be excluded and the test will, in effect, control the entry of women into such jobs. Ultimately, the only completely reliable selection tool for ability to perform a physically demanding job is employing the worker to perform the actual job. Such a procedure is, in reality, impractical and therefore if selection purely on the basis of gender is to be avoided, the ability, in pre-placement screening, to perform the actual or simulated tasks which make up the job should be the paramount selection criterion.

CHAPTER 9

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APPENDIX 1

SUMMARY DATA FOR THE HYDRODYNAMOMETER EVENTS AND RANGES

Table A1.1: Event 1: Hand height of 0.7 m

Variable:	Time1	Force1	Velocity1	Power1	Time1	Force1	Velocity1	Power1	Time1	Force1	Velocity1	Power1
	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	females	females	females	females
Sample size	270	270	270	270	201	201	201	201	69	69	69	69
Mean	437.730	829.737	736.433	632.078	413.562	911.124	779.234	721.393	508.135	592.652	611.754	371.899
Standard deviation	64.759	200.224	106.458	231.975	46.803	148.567	78.729	188.070	58.230	130.601	73.587	128.750
Minimum	312.584	310	424	131	312.584	514	570	293	387.79	310	424	131
Maximum	688.055	1321	979	1293	589.327	1321	979	1293	688.055	1004	837	841
Standardized skewness	5.443	-1.269	-1.682	1.385	4.679	0.616	0.222	2.556	1.105	1.931	1.552	3.924
Standardized kurtosis	1.585	-1.368	-1.190	-1.087	3.188	0.331	-0.137	0.777	0.823	1.694	2.316	4.194

Table A1.2: Event 2: Hand height of 1.0 m

Variable	Time2	Force2	Velocity2	Power2	Time2	Force2	Velocity2	Power2	Time2	Force2	Velocity2	Power2
	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	females	females	females	females
Sample size	270	270	270	270	201	201	201	201	69	69	69	69
Mean	968.360	421.289	493.130	231.048	885.377	486.134	536.955	278.284	1210.096	232.391	365.464	93.449
Standard deviation	208.752	181.735	132.576	136.815	119.845	158.411	113.241	124.668	224.708	90.618	97.971	50.284
Minimum	683.095	7	15	0	683.095	49	139	7	864.549	7	15	0
Maximum	2193.855	957	747	715	1406.672	957	747	715	2193.855	408	507	205
Standardized skewness	12.934	-1.104	-5.410	2.047	10.121	-3.596	-7.881	-0.042	6.575	-1.675	-3.867	0.201
Standardized kurtosis	19.612	-1.963	0.818	-1.077	12.799	2.108	5.720	1.240	9.244	-0.351	2.404	-0.819

Table A1.3: Event 3: Hand height of 1.45 m

Variable	Time3	Force3	Velocity3	Power3	Time3	Force3	Velocity3	Power3	Time3	Force3	Velocity3	Power3
	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	females	females	females	females
Sample size	270	270	270	270	201	201	201	201	69	69	69	69
Mean	2227.139	366.578	452.159	190.785	2054.713	404.826	479.04	220.224	2729.425	255.159	373.855	105.029
Standard deviation	384.182	186.123	139.307	144.490	214.729	192.783	141.543	152.738	323.072	103.965	97.404	62.845
Minimum	1584.127	11	29	0	1584.127	23	108	2	2006.481	11	29	0
Maximum	3874.309	1016	858	868	2728.698	1016	858	868	3874.309	470	543	255
Standardized skewness	7.202	3.836	-1.194	9.455	2.982	1.844	-2.368	6.734	2.446	0.436	-2.284	2.014
Standardized kurtosis	3.988	1.326	-0.042	11.030	1.478	0.557	0.194	7.324	2.789	-0.998	2.210	-0.827

Table A1.4: Event 4: Hand height of 1.7 m

Variable	Time4	Force4	Velocity4	Power4	Time4	Force4	Velocity4	Power4	Time4	Force4	Velocity4	Power4
	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	females	females	females	females
Sample size	270	270	270	270	201	201	201	201	69	69	69	69
Mean	2874.293	259.585	384.056	111.093	2630.050	303.761	423.154	136.557	3585.784	130.899	270.159	36.913
Standard deviation	519.691	119.331	97.692	77.690	248.236	104.894	78.809	73.944	444.031	37.393	42.483	17.169
Minimum	1980.238	74	175	13	1980.238	80	213	17	2594.528	74	175	13
Maximum	5220.738	692	649	449	3430.835	692	649	449	5220.738	242	382	92
Standardized skewness	8.517	4.959	1.357	8.697	3.153	5.219	2.001	7.778	2.595	4.022	2.032	5.147
Standardized kurtosis	5.449	1.420	-1.802	6.629	1.215	2.844	-0.225	6.192	3.315	2.524	0.645	4.227

Table A1.5: Event 5: Initial force peak below 0.9 m

Variable	Height5	Time5	Force5	Velocity5	Power5	Height5	Time5	Force5	Velocity5	Power5	Height5	Time5	Force5	Velocity5	Power5
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	129	129	129	129	129	116	116	116	116	116	13	13	13	13	13
Mean	479.452	108.611	908.008	787.295	734.225	481.041	108.961	935.293	800.931	764.897	465.266	105.485	664.538	665.615	460.538
Standard deviation	20.826	31.456	200.133	99.606	247.247	20.970	32.693	182.764	89.528	233.622	13.038	17.317	188.976	105.725	196.906
Minimum	443.368	63.206	342	457	156	443.368	63.206	529	599	317	447.538	74.326	342	457	156
Maximum	572.638	249.700	1416	1086	1538	572.638	249.700	1416	1086	1538	496.188	130.730	957	808	773
Standardized skewness	6.976	8.717	0.096	-0.716	2.153	6.639	8.123	1.215	0.958	2.817	1.399	-0.483	0.302	-0.310	0.545
Standardized kurtosis	10.722	11.946	0.056	1.367	0.934	10.226	10.340	-0.333	0.415	1.045	1.048	-0.340	-0.707	-0.369	-0.842

Table A1.6: Event 6: Dip in force after initial peak

Variable	Height6	Time6	Force6	Velocity6	Power6	Height6	Time6	Force6	Velocity6	Power6	Height6	Time6	Force6	Velocity6	Power6
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	129	129	129	129	129	116	116	116	116	116	13	13	13	13	13
Mean	542.293	193.802	774.891	721.930	571.256	546.101	196.261	795.069	731.388	591.448	508.313	171.860	594.846	637.538	391.077
Standard deviation	37.603	42.643	152.824	79.513	169.383	37.008	43.953	140.262	73.112	160.186	23.804	17.388	146.733	87.357	144.979
Minimum	459.770	113.769	340	466	159	479.230	113.769	490	570	279	459.770	139.450	340	466	159
Maximum	700.518	375.069	1143	903	1015	700.518	375.069	1143	903	1015	550.676	201.536	851	790	672
Standardized skewness	3.410	6.363	-0.407	-1.494	0.949	3.316	5.570	0.498	-0.551	1.399	0.066	-0.341	0.126	-0.309	0.486
Standardized kurtosis	3.293	7.504	-0.064	-0.075	-0.280	3.358	6.196	-0.437	-1.089	-0.316	0.436	0.151	-0.54	-0.097	-0.364

Table A1.7: Event 7: Main force peak, below 0.9 m

Variable	Height7	Time7	Force7	Velocity7	Power7	Height7	Time7	Force7	Velocity7	Power7	Height7	Time7	Force7	Velocity7	Power7
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	270	270	270	270	270	201	201	201	201	201	69	69	69	69	69
Mean	671.553	392.025	870.804	756.174	675.996	688.211	395.724	941.990	790.896	756.458	623.029	381.249	663.435	655.029	441.609
Standard deviation	73.977	105.838	187.211	94.722	224.791	70.912	103.164	150.375	77.485	193.798	60.411	113.365	116.295	62.375	120.616
Minimum	458.936	86.486	366	479	175	458.936	86.486	552	570	314	461.160	108.330	366	479	175
Maximum	908.740	773.423	1351	993	1322	908.740	761.421	1351	993	1322	799.764	773.423	1029	837	862
Standardized skewness	-0.876	1.634	0.091	-0.063	2.660	-1.647	1.029	1.054	0.663	3.054	-0.281	1.521	1.642	1.163	3.171
Standardized kurtosis	2.589	6.698	-1.236	-0.909	-0.240	4.334	6.759	0.276	0.654	1.181	1.247	2.639	1.937	1.77	3.221

Table A1.8: Event 8: Minimum force at first grip change below 1.7 m

Variable	Height8	Time8	Force8	Velocity8	Power8	Height8	Time8	Force8	Velocity8	Power8	Height8	Time8	Force8	Velocity8	Power8
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	269	269	269	269	269	201	201	201	201	201	68	68	68	68	68
Mean	1192.650	1516.289	32.922	105.349	8.294	1216.032	1457.371	40.104	123.657	10.070	1123.536	1690.443	11.691	51.235	3.044
Standard deviation	164.891	391.351	47.515	111.295	12.204	164.670	364.832	50.334	110.687	13.381	146.029	417.259	29.257	94.851	4.888
Minimum	775.022	707.178	41	200	1	856.754	707.178	41	200	0	775.022	735.338	37	186	1
Maximum	1780.548	2736.298	239	388	93	1780.548	2464.117	239	388	93	1440.276	2736.298	116	254	29
Standardized skewness	2.272	2.372	6.542	-3.018	18.13	2.188	1.912	4.484	-3.572	13.784	0.100	0.545	3.363	-1.623	10.053
Standardized kurtosis	0.347	-1.545	3.528	0.216	35.901	0.042	-1.897	1.655	0.984	24.171	-0.381	-0.69	2.353	0.206	19.935

Table A1.9: Event 9: Force peak after (8) but before any second grip change

Variable	Height9	Time9	Force9	Velocity9	Power9	Height9	Time9	Force9	Velocity9	Power9	Height9	Time9	Force9	Velocity9	Power9
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	269	269	269	269	269	201	201	201	201	201	68	68	68	68	68
Mean	1424.874	2150.847	478.074	541.424	276.390	1455.739	2066.452	519.234	569.134	310.905	1333.643	2400.308	356.412	459.515	174.368
Standard deviation	143.662	388.544	166.645	107.709	148.513	138.903	346.848	159.944	98.794	147.686	116.86	400.278	120.883	90.317	94.759
Minimum	1005.762	1159.053	88	200	18	1056.358	1159.053	140	276	39	1005.762	1427.953	88	200	18
Maximum	1960.136	3326.265	1101	903	994	1960.136	2939.036	1101	903	994	1541.468	3326.265	855	764	653
Standardized skewness	-0.632	0.382	3.712	-0.474	8.467	-0.387	-1.016	2.938	-0.524	7.136	-3.249	-0.432	3.084	-0.08	6.798
Standardized kurtosis	2.673	0.232	2.872	1.689	10.386	2.308	-0.145	3.297	2.479	9.527	1.392	-0.088	5.534	2.985	14.395

Table A1.10: Event 10: Minimum force at second grip change below 1.7 m

Variable	**Height10**	**Time10**	**Force10**	**Velocity10**	**Power10**	**Height10**	**Time10**	**Force10**	**Velocity10**	**Power10**	**Height10**	**Time10**	**Force10**	**Velocity10**	**Power10**
	(mm)	**(ms)**	**(N)**	**(mm·s^{-1})**	**(W)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	74	74	74	74	74	56	56	56	56	56	18	18	18	18	18
Mean	1489.129	2326.082	42.770	117.554	10.365	1508.902	2199.952	48.214	138.000	11.821	1427.612	2718.489	25.833	53.944	5.833
Standard deviation	144.148	428.270	50.328	117.244	13.805	136.049	341.150	52.670	106.150	15.147	155.075	442.299	38.730	130.045	6.888
Minimum	1079.154	1500.442	32	205	0	1178.956	1500.442	25	96	0	1079.154	2251.860	32	205	0
Maximum	1831.422	3684.774	171	349	60	1831.422	3202.257	171	349	60	1674.908	3684.774	90	236	21
Standardized skewness	-0.249	3.265	2.480	-1.275	5.679	0.734	2.228	1.983	-0.285	4.209	-0.870	1.567	0.486	-0.763	1.967
Standardized kurtosis	0.453	1.895	-0.607	-0.286	3.378	-0.135	1.511	-0.955	-0.989	1.392	-0.020	-0.227	-0.921	-0.644	-0.020

Table A1.11: Event 11: Force peak after second grip change but below 1.7 m

Variable	**Height11**	**Time11**	**Force11**	**Velocity11**	**Power11**	**Height11**	**Time11**	**Force11**	**Velocity11**	**Power11**	**Height11**	**Time11**	**Force11**	**Velocity11**	**Power11**
	(mm)	**(ms)**	**(N)**	**(mm·s^{-1})**	**(W)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	74	74	74	74	74	56	56	56	56	56	18	18	18	18	18
Mean	1635.293	2801.039	349.527	456.486	173.432	1669.100	2685.013	390.607	488.107	202.518	1530.116	3162.008	221.722	358.111	82.944
Standard deviation	158.453	472.846	138.997	102.800	111.027	146.239	432.236	131.137	94.063	111.216	152.138	416.344	66.876	56.692	38.209
Minimum	1236.780	1916.554	122	255	31	1395.240	1916.554	207	339	70	1236.780	2632.610	122	255	31
Maximum	2078.842	4030.163	809	755	611	2078.842	3942.795	809	755	611	1819.746	4030.163	379	466	177
Standardized skewness	1.156	2.553	3.466	1.769	5.748	1.906	2.974	3.354	1.654	4.923	0.428	1.456	1.230	0.194	1.776
Standardized kurtosis	0.548	0.315	2.544	0.042	6.612	0.432	1.441	2.686	0.101	5.486	-0.015	-0.242	0.621	-0.085	1.020

Table A1.12: Event 12: Initial velocity peak below 0.9 m

Variable	**Height12**	**Time12**	**Force12**	**Velocity12**	**Power12**	**Height12**	**Time12**	**Force12**	**Velocity12**	**Power12**	**Height12**	**Time12**	**Force12**	**Velocity12**	**Power12**
	(mm)	**(ms)**	**(N)**	**(mm·s^{-1})**	**(W)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	132	132	132	132	132	118	118	118	118	118	14	14	14	14	14
Mean	443.226	65.489	685.500	869.758	607.258	443.804	65.274	702.178	888.703	631.890	438.364	67.303	544.929	710.071	399.643
Standard deviation	19.247	32.394	147.319	145.666	200.068	19.929	33.531	141.174	135.895	190.856	11.389	21.243	124.597	129.966	153.586
Minimum	421.128	26.242	329	470	154	421.128	26.242	387	638	251	421.128	36.083	329	470	154
Maximum	548.730	219.378	1128	1336	1208	548.730	219.378	1128	1336	1208	462.828	106.409	720	939	638
Standardized skewness	10.053	9.919	2.406	1.963	3.400	9.302	9.842	2.975	3.076	4.087	0.691	-0.032	0.089	0.328	0.442
Standardized kurtosis	16.913	13.912	0.890	1.577	2.151	14.846	12.792	0.762	1.561	2.257	0.211	-0.583	-0.931	-0.23	-1.017

Table A1.13: Event 13: Dip in velocity after initial peak

Variable	Height13	Time13	Force13	Velocity13	Power13	Height13	Time13	Force13	Velocity13	Power13	Height13	Time13	Force13	Velocity13	Power13
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	132	132	132	132	132	118	118	118	118	118	14	14	14	14	14
Mean	526.618	172.004	799.144	713.311	581.902	530.029	174.035	821.576	723.085	603.958	497.876	154.881	610.071	630.929	396.000
Standard deviation	38.208	46.577	155.865	79.466	171.045	38.029	48.107	141.629	73.416	160.991	26.453	26.059	145.649	83.362	141.135
Minimum	446.982	88.807	341	460	157	460.604	88.807	497	552	281	446.982	111.769	341	460	157
Maximum	679.112	351.388	1150	891	1013	679.112	351.388	1150	891	1013	560.684	220.338	857	772	662
Standardized skewness	4.720	6.873	-1.008	-1.251	0.704	4.535	6.164	-0.160	-0.356	1.138	1.136	1.376	-0.062	-0.486	0.302
Standardized kurtosis	3.480	6.708	-0.208	-0.044	-0.370	3.222	5.516	-0.655	-0.965	-0.413	1.627	1.692	-0.532	-0.088	-0.474

Table A1.14: Event 14: Main velocity peak, below 0.9 m

Variable	Height14	Time14	Force14	Velocity14	Power14	Height14	Time14	Force14	Velocity14	Power14	Height14	Time14	Force14	Velocity14	Power14
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	270	270	270	270	270	201	201	201	201	201	69	69	69	69	69
Mean	655.617	371.389	854.844	770.604	676.111	670.650	373.827	923.662	806.622	756.174	611.824	364.288	654.377	665.681	442.884
Standard deviation	80.742	116.710	185.760	97.929	225.594	80.539	116.258	152.441	79.653	195.298	64.010	118.583	115.671	65.355	122.489
Minimum	423.908	39.043	359	489	176	423.908	39.043	494	594	311	438.086	71.847	359	489	176
Maximum	897.898	853.188	1347	1007	1357	897.898	853.188	1347	1007	1357	795.316	765.823	1016	848	861
Standardized skewness	-0.943	1.980	0.066	-0.364	2.549	-1.907	1.599	0.379	0.260	2.775	-0.481	1.231	1.622	1.198	3.115
Standardized kurtosis	2.726	7.428	-1.250	-1.270	-0.405	3.717	7.471	0.721	0.095	0.974	1.229	2.471	1.891	1.418	2.987

Table A1.15: Event 15: Minimum velocity at first grip change below 1.7 m

Variable	Height15	Time15	Force15	Velocity15	Power15	Height15	Time15	Force15	Velocity15	Power15	Height15	Time15	Force15	Velocity15	Power15
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	269	269	269	269	269	201	201	201	201	201	68	68	68	68	68
Mean	1191.401	1512.776	40.238	97.822	8.993	1214.377	1449.702	47.259	117.801	10.886	1123.487	1699.215	19.485	38.765	3.397
Standard deviation	164.366	394.811	48.890	114.977	12.634	164.322	365.489	52.205	112.053	13.831	145.594	421.353	28.993	103.254	4.993
Minimum	773.910	676.135	40	237	0	853.974	676.135	40	237	0	773.910	726.296	33	199	0
Maximum	1749.690	2720.697	241	374	90	1749.690	2466.917	241	374	90	1443.334	2720.697	122	249	30
Standardized skewness	2.187	2.310	6.596	-3.705	16.914	2.074	1.855	4.500	-4.269	12.734	0.119	0.387	2.717	-1.402	9.895
Standardized kurtosis	0.053	-1.686	3.585	0.062	29.300	-0.268	-1.927	1.479	1.451	19.189	-0.358	-0.898	2.092	-0.732	19.914

Table A1.16: Event 16: Peak velocity after (8), but before any second grip change

Variable	Height16	Time16	Force16	Velocity16	Power16	Height16	Time16	Force16	Velocity16	Power16	Height16	Time16	Force16	Velocity16	Power16
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	269	269	269	269	269	201	201	201	201	201	68	68	68	68	68
Mean	1418.042	2138.116	467.089	552.896	275.926	1449.886	2056.484	507.726	581.373	310.622	1323.917	2379.411	346.971	468.721	173.368
Standard deviation	146.683	390.296	164.648	110.387	149.844	141.854	350.696	158.000	101.091	148.950	118.164	403.872	119.658	92.798	96.428
Minimum	994.920	1165.053	86	206	18	1079.710	1165.053	142	278	39	994.920	1404.270	86	206	18
Maximum	1974.314	3312.024	1098	927	1017	1974.314	2917.995	1098	927	1017	1531.460	3312.024	847	790	669
Standardized skewness	-0.418	0.250	4.051	-0.343	8.776	-0.216	-1.002	3.369	-0.529	7.462	-3.179	-0.522	3.174	0.479	7.168
Standardized kurtosis	2.160	-0.049	3.393	1.369	11.097	1.672	-0.533	3.773	2.358	10.202	1.251	-0.039	5.810	2.986	15.585

Table A1.17: Event 17: Minimum velocity at second grip change below 1.7 m

Variable	Height17	Time17	Force17	Velocity17	Power17	Height17	Time17	Force17	Velocity17	Power17	Height17	Time17	Force17	Velocity17	Power17
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	74	74	74	74	74	56	56	56	56	56	18	18	18	18	18
Mean	1488.163	2324.180	46.676	109.000	10.730	1507.671	2195.061	53.964	128.232	12.482	1427.473	2725.885	24.000	49.167	5.278
Standard deviation	143.349	428.272	53.180	118.416	14.579	135.018	341.085	55.749	110.294	15.966	155.263	430.634	37.012	125.888	6.815
Minimum	1076.930	1489.640	30	149	0	1177.566	1489.640	16	124	0	1076.93	2247.460	30	149	0
Maximum	1832.256	3675.174	194	329	64	1832.256	3205.136	194	329	64	1674.074	3675.174	88	237	21
Standardized skewness	-0.231	3.127	3.000	-0.973	5.678	0.806	2.141	2.254	-0.684	4.132	-0.878	1.616	0.857	-0.203	2.099
Standardized kurtosis	0.555	1.784	-0.343	-1.126	3.497	-0.045	1.461	-0.922	-0.961	1.410	0.000	-0.187	-0.826	-1.051	0.161

Table A1.18: Event 18: Velocity peak after second grip change but below 1.7 m

Variable	Height18	Time18	Force18	Velocity18	Power18	Height18	Time18	Force18	Velocity18	Power18	Height18	Time18	Force18	Velocity18	Power18
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	74	74	74	74	74	56	56	56	56	56	18	18	18	18	18
Mean	1625.371	2781.304	339.851	465.162	171.878	1656.828	2661.320	378.482	497.964	200.357	1527.506	3154.586	219.667	363.111	83.278
Standard deviation	158.597	484.933	132.589	107.072	110.267	149.416	444.816	125.399	98.253	110.836	149.606	417.978	66.374	58.531	38.512
Minimum	1249.012	1887.831	118	256	30	1373.556	1887.831	203	339	71	1249.012	2610.690	118	256	30
Maximum	2101.638	4030.163	791	781	618	2101.638	4002.880	791	781	618	1819.746	4030.163	375	476	178
Standardized skewness	1.649	2.569	3.346	2.061	5.988	2.257	3.091	3.200	2.051	5.149	0.454	1.499	1.173	0.069	1.698
Standardized kurtosis	0.928	0.336	2.340	0.656	7.343	0.892	1.604	2.433	0.799	6.105	-0.069	-0.161	0.575	-0.068	0.948

Table A1.19: Event 19: Initial power peak below 0.9 m

Variable	Height19	Time19	Force19	Velocity19	Power19	Height19	Time19	Force19	Velocity19	Power19	Height19	Time19	Force19	Velocity19	Power19
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	131	131	131	131	131	117	117	117	117	117	14	14	14	14	14
Mean	471.049	98.500	889.786	819.084	750.427	472.370	98.608	917.744	835.571	784.632	460.008	97.602	656.143	681.214	464.571
Standard deviation	19.503	31.481	191.429	116.034	259.937	19.713	32.742	173.475	106.105	245.935	13.746	18.537	179.166	106.121	193.492
Minimum	434.750	50.085	337	470	158	434.75	50.085	524	604	317	436.418	66.086	337	470	158
Maximum	555.402	227.78	1308	1198	1552	555.402	227.78	1308	1198	1552	490.628	134.492	942	827	779
Standardized skewness	4.944	7.341	-0.266	0.414	2.225	4.570	6.837	0.828	1.662	2.752	1.162	0.494	0.306	-0.166	0.636
Standardized kurtosis	4.814	8.188	-0.279	1.252	0.566	4.401	7.072	-0.806	1.044	0.639	0.953	0.024	-0.589	-0.370	-0.770

Table A1.20: Event 20: Dip in power after initial peak

Variable	Height20	Time20	Force20	Velocity20	Power20	Height20	Time20	Force20	Velocity20	Power20	Height20	Time20	Force20	Velocity20	Power20
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	131	131	131	131	131	117	117	117	117	117	14	14	14	14	14
Mean	536.532	185.958	777.725	713.313	566.534	540.509	188.660	798.949	723.479	587.923	503.297	163.373	600.357	628.357	387.786
Standard deviation	38.294	43.675	152.080	79.934	168.644	37.535	44.800	139.454	73.654	159.550	27.581	23.476	140.778	82.365	136.875
Minimum	451.708	86.086	343	460	158	458.658	86.086	491	552	277	451.708	122.009	343	460	158
Maximum	683.004	352.748	1143	891	1005	683.004	352.748	1143	891	1005	554.846	212.098	851	772	657
Standardized skewness	2.840	5.511	-0.417	-1.239	1.085	2.790	4.860	0.430	-0.352	1.482	0.671	0.553	0.005	-0.479	0.38
Standardized kurtosis	1.781	5.791	-0.108	-0.160	-0.225	1.873	4.858	-0.479	-1.118	-0.256	0.179	0.446	-0.44	-0.056	-0.32

Table A1.21: Event 21: Main power peak, below 0.9 m

Variable	Height21	Time21	Force21	Velocity21	Power21	Height21	Time21	Force21	Velocity21	Power21	Height21	Time21	Force21	Velocity21	Power21
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	270	270	270	270	270	201	201	201	201	201	69	69	69	69	69
Mean	666.439	385.259	867.344	767.152	683.381	682.969	389.163	938.423	802.711	765.035	618.286	373.887	660.290	663.565	445.522
Standard deviation	76.358	109.960	186.379	97.185	227.896	74.038	108.254	149.739	79.474	196.215	61.501	114.838	116.089	64.503	122.887
Minimum	449.206	72.805	359	489	176	449.206	72.805	547	570	312	455.600	99.449	359	489	176
Maximum	908.740	890.231	1347	1007	1357	908.74	890.231	1347	1007	1357	799.764	773.423	1026	848	870
Standardized skewness	-0.230	3.249	0.041	-0.175	2.568	-1.033	2.868	0.999	0.450	2.941	-0.033	1.721	1.619	1.284	3.192
Standardized kurtosis	3.003	9.718	-1.250	-1.081	-0.330	4.542	10.389	0.261	0.479	1.113	1.117	2.62	1.999	1.571	3.184

Table A1.22: Event 22: Minimum power at first grip change below 1.7 m

Variable	Height22	Time22	Force22	Velocity22	Power22	Height22	Time22	Force22	Velocity22	Power22	Height22	Time22	Force22	Velocity22	Power22
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	269	269	269	269	269	201	201	201	201	201	68	68	68	68	68
Mean	1191.944	1489.808	42.219	120.156	8.004	1215.316	1434.857	48.791	135.139	9.826	1122.861	1652.238	22.794	75.868	2.618
Standard deviation	164.803	384.643	41.867	84.467	12.345	164.353	361.701	44.790	85.282	13.509	146.717	406.735	22.595	64.532	5.040
Minimum	774.188	662.293	34	83	1	854.252	662.293	34	80	1	774.188	728.377	20	83	1
Maximum	1766.092	2715.017	242	386	93	1766.092	2432.435	242	386	93	1439.442	2715.017	118	252	30
Standardized skewness	2.207	2.248	9.182	2.059	17.896	2.168	1.762	6.534	0.942	13.618	0.053	0.679	5.423	1.203	10.649
Standardized kurtosis	0.262	-1.456	7.622	-1.391	34.828	-0.063	-1.962	4.277	-1.486	23.535	-0.366	-0.446	7.069	-0.007	21.788

Table A1.23: Event 23: Peak power after (8), but before any second grip change

Variable	Height23	Time23	Force23	Velocity23	Power23	Height23	Time23	Force23	Velocity23	Power23	Height23	Time23	Force23	Velocity23	Power23
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	269	269	269	269	269	201	201	201	201	201	68	68	68	68	68
Mean	1422.290	2145.846	474.974	550.141	279.327	1453.511	2062.452	515.910	578.652	314.338	1330.004	2392.347	353.971	465.868	175.838
Standard deviation	144.444	388.406	165.827	110.521	151.191	139.532	347.151	159.261	101.306	150.427	117.351	401.449	119.968	92.612	96.644
Minimum	1003.260	1165.053	88	199	17	1064.698	1165.053	142	279	40	1003.26	1422.513	88	199	17
Maximum	1968.198	3320.184	1098	927	1017	1968.198	2931.355	1098	927	1017	1535.352	3320.184	848	790	670
Standardized skewness	-0.597	0.358	3.776	-0.161	8.722	-0.309	-0.971	3.021	-0.295	7.385	-3.357	-0.506	3.006	0.496	7.067
Standardized kurtosis	2.708	0.172	3.025	1.660	10.954	2.262	-0.220	3.430	2.663	10.034	1.478	-0.008	5.499	3.173	15.252

Table A1.24: Event 24: Minimum power at second grip change below 1.7 m

Variable	Height24	Time24	Force24	Velocity24	Power24	Height24	Time24	Force24	Velocity24	Power24	Height24	Time24	Force24	Velocity24	Power24
	(mm)	(ms)	(N)	(mm·s^{-1})	(W)	males	males	males	males	males	females	females	females	females	females
Sample size	74	74	74	74	74	56	56	56	56	56	18	18	18	18	18
Mean	1488.610	2303.112	48.311	125.095	10.189	1508.331	2183.410	54.071	139.804	11.839	1427.256	2675.516	30.389	79.333	5.056
Standard deviation	143.410	413.412	46.690	99.934	13.907	135.008	338.436	49.302	98.223	15.149	155.167	411.456	32.368	93.493	7.158
Minimum	1076.374	1487.640	21	100	0	1177.288	1487.640	9	100	0	1076.374	2210.736	21	71	0
Maximum	1828.364	3430.594	174	336	58	1828.364	3191.376	174	336	58	1666.568	3430.594	90	239	21
Standardized skewness	-0.321	2.722	3.503	0.232	5.477	0.739	2.033	2.701	-0.027	4.047	-0.951	1.208	1.117	0.513	2.147
Standardized kurtosis	0.537	1.026	-0.075	-1.274	2.781	-0.112	1.441	-0.762	-0.88	0.984	-0.005	-0.862	-0.591	-0.984	0.056

Table A1.25: Event 25: Power peak after second grip change but below 1.7 m

Variable	**Height25**	**Time25**	**Force25**	**Velocity25**	**Power25**	**Height25**	**Time25**	**Force25**	**Velocity25**	**Power25**	**Height25**	**Time25**	**Force25**	**Velocity25**	**Power25**
	(mm)	**(ms)**	**(N)**	**(mm·s^{-1})**	**(W)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	74	74	74	74	74	56	56	56	56	56	18	18	18	18	18
Mean	1633.448	2797.379	348.622	460.243	174.595	1666.642	2680.283	389.679	492.143	203.929	1530.178	3161.679	220.889	361.000	83.333
Standard deviation	158.216	474.677	137.887	105.095	112.468	146.951	433.415	129.657	96.806	112.847	150.683	417.263	66.538	57.697	38.264
Minimum	1248.734	1924.554	122	255	31	1386.344	1924.554	205	337	69	1248.734	2625.410	122	255	31
Maximum	2079.120	4030.163	791	781	618	2079.120	3943.516	791	781	618	1819.746	4030.163	379	466	177
Standardized skewness	1.286	2.579	3.284	2.071	5.894	1.952	3.023	3.157	2.029	5.058	0.488	1.453	1.275	-0.022	1.728
Standardized kurtosis	0.535	0.318	2.151	0.642	6.999	0.464	1.479	2.297	0.732	5.807	-0.065	-0.217	0.691	-0.139	0.959

Table A1.26: Ranges 26, 40, 54, 68 and 82: 0.4 m - Event 8

Variable	**Range26**	**Range40**	**Range54**	**Range68**	**Range82**	**Range26**	**Range40**	**Range54**	**Range68**	**Range82**	**Range26**	**Range40**	**Range54**	**Range68**	**Range82**
	(N)	**(mm·s^{-1})**	**(W)**	**(J)**	**(N·s)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	269	269	269	269	269	201	201	201	201	201	68	68	68	68	68
Mean	599.491	610.160	412.532	474.309	731.223	658.786	645.552	470.010	531.284	786.453	424.221	505.544	242.632	305.897	567.971
Standard deviation	142.614	84.715	147.057	138.342	164.142	107.003	61.914	119.873	105.291	141.423	73.830	48.971	66.340	70.259	108.938
Minimum	280	396	126	135	312	392	476	205	275	447	280	396	126	135	312
Maximum	1016	836	904	866	1274	1016	836	904	866	1274	648	649	462	477	817
Standardized skewness	-0.016	-0.984	2.294	-0.178	1.013	2.229	1.392	3.788	1.293	1.753	1.76	1.277	2.951	0.8	-0.12
Standardized kurtosis	-1.228	-1.244	-0.266	-1.601	-0.151	1.143	0.808	2.009	0.415	0.584	0.943	0.885	2.294	0.119	-0.118

Table A1.27: Ranges 27, 41, 55, 69 and 83: 0.4 m - Event 10

Variable	**Range27**	**Range41**	**Range55**	**Range69**	**Range83**	**Range27**	**Range41**	**Range55**	**Range69**	**Range83**	**Range27**	**Range41**	**Range55**	**Range69**	**Range83**
	(N)	**(mm·s^{-1})**	**(W)**	**(J)**	**(N·s)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	74	74	74	74	74	56	56	56	56	56	18	18	18	18	18
Mean	520.838	559.068	340.905	573.689	943.081	570.304	590.071	387.071	633.857	999.982	366.944	462.611	197.278	386.500	766.056
Standard deviation	118.872	73.553	116.508	160.084	174.374	84.777	50.247	89.834	122.318	139.944	65.487	45.229	57.585	112.309	152.840
Minimum	269	384	120	212	477	358	473	183	356	720	269	384	120	212	477
Maximum	777	700	600	993	1350	777	700	600	993	1350	564	596	381	712	1114
Standardized skewness	-0.983	-1.469	-0.201	-0.212	-0.646	-0.550	-0.900	-0.100	1.122	0.825	2.548	2.220	3.291	1.985	0.256
Standardized kurtosis	-1.447	-1.363	-1.61	-0.343	0.189	-0.257	-0.756	-0.572	0.757	-0.194	3.496	3.315	4.894	2.806	0.384

Table A1.28: Ranges 28, 42, 56, 70 and 84: 0.4 m - 1.45 m

Variable	Range28	Range42	Range56	Range70	Range84	Range28	Range42	Range56	Range70	Range84	Range28	Range42	Range56	Range70	Range84
	(N)	(mm·s^{-1})	(W)	(J)	(N·s)	males	males	males	males	males	females	females	females	females	females
Sample size	270	270	270	270	270	201	201	201	201	201	69	69	69	69	69
Mean	531.885	567.174	350.926	561.015	913.285	586.831	601.592	402.269	618.040	958.413	371.826	466.913	201.362	394.899	781.826
Standard deviation	123.684	77.788	121.948	129.263	98.237	84.644	52.064	92.150	89.067	60.368	67.262	47.568	58.002	71.792	62.471
Minimum	228	344	95	249	652	338	438	167	356	750	228	344	95	249	652
Maximum	822	753	685	863	1132	822	753	685	863	1132	624	636	433	669	1002
Standardized skewness	-1.903	-2.725	0.249	-1.859	-3.875	0.060	-0.699	1.731	0.071	-1.146	2.788	1.891	4.308	2.873	1.404
Standardized kurtosis	-2.083	-1.652	-1.969	-2.042	-1.078	0.341	0.325	0.385	0.337	1.736	3.937	3.406	5.880	4.111	2.294

Table A1.29: Ranges 29, 43, 57, 71 and 85: 0.4 m - 1.7 m

Variable	Range29	Range43	Range57	Range71	Range85	Range29	Range43	Range57	Range71	Range85	Range29	Range43	Range57	Range71	Range85
	(N)	(mm·s^{-1})	(W)	(J)	(N·s)	males	males	males	males	males	females	females	females	females	females
Sample size	270	270	270	270	270	201	201	201	201	201	69	69	69	69	69
Mean	491.896	542.241	314.730	642.567	1087.026	546.060	578.070	362.876	712.517	1146.030	334.116	437.870	174.478	438.797	915.145
Standard deviation	121.132	79.464	113.994	157.208	126.575	83.045	52.052	86.455	108.369	77.454	61.875	46.504	51.085	81.429	73.929
Minimum	200	314	80	268	763	309	417	147	402	876	200	314	80	268	763
Maximum	814	749	664	1059	1368	814	749	664	1059	1368	543	581	365	719	1141
Standardized skewness	-1.511	-2.689	0.678	-1.471	-3.547	0.995	0.026	2.528	0.993	-0.324	2.557	1.618	4.141	2.567	0.911
Standardized kurtosis	-1.823	-1.449	-1.445	-1.803	-1.213	1.264	1.224	1.535	1.197	1.976	2.954	2.542	5.099	2.951	1.005

Table A1.30: Ranges 30, 44, 58, 72 and 86: 0.7 m - 1.0 m

Variable	Range30	Range44	Range58	Range72	Range86	Range30	Range44	Range58	Range72	Range86	Range30	Range44	Range58	Range72	Range86
	(N)	(mm·s^{-1})	(W)	(J)	(N·s)	males	males	males	males	males	females	females	females	females	females
Sample size	270	270	270	270	270	201	201	201	201	201	69	69	69	69	69
Mean	644.326	624.533	437.604	193.156	295.870	731.692	674.692	518.040	219.254	317.104	389.826	478.420	203.290	117.130	234.014
Standard deviation	196.327	113.675	190.962	58.678	45.722	138.046	77.820	148.044	41.389	28.507	90.239	64.861	70.430	26.540	25.777
Minimum	200	330	67	60	167	371	455	182	111	227	200	330	67	60	167
Maximum	1207	925	1120	362	390	1207	925	1120	362	390	639	640	425	191	294
Standardized skewness	-1.048	-2.718	1.747	-0.985	-3.911	1.092	-1.435	3.859	1.053	-2.581	0.922	-0.521	2.668	1.008	-1.185
Standardized kurtosis	-1.818	-1.394	-0.493	-1.862	-1.331	1.301	1.907	3.115	1.318	1.992	1.142	0.869	2.504	1.38	0.91

Table A1.31: Ranges 31, 45, 59, 73 and 87: 0.7 m - Event (8)

Variable	Range31	Range45	Range59	Range73	Range87	Range31	Range45	Range59	Range73	Range87	Range31	Range45	Range59	Range73	Range87
	(N)	(mm·s^{-1})	(W)	(J)	(N·s)	males	males	males	males	males	females	females	females	females	females
Sample size	269	269	269	269	269	201	201	201	201	201	68	68	68	68	68
Mean	523.881	544.439	332.439	257.156	435.770	588.428	583.333	389.075	296.697	480.557	333.088	429.471	165.029	140.279	303.382
Standard deviation	150.312	87.394	140.806	104.044	150.340	110.514	59.104	113.642	86.546	137.879	66.877	46.58	51.840	48.864	99.273
Minimum	183	314	59	17	48	327	426	152	86	154	183	314	59	17	48
Maximum	1065	827	946	572	949	1065	827	946	572	949	508	539	307	254	542
Standardized skewness	0.657	-1.466	3.637	1.324	1.939	4.228	2.949	6.581	1.513	1.736	1.763	0.218	2.601	0.095	-0.147
Standardized kurtosis	-0.335	-0.621	2.529	-1.276	0.092	3.721	2.596	7.549	0.429	0.455	0.700	0.260	1.154	0.200	0.075

Table A1.32: Ranges 32, 46, 60, 74 and 88: 0.7 m - Event (10)

Variable	Range32	Range46	Range60	Range74	Range88	Range32	Range46	Range60	Range74	Range88	Range32	Range46	Range60	Range74	Range88
	(N)	(mm·s^{-1})	(W)	(J)	(N·s)	males	males	males	males	males	females	females	females	females	females
Sample size	74	74	74	74	74	56	56	56	56	56	18	18	18	18	18
Mean	440.311	497.676	260.243	354.216	646.014	487.375	527.696	299.714	396.446	692.143	293.889	404.278	137.444	222.833	502.500
Standard deviation	113.321	70.698	100.632	121.364	155.137	80.889	46.984	78.470	98.634	130.908	63.068	46.002	49.651	87.306	138.160
Minimum	207	330	77	91	244	292	422	130	203	398	207	330	77	91	244
Maximum	738	661	552	722	1018	738	661	552	722	1018	487	539	300	468	803
Standardized skewness	-0.549	-1.365	0.567	0.631	-0.259	0.801	0.407	1.556	1.886	0.799	2.755	2.125	3.612	1.939	0.276
Standardized kurtosis	-0.848	-0.782	-0.551	0.247	-0.027	0.897	-0.030	1.136	1.490	-0.303	3.787	3.026	5.561	2.169	0.065

Table A1.33: Ranges 33, 47, 61, 75 and 89: 0.7 m - 1.45 m

Variable	Range33	Range47	Range61	Range75	Range89	Range33	Range47	Range61	Range75	Range89	Range33	Range47	Range61	Range75	Range89
	(N)	(mm·s^{-1})	(W)	(J)	(N·s)	males	males	males	males	males	females	females	females	females	females
Sample size	270	270	270	270	270	201	201	201	201	201	69	69	69	69	69
Mean	456.167	509.115	274.481	344.052	618.004	509.299	542.746	319.736	383.443	652.572	301.391	411.145	142.652	229.304	517.304
Standard deviation	118.93	75.603	106.119	88.926	75.945	81.207	49.890	79.538	61.246	47.909	62.494	46.988	47.468	47.984	47.367
Minimum	156	279	47	123	421	281	397	124	211	494	156	279	47	123	421
Maximum	754	677	571	577	800	754	677	571	577	800	551	581	352	426	692
Standardized skewness	-1.533	-2.687	0.659	-1.428	-3.256	1.185	0.427	2.872	1.29	-0.028	3.036	1.537	4.888	3.295	1.919
Standardized kurtosis	-1.924	-1.276	-1.582	-1.853	-1.242	0.233	-0.211	0.94	0.308	1.023	4.847	3.415	8.088	5.309	2.738

Table A1.34: Ranges 34, 48, 62, 76 and 90: 0.7 m - 1.7 m

Variable	**Range34**	**Range48**	**Range62**	**Range76**	**Range90**	**Range34**	**Range48**	**Range62**	**Range76**	**Range90**	**Range34**	**Range48**	**Range62**	**Range76**	**Range90**
	(N)	**(mm·s^{-1})**	**(W)**	**(J)**	**(N·s)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	270	270	270	270	270	201	201	201	201	201	69	69	69	69	69
Mean	423.174	491.211	246.530	425.630	791.689	475.766	526.905	289.174	477.900	840.124	269.971	387.232	122.304	273.362	650.594
Standard deviation	117.900	78.926	100.927	117.849	104.771	81.844	51.416	77.193	82.361	65.923	57.405	46.155	41.661	58.202	59.217
Minimum	136	257	39	142	522	249	380	105	249	620	136	257	39	142	522
Maximum	727	683	544	728	1036	727	683	544	728	1036	465	523	284	476	830
Standardized skewness	-0.923	-2.563	1.474	-0.846	-2.970	2.204	1.028	3.982	2.239	0.597	2.431	1.084	4.152	2.463	0.940
Standardized kurtosis	-1.564	-1.188	-0.677	-1.526	-1.310	1.422	0.806	2.665	1.377	1.391	2.581	1.848	5.083	2.608	0.658

Table A1.35: Ranges 35, 49, 63, 77 and 91: Event (8) - Event (10)

Variable	**Range35**	**Range49**	**Range63**	**Range77**	**Range91**	**Range35**	**Range49**	**Range63**	**Range77**	**Range91**	**Range35**	**Range49**	**Range63**	**Range77**	**Range91**
	(N)	**(mm·s^{-1})**	**(W)**	**(J)**	**(N·s)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	74	74	74	74	74	56	56	56	56	56	18	18	18	18	18
Mean	305.959	414.865	149.473	139.122	292.932	328.911	434.214	165.107	149.339	304.143	234.556	354.667	100.833	107.333	258.056
Standard deviation	113.031	90.365	84.854	91.740	149.476	109.955	81.746	85.591	95.334	152.809	92.807	91.518	62.505	72.950	136.732
Minimum	53	126	8	2	20	112	239	28	11	47	53	126	8	2	20
Maximum	695	653	495	497	724	695	653	495	497	724	475	539	296	291	529
Standardized skewness	1.562	-1.712	4.517	4.019	1.612	1.438	-0.803	3.917	3.385	1.491	0.561	-1.501	2.739	1.673	0.324
Standardized kurtosis	2.310	2.114	6.281	4.230	0.626	2.481	1.142	5.889	3.568	0.572	1.963	1.838	4.505	1.221	0.020

Table A1.36: Ranges 36, 50, 64, 78 and 92: Event (8) - 1.45 m

Variable	**Range36**	**Range50**	**Range64**	**Range78**	**Range92**	**Range36**	**Range50**	**Range64**	**Range78**	**Range92**	**Range36**	**Range50**	**Range64**	**Range78**	**Range92**
	(N)	**(mm·s^{-1})**	**(W)**	**(J)**	**(N·s)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	251	251	251	248	250	183	183	183	181	182	68	68	68	67	68
Mean	304.518	416.359	151.936	95.677	199.448	323.787	431.836	167.301	97.652	194.110	252.662	374.706	110.588	90.343	213.735
Standard deviation	121.843	98.945	91.816	64.306	111.461	126.848	100.830	96.773	68.829	114.590	89.126	80.612	60.303	50.158	102.046
Minimum	46	148	4	1	3	46	157	4	1	3	52	148	7	2	3
Maximum	702	688	500	353	507	702	688	500	353	507	587	615	388	249	473
Standardized skewness	2.975	-0.555	7.536	5.365	1.481	1.526	-1.189	5.326	4.465	1.776	1.936	-0.805	5.222	1.980	-0.020
Standardized kurtosis	1.816	0.997	7.124	2.950	-1.772	0.984	0.737	4.584	1.847	-1.551	3.541	2.241	9.254	1.041	-0.510

Table A1.37: Ranges 37, 51, 65, 79 and 93: Event (8) - 1.7 m

Variable	**Range37**	**Range51**	**Range65**	**Range79**	**Range93**	**Range37**	**Range51**	**Range65**	**Range79**	**Range93**	**Range37**	**Range51**	**Range65**	**Range79**	**Range93**
	(N)	**(mm·s^{-1})**	**(W)**	**(J)**	**(N·s)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	267	267	267	267	267	199	199	199	199	199	68	68	68	68	68
Mean	327.978	439.787	166.221	170.060	359.000	363.427	468.734	191.704	182.648	363.000	224.235	355.074	91.647	133.221	347.294
Standard deviation	110.822	84.191	86.933	80.360	125.924	100.717	71.307	83.442	84.022	133.153	64.237	57.811	43.065	54.108	101.845
Minimum	104	216	25	25	76	163	312	52	25	76	104	216	25	35	127
Maximum	706	694	531	503	743	706	694	531	503	743	443	515	272	299	595
Standardized skewness	3.981	1.030	7.695	4.965	0.388	4.036	2.091	7.078	3.389	0.188	2.661	1.211	4.817	1.786	-0.103
Standardized kurtosis	1.743	-0.074	7.361	2.267	-1.413	2.823	1.145	7.511	1.077	-1.579	1.988	0.741	6.182	0.624	-0.523

Table A1.38: Ranges 38, 52, 66, 80 and 94: Event (10) - 1.45 m

Variable	**Range38**	**Range52**	**Range66**	**Range80**	**Range94**	**Range38**	**Range52**	**Range66**	**Range80**	**Range94**	**Range38**	**Range52**	**Range66**	**Range80**	**Range94**
	(N)	**(mm·s^{-1})**	**(W)**	**(J)**	**(N·s)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	27	27	27	26	27	19	19	19	18	19	8	8	8	8	8
Mean	186.519	312.593	72.889	25.231	62.815	188.737	312.316	76.368	21.611	48.895	181.25	313.25	64.625	33.375	95.875
Standard deviation	92.383	91.445	62.467	31.578	61.707	104.687	104.873	71.888	32.444	52.575	58.938	52.703	33.075	29.923	72.529
Minimum	28	84	3	1	7	28	84	3	1	7	135	253	39	7	27
Maximum	501	569	319	135	253	501	569	319	135	222	276	394	121	99	253
Standardized skewness	3.601	0.903	5.730	4.964	3.989	2.916	0.711	4.425	5.115	4.250	1.092	0.812	1.177	2.024	1.865
Standardized kurtosis	4.798	2.565	9.636	6.076	3.682	3.426	1.553	6.366	8.081	5.604	-0.625	-0.705	-0.436	1.986	1.835

Table A1.39: Ranges 39, 53, 67, 81 and 95: Event (10) - 1.7 m

Variable	**Range39**	**Range53**	**Range67**	**Range81**	**Range95**	**Range39**	**Range53**	**Range67**	**Range81**	**Range95**	**Range39**	**Range53**	**Range67**	**Range81**	**Range95**
	(N)	**(mm·s^{-1})**	**(W)**	**(J)**	**(N·s)**	**males**	**males**	**males**	**males**	**males**	**females**	**females**	**females**	**females**	**females**
Sample size	69	69	69	68	69	51	51	51	50	51	18	18	18	18	18
Mean	227.841	362.275	97.928	58.382	141.072	256.941	390.098	116.373	63.960	141.569	145.389	283.444	45.667	42.889	139.667
Standard deviation	101.829	93.962	68.014	44.459	86.979	101.006	91.491	69.32	47.181	87.153	41.602	42.355	21.398	32.062	88.988
Minimum	53	127	7	2	7	53	127	7	4	7	85	212	17	2	10
Maximum	513	579	323	247	426	513	579	323	247	426	236	361	97	128	369
Standardized skewness	2.274	0.507	3.913	4.886	2.398	1.037	-0.955	2.553	3.905	1.900	1.121	0.355	1.565	2.281	1.628
Standardized kurtosis	-0.055	-0.736	1.975	6.284	1.465	-0.168	0.329	0.985	4.933	1.427	-0.252	-0.478	0.318	1.65	1.047

APPENDIX 2

SUMMARY DATA FOR OTHER HYDRODYNAMOMETER QUESTIONS

Table A2.1: Heights, in mm, of power-related Events, for males

Variable:	**ht19**	**ht20**	**ht21**	**ht22**	**ht23**	**ht24**	**ht25**
Sample size	118	117	200	201	201	56	56
Mean	472.527	540.509	683.930	1215.316	1453.511	1508.331	1666.642
Std. deviation	19.703	37.535	72.958	164.353	139.532	135.008	146.951
Minimum	434.750	458.658	449.206	854.252	1064.698	1177.288	1386.344
Maximum	555.402	683.004	908.740	1766.092	1968.198	1828.364	2079.120
Standard skewness	4.481	2.790	-0.778	2.168	-0.309	0.739	1.952
Standard kurtosis	4.284	1.873	4.710	-0.063	2.262	-0.112	0.464

Table A2.2: Heights, in mm, of power-related Events, for females

	ht19	**ht20**	**ht21**	**ht22**	**ht23**	**ht24**	**ht25**
Sample size	14	14	69	68	68	18	18
Mean	460.008	503.297	618.286	1122.861	1330.004	1427.256	1530.178
Std. deviation	13.746	27.581	61.501	146.717	117.351	155.167	150.683
Minimum	436.418	451.708	455.600	774.188	1003.260	1076.374	1248.734
Maximum	490.628	554.846	799.764	1439.442	1535.352	1666.568	1819.746
Standard skewness	1.162	0.671	-0.033	0.053	-3.357	-0.951	0.488
Standard kurtosis	0.953	0.179	1.117	-0.366	1.478	-0.005	-0.065

Table A2.3: Heights, as percent stature, of power-related Events, for males

Variable:	**ht1**	**ht2**	**ht3**	**ht4**
Sample size	201	201	201	201
Mean	39.82%	56.89%	82.49%	96.71%
Std. deviation	1.43%	2.04%	2.95%	3.46%
Minimum	36.53%	52.19%	75.68%	88.73%
Maximum	44.33%	63.33%	91.83%	107.66%
Standard skewness	2.512	2.512	2.512	2.512
Standard kurtosis	0.901	0.901	0.901	0.901

Variable:	**ht19**	**ht20**	**ht21**	**ht22**	**ht23**	**ht24**	**ht25**
Sample size	118	117	200	201	201	56	56
Mean	26.79%	30.63%	38.86%	69.06%	82.59%	85.91%	94.95%
Std. deviation	1.32%	2.19%	3.97%	9.11%	7.44%	7.75%	8.84%
Minimum	23.70%	25.89%	26.40%	48.98%	60.91%	67.35%	79.31%
Maximum	30.37%	39.83%	54.64%	100.92%	112.47%	105.08%	117.49%
Standard skewness	1.413	2.931	-0.243	2.639	-0.754	0.695	2.495
Standard kurtosis	-0.556	4.000	6.947	-0.049	3.577	0.292	0.346

Table A2.4: Heights, as percent stature, of power-related Events, for females

Variable:	**ht1**	**ht2**	**ht3**	**ht4**
Sample size	69	69	69	69
Mean	42.87%	61.24%	88.80%	104.11%
Std. deviation	1.71%	2.44%	3.54%	4.15%
Minimum	37.94%	54.20%	78.60%	92.14%
Maximum	47.23%	67.48%	97.84%	114.71%
Standard skewness	-0.268	-0.268	-0.268	-0.268
Standard kurtosis	0.345	0.345	0.345	0.345

Variable:	**ht19**	**ht20**	**ht21**	**ht22**	**ht23**	**ht24**	**ht25**
Sample size	14	14	69	68	68	18	18
Mean	27.85%	30.48%	37.82%	68.61%	81.28%	87.70%	94.03%
Std. deviation	1.03%	2.08%	3.58%	8.52%	6.61%	8.93%	8.44%
Minimum	25.77%	28.03%	28.03%	46.44%	60.18%	68.30%	79.23%
Maximum	29.72%	34.68%	47.95%	86.72%	93.16%	101.26%	109.51%
Standard skewness	0.182	1.564	0.209	-0.156	-3.158	-0.874	0.321
Standard kurtosis	0.344	0.152	1.852	-0.508	2.029	-0.173	-0.404

Table A2.5: Absolute times (s), of power-related Events, for males

Variable:	ti19	ti20	ti21	ti22	ti23	ti24	ti25
Sample size	118	117	200	201	201	56	56
Mean	0.099	0.189	0.391	1.435	2.062	2.183	2.680
Std. deviation	0.033	0.045	0.107	0.362	0.347	0.338	0.433
Minimum	0.050	0.086	0.728	0.662	1.165	1.488	1.925
Maximum	0.228	0.353	0.890	2.432	2.931	3.191	3.944
Standard skewness	6.814	4.860	3.231	1.762	-0.971	2.033	3.023
Standard kurtosis	7.020	4.858	10.822	-1.962	-0.220	1.441	1.479

Table A2.6: Absolute times (s), of power-related Events, for females

Variable:	ti19	ti20	ti21	ti22	ti23	ti24	ti25
Sample size	14	14	69	68	68	18	18
Mean	0.098	0.163	0.374	1.652	2.392	2.676	3.162
Std. deviation	0.019	0.023	0.115	0.407	0.401	0.411	0.417
Minimum	0.066	0.122	0.099	0.728	1.423	2.211	2.625
Maximum	0.134	0.212	0.773	2.715	3.320	3.431	4.030
Standard skewness	0.494	0.553	1.721	0.679	-0.506	1.208	1.453
Standard kurtosis	0.024	0.446	2.620	-0.446	-0.008	-0.862	-0.217

Table A2.7: Times, as percent time to 1.7 m, of power-related Events, for males

Variable:	ti1	ti2	ti3
Sample size	201	201	201
Mean	15.76%	33.71%	78.18%
Std. deviation	1.47%	3.66%	4.48%
Minimum	12.09%	26.27%	66.06%
Maximum	20.78%	50.30%	85.99%
Standard skewness	2.695	12.337	-4.800
Standard kurtosis	2.135	20.206	-0.706

Variable:	ti19	ti20	ti21	ti22	ti23	ti24	ti25
Sample size	118	117	200	201	201	56	56
Mean	3.86%	7.37%	14.97%	54.91%	78.88%	80.81%	98.98%
Std. deviation	1.41%	2.00%	4.20%	14.33%	13.86%	13.20%	15.18%
Minimum	1.68%	3.24%	2.37%	25.94%	40.11%	59.01%	76.96%
Maximum	9.79%	14.29%	30.23%	108.02%	131.53%	117.15%	152.76%
Standard skewness	7.563	4.085	1.794	2.611	-0.84165	3.159	4.047
Standard kurtosis	9.851	2.833	5.618	0.739	2.442	1.559	3.206

Table A2.8: Times, as percent time to 1.7 m, of power-related Events, for females

Variable:	ti1	ti2	ti3
Sample size	69	69	69
Mean	14.27%	33.86%	76.24%
Std. deviation	1.54%	5.30%	3.26%
Minimum	10.72%	25.80%	65.03%
Maximum	17.50%	50.89%	82.23%
Standard skewness	-0.771	5.561	-3.986
Standard kurtosis	-0.241	4.859	3.367

Variable:	ti19	ti20	ti21	ti22	ti23	ti24	ti25
Sample size	14	14	69	68	68	18	18
Mean	2.932%	4.876%	10.575%	46.528%	67.261%	71.668%	84.67%
Std. deviation	0.805%	0.938%	3.433%	11.708%	10.985%	12.6940%	13.53%
Minimum	2.047%	3.352%	2.740%	18.155%	35.457%	52.944%	66.08%
Maximum	4.770%	6.858%	21.671%	72.785%	87.827%	95.546%	112.24%
Standard skewness	2.010	0.753	1.237	0.358	-3.301	0.572	1.141
Standard kurtosis	0.919	0.194	1.303	-0.574	1.453	-0.760	-0.166

Table A2.9: Time differences (ms) between related force and velocity Events

Variable:	f5v12	f6v13	f7v14	f8v15	f9v16	f10v17	f11v18
Sample size	130	129	269	269	269	74	74
Mean	43	21	21	4	13	2	20
Std. deviation	14	21	31	33	45	33	38
Minimum	11	-118	-128	-218	-202	-121	-68
Maximum	99	110	193	157	460	73	219
Standard skewness	4.168	-5.515	4.888	-10.554	13.844	-5.844	12.439
Standard kurtosis	5.592	40.698	30.389	31.993	142.665	8.143	34.010

Table A2.10: Time differences (ms) between related force and power Events

Variable:	f5p19	f6p20	f7p21	f8p22	f9p23	f10p24	f11p25
Sample size	130	129	269	269	269	74	74
Mean	10	7	7	26	5	23	4
Std. deviation	9	8	19	47	17	54	12
Minimum	-22	-19	-166	-201	-172	-129	-62
Maximum	69	40	188	253	34	315	29
Standard skewness	6.807	-0.109	1.871	7.556	-47.590	7.723	-8.708
Standard kurtosis	39.112	3.973	189.435	19.521	228.772	22.773	23.295

Table A2.11: Time differences (ms) between related velocity and power Events

Variable:	v12p19	v13p20	v14p21	v15p22	v16p23	v17p24	v18p25
Sample size	132	131	269	269	269	74	74
Mean	-33	-14	-14	23	-8	21	-16
Std. deviation	15	22	27	56	42	53	35
Minimum	-90	-102	-179	-205	-460	-24	-212
Maximum	-1	143	117	280	210	306	59
Standard skewness	-5.057	6.922	-8.541	9.643	-21.796	11.079	-15.927
Standard kurtosis	5.675	51.196	34.052	14.244	189.019	22.015	43.647

Table A2.12: Height differences (mm) between related force and velocity Events

Variable:	f5v12	f6v13	f7v14	f8v15	f9v16	f10v17	f11v18
Sample size	130	129	269	269	269	74	74
Mean	36	15	16	1	7	1	10
Std. deviation	13	16	24	4	26	5	19
Minimum	7	-96	-85	-15	-133	-34	-26
Maximum	87	70	136	31	269	9	113
Standard skewness	3.024	-8.892	4.962	5.942	15.100	-18.674	14.406
Standard kurtosis	3.540	47.690	24.341	48.206	147.583	69.171	38.537

Table A2.13: Height differences (mm) between related force and power Events

Variable:	f5p19	f6p20	f7p21	f8p22	f9p23	f10p24	f11p25
Sample size	130	129	269	269	269	74	74
Mean	8	5	5	1	3	1	2
Std. deviation	7	6	13	4	10	5	5
Minimum	-18	-15	-103	-38	-110	-34	-24
Maximum	59	29	133	14	14	9	11
Standard skewness	8.758	0.093	6.638	-25.409	-53.624	-18.483	-7.260
Standard kurtosis	41.656	5.124	153.510	107.178	275.273	66.117	17.240

Table A2.14: Height differences (mm) between related velocity and power Events

Variable:	v12p19	v13p20	v14p21	v15p22	v16p23	v17p24	v18p25
Sample size	132	131	269	269	269	74	74
Mean	-28	-10	-11	-1	-4	-0	-8
Std. deviation	13	17	21	4	25	3	18
Minimum	-75	-81	-134	-39	-269	-7	-111
Maximum	-1	116	94	16	134	8	23
Standard skewness	-4.483	10.116	-8.272	-18.273	-22.790	0.814	-17.047
Standard kurtosis	5.022	61.450	32.396	74.759	193.087	3.535	46.651

Table A2.15: Summary statistics for mean power between 0.7 m and 1.0 m for the subject groups

	Group B	Group C	Group D	Group B	Group C	Group B	Group C
	Males	Males	Males	Females	Females	All	All
Sample size	51	54	96	21	48	72	102
Mean (W)	572.196	542.833	475.323	193.381	207.625	461.708	385.088
Std. dev. (W)	175.070	142.678	122.003	50.530	77.635	228.840	204.348
Minimum (W)	209	182	221	67	77	67	77
Maximum (W)	1120	873	954	301	425	1120	873
Standard skewness	1.669	-0.094	3.221	-1.037	2.321	1.157	1.543
Standard kurtosis	1.356	-0.040	3.469	1.446	1.276	-0.685	-2.045

Table A2.16: Summary statistics for mean power between 0.4 m and 1.45 m for the subject groups

	Group B	Group C	Group D	Group B	Group C	Group B	Group C
	Males	**Males**	**Males**	**Females**	**Females**	**All**	**All**
Sample size	51	54	96	21	48	72	102
Mean (W)	423.039	436.5	371.979	192.571	205.208	355.819	327.657
Std. dev. (W)	100.154	87.115	80.863	45.258	62.818	137.000	138.846
Minimum (W)	167	175	216	95	101	95	101
Maximum (W)	647	685	623	270	433	647	685
Standard skewness	-0.129	0.163	2.485	-0.614	4.020	0.049	0.971
Standard kurtosis	0.292	1.875	0.737	-0.205	4.585	-1.564	-2.125

Table A2.17: Summary statistics for mean power between 0.4 m and 1.7 m for the subject groups

	Group B	Group C	Group D	Group B	Group C	Group B	Group C
	Males	**Males**	**Males**	**Females**	**Females**	**All**	**All**
Sample size	51	54	96	21	48	72	102
Mean (W)	379.216	392.815	337.354	165.333	178.479	316.833	291.951
Std. deviation (W)	94.879	85.697	74.763	39.341	55.348	127.904	129.761
Minimum (W)	147	151	199	80	88	80	88
Maximum (W)	615	664	585	231	365	615	664
Standard skewness	0.346	1.019	2.433	-0.680	3.808	0.336	1.434
Standard kurtosis	0.496	2.322	0.871	-0.112	3.765	-1.369	-1.597

APPENDIX 3

RESULTS OF ANOVA AND ANCOVA REGARDING GENDER ISSUES

In all the following tables there were no missing values; all F ratios were calculated using the residual mean square error; R^2 values were calculated by dividing individual sums of squares by the total sum of squares; Total R^2 is the total proportion of variance accounted for by the model, excluding the residual variance.

A3.1 Choice of fat free mass instead of body mass as a covariate

Table A3.1: Two-way Ancova of power at 100 mm intervals

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	24324601	1	24324601	1315.422	0.0000	10.243%
Hand height (mm)	135696119	13	10438163	564.473	0.0000	57.142%
Interactions						
Gender × Height	8072891.2	13	620991.6	33.582	0.0000	3.399%
Residual	69381454	3752	18491.9			
Total (Corrected)	237475064	3779				70.784%

Table A3.2: Two-way Ancova of power at 100 mm intervals - body mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Body mass	21220213	1	21220213	1304.451	0.0000	8.936%
Iso strength at 850 mm	7679133	1	7679133	472.052	0.0000	3.234%
Stature	588900	1	588900	36.201	0.0000	0.248%
Main Effects						
Gender	3230767	1	3230767	198.602	0.0000	1.360%
Hand height (mm)	135696119	13	10438163	641.656	0.0000	57.141%
Interactions						
Gender × Height	8072891.2	13	620991.6	38.174	0.0000	3.399%
Residual	60987041	3749	16267.5			
Total (Corrected)	237475064	3779				74.318%

Table A3.3: Two-way Ancova of power at 100 mm intervals - fat free mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	32512584	1	32512584	2033.634	0.0000	13.691%
Iso strength at 850 mm	910220	1	910220	56.933	0.0000	0.383%
Stature	77989	1	77989	4.878	0.0273	0.033%
Main Effects						
Gender	268369	1	268369	16.786	0.0000	0.113%
Hand height (mm)	135696119	13	10438163	652.898	0.0000	57.141%
Interactions						
Gender × Height	8072891.2	13	620991.6	38.842	0.0000	3.399%
Residual	59936892	3749	15987.4			
Total (Corrected)	237475064	3779				74.761%

Table A3.4: Two-way Ancova of work done at 100 mm intervals

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	18844902	1	18844902	3867.551	0.0000	10.236%
Hand height (mm)	141745513	13	10903501	2237.732	0.0000	76.992%
Interactions						
Gender × Height	5233009.2	13	402539.2	82.613	0.0000	2.842%
Residual	18281873	3752	4872.6			
Total (Corrected)	184105297	3779				90.070%

Table A3.5: Two-way Ancova of work done at 100 mm intervals - body mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Body mass	14786632	1	14786632	4270.702	0.0000	8.032%
Iso strength at 850 mm	5926352	1	5926352	1711.66	0.0000	3.219%
Stature	466505	1	466505	134.737	0.0000	0.253%
Main Effects						
Gender	2966966	1	2966966	856.924	0.0000	1.612%
Hand height (mm)	141745513	13	10903501	3149.169	0.0000	76.992%
Interactions						
Gender x Height	5233009.2	13	402539.2	116.262	0.0000	2.842%
Residual	12980320	3749	3462.3			
Total (Corrected)	184105297	3779				92.950%

Table A3.6: Two-way Ancova of work done at 100 mm intervals - fat free mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	23549906	1	23549906	7129.024	0.0000	12.792%
Iso strength at 850 mm	671010	1	671010	203.128	0.0000	0.364%
Stature	53659	1	53659	16.244	0.0001	0.029%
Main Effects						
Gender	467811	1	467811	141.616	0.0000	0.254%
Hand height (mm)	141745513	13	10903501	3300.706	0.0000	76.992%
Interactions						
Gender x Height	5233009.2	13	402539.2	121.857	0.0000	2.842%
Residual	12384388	3749	3303.4			
Total (Corrected)	184105297	3779				93.273%

Table A3.7: Two-way Ancova of impulse at 100 mm intervals

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	11134209	1	11134209	4631.111	0.0000	2.481%
Hand height (mm)	424719035	13	32670695	13588.896	0.0000	94.624%
Interactions						
Gender x Height	3976401.9	13	305877.1	127.225	0.0000	0.886%
Residual	9020633.1	3752	2404.2			
Total (Corrected)	448850279	3779				97.991%

Table A3.8: Two-way Ancova of impulse at 100 mm intervals - body mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Body mass	7294294.8	1	7294294.8	4013.559	0.0000	1.625%
Iso strength at 850 mm	3528896.2	1	3528896.2	1941.714	0.0000	0.786%
Stature	417104.4	1	417104.4	229.504	0.0000	0.093%
Main Effects						
Gender	2101064	1	2101064	1156.074	0.0000	0.468%
Hand height (mm)	424719035	13	32670695	17976.48	0.0000	94.624%
Interactions						
Gender x Height	3976401.9	13	305877.1	168.304	0.0000	0.886%
Residual	6813482.6	3749	1817.4			
Total (Corrected)	448850279	3779				98.482%

Table A3.9: Two-way Ancova of impulse at 100 mm intervals - fat free mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	12866455	1	12866455	7465.128	0.0000	2.867%
Iso strength at 850 mm	291359	1	291359	169.047	0.0000	0.065%
Stature	8113	1	8113	4.707	0.0301	0.002%
Main Effects						
Gender	527358	1	527358	305.974	0.0000	0.117%
Hand height (mm)	424719035	13	32670695	18955.563	0.0000	94.624%
Interactions						
Gender x Height	3976401.9	13	305877.1	177.47	0.0000	0.886%
Residual	6461556.1	3749	1723.5			
Total (Corrected)	448850279	3779				98.560%

Table A3.10: Two-way Ancova of power at 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	19696170	1	19696170	1287.164	0.0000	8.325%
Hand height	148472492	14	10605178	693.058	0.0000	62.757%
Interactions						
Gender x Height	6900847.7	14	492917.7	32.213	0.0000	2.917%
Residual	61514021	4020	15302.0			
Total (Corrected)	236583531	4049				73.999%

Table A3.11: Two-way Ancova of power at 5% intervals of stature - body mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Body mass	16966530	1	16966530	1239.358	0.0000	7.171%
Iso strength at 850 mm	5667336	1	5667336	413.983	0.0000	2.395%
Stature	24144	1	24144	1.764	0.1842	0.010%
Main Effects						
Gender	3560352	1	3560352	260.074	0.0000	1.505%
Hand height	148472492	14	10605178	774.679	0.0000	62.757%
Interactions						
Gender x Height	6900847.7	14	492917.7	36.006	0.0000	2.917%
Residual	54991829	4017	13689.8			
Total (Corrected)	236583531	4049				76.756%

Table A3.12: Two-way Ancova of power at 5% intervals of stature - fat free mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	25616997	1	25616997	1907.761	0.0000	10.828%
Iso strength at 850 mm	613876	1	613876	45.717	0.0000	0.259%
Stature	728595	1	728595	54.26	0.0000	0.308%
Main Effects						
Gender	311319	1	311319	23.185	0.0000	0.132%
Hand height	148472492	14	10605178	789.794	0.0000	62.757%
Interactions						
Gender x Height	6900847.7	14	492917.7	36.709	0.0000	2.917%
Residual	53939403	4017	13427.8			
Total (Corrected)	236583530	4049				77.201%

Table A3.13: Two-way Ancova of work done at 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	29440468	1	29440468	4737.298	0.0000	16.295%
Hand height	121808134	14	8700581	1400.020	0.0000	67.421%
Interactions						
Gender x Height	4443514.6	14	317393.9	51.072	0.0000	2.459%
Residual	24982738	4020	6214.6			
Total (Corrected)	180674851	4049				86.175%

Table A3.14: Two-way Ancova of work done at 5% intervals of stature - body mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Body mass	25057216	1	25057216	7158.777	0.0000	13.869%
Iso strength at 850 mm	9910816	1	9910816	2831.493	0.0000	5.485%
Stature	2458739	1	2458739	702.455	0.0000	1.361%
Main Effects						
Gender	2936098	1	2936097.8	838.835	0.0000	1.625%
Hand height	121808130	14	8700580.7	2485.732	0.0000	67.418%
Interactions						
Gender x Height	4443514.6	14	317393.9	90.679	0.0000	2.459%
Residual	14060339	4017	3500.2			
Total (Corrected)	180674853	4049				92.218%

Table A3.15: Two-way Ancova of work done at 5% intervals of stature - fat free mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	39250250	1	39250250	11830.90	0.0000	21.724%
Iso strength at 850 mm	1236649	1	1236649	372.754	0.0000	0.684%
Stature	264827	1	264827	79.825	0.0000	0.147%
Main Effects						
Gender	344672	1	344671.7	103.892	0.0000	0.191%
Hand height	121808130	14	8700580.7	2622.551	0.0000	67.418%
Interactions						
Gender x Height	4443514.6	14	317393.9	95.67	0.0000	2.459%
Residual	13326809	4017	3317.6			
Total (Corrected)	180674851	4049				92.624%

Table A3.16: Two-way Ancova of impulse at 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	26639712	1	26639712	5655.090	0.0000	6.171%
Hand height	381500434	14	27250031	5784.649	0.0000	88.376%
Interactions						
Gender x Height	4601553.2	14	328682.4	69.773	0.0000	1.066%
Residual	18937213	4020	4710.7			
Total (Corrected)	431678912	4049				95.613%

Table A3.17: Two-way Ancova of impulse at 5% intervals of stature - body mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Body mass	20663214	1	20663214	10630	0.0000	4.787%
Iso strength at 850 mm	9601834	1	9601834	4939.575	0.0000	2.224%
Stature	5473502	1	5473502	2815.793	0.0000	1.268%
Main Effects						
Gender	2029894	1	2029894	1044.26	0.0000	0.470%
Hand height	381500434	14	27250031	14018.53	0.0000	88.376%
Interactions						
Gender x Height	4601553.2	14	328682.4	169.088	0.0000	1.066%
Residual	7808479.2	4017	1943.9			
Total (Corrected)	431678912	4049				98.191%

Table A3.18: Two-way Ancova of impulse at 5% intervals of stature - fat free mass as a covariate

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	34844876	1	34844876	18991.14	0.0000	8.072%
Iso strength at 850 mm	1028921	1	1028921	560.782	0.0000	0.238%
Stature	1913837	1	1913837	1043.079	0.0000	0.443%
Main Effects						
Gender	418913	1	418913	228.316	0.0000	0.097%
Hand height	381500434	14	27250031	14851.8	0.0000	88.376%
Interactions						
Gender x Height	4601553.2	14	328682.4	179.138	0.0000	1.066%
Residual	7370377.8	4017	1834.8			
Total (Corrected)	431678912	4049				98.292%

A3.2 Effect of sequence of entry of covariates on covariance accounted for

A3.2.1 Two-way analyses at fixed percentages of stature

Table A3.19: Two-way Ancova of power at 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	14001696	1	14001696	1042.741	0.0000	5.918%
Fat-free mass	11979307	1	11979307	892.128	0.0000	5.063%
Iso strength at 850 mm	978466	1	978466	72.869	0.0000	0.414%
Subtotal	26959469	3				11.935%
Covariates						
Stature	14001696	1	14001696	1042.741	0.0000	5.918%
Iso strength at 850 mm	6958500	1	6958500	518.217	0.0000	2.941%
Fat-free mass	5999273	1	5999273	446.781	0.0000	2.536%
Subtotal	26959469	3				11.935%
Covariates						
Fat-free mass	25616997	1	25616997	1907.761	0.0000	10.829%
Stature	364006	1	364006	27.108	0.0000	0.154%
Iso strength at 850 mm	978466	1	978466	72.869	0.0000	0.413%
Subtotal	26959469	3				11.936%
Covariates						
Fat-free mass	25616997	1	25616997	1907.761	0.0000	10.829%
Iso strength at 850 mm	613876	1	613876	45.717	0.0000	0.259%
Stature	728595	1	728595	54.260	0.0000	0.308%
Subtotal	26959468	3				11.936%
Covariates						
Iso strngth at 850 mm	20711576	1	20711576	1542.442	0.0000	8.754%
Stature	248620	1	248620	18.515	0.0000	0.105%
Fat-free mass	5999273	1	5999273	446.781	0.0000	2.536%
Subtotal	26959469	3				11.935%
Covariates						
Iso strngth at 850 mm	20711576	1	20711576	1542.442	0.0000	8.754%
Fat-free mass	5519297	1	5519297	411.036	0.0000	2.333%
Stature	728595	1	728595	54.260	0.0000	0.307%
Subtotal	26959468	3				11.934%
Main Effects						
Gender	311319	1	311319	23.185	0.0000	0.132%
Hand height	148472492	14	10605178	789.794	0.0000	62.757%
Interactions						
Gender x Height	6900848	14	492917.7	36.709	0.0000	2.917%
Residual	53939403	4017	13427.8			
Total (Corrected)	236583530	4049				77.201%

A3.2.2 Two-way analyses at absolute heights

Table A3.20: Two-way Ancova of power at 100 mm intervals

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	21272955	1	21272955	1330.605	0.0000	8.958%
Fat-free mass	11239647	1	11239647	703.030	0.0000	4.733%
Iso strength at 850 mm	988191	1	988191	61.810	0.0000	0.416%
Subtotal	33500793	3				14.107%
Covariates						
Stature	21272955	1	21272955	1330.605	0.0000	8.958%
Iso strength at 850 mm	6686887	1	6686887	418.259	0.0000	2.816%
Fat-free mass	5540951	1	5540951	346.582	0.0000	2.333%
Subtotal	33500793	3			14.107%	
Covariates						
Fat-free mass	32512584	1	32512584	2033.634	0.0000	13.691%
Stature	18	1	18	0.001	0.9736	0.000%
Iso strength at 850 mm	988191	1	988191	61.810	0.0000	0.416%
Subtotal	33500793	3				14.107%

Covariates						
Fat-free mass	32512584	1	32512584	2033.634	0.0000	13.691%
Iso strngth at 850 mm	910220	1	910220	56.933	0.0000	0.383%
Stature	77989	1	77989	4.878	0.0273	0.033%
Subtotal	33500793	3				14.107%
Covariates						
Iso strngth at 850 mm	26719761	1	26719761	1671.298	0.0000	11.252%
Stature	1240081	1	1240081	77.566	0.0000	0.522%
Fat-free mass	5540951	1	5540951	346.582	0.0000	2.333%
Subtotal	33500793	3				14.107%
Covariates						
Iso strngth at 850 mm	26719761	1	26719761	1671.298	0.0000	11.252%
Fat-free mass	6703043	1	6703043	419.269	0.0000	2.823%
Stature	77989	1	77989	4.878	0.0273	0.033%
Subtotal	33500793	3				14.107%
Main Effects						
Gender	268369	1	268369	16.786	0.0000	0.113%
Hand height (mm)	135696119	13	10438163	652.898	0.0000	57.171%
Interactions						
Gender x Height	8072891	13	620991.6	38.842	0.0000	3.399%
Residual	59936892	3749	15987.4			
Total (Corrected)	237475064	3779				74.761%

A3.2.3 One-way analyses at fixed percentages of stature

Table A3.21: One-way Ancova of power at 25% stature

Source of variation	**Sum of squares**	**D.F.**	**Mean squares**	**F ratio**	**Probability**	**R^2**
Covariates						
Stature	8510118.0	1	8510118.0	204.348	0.0000	43.542%
Fat-free mass	718409.6	1	718409.6	17.251	0.0000	3.676%
Iso strength at 850 mm	171255.9	1	171255.9	4.112	0.0437	0.876%
Subtotal	9399783.5	3				48.094%
Covariates						
Stature	8510118.0	1	8510118.0	204.348	0.0000	43.542%
Iso strength at 850 mm	632907.5	1	632907.5	15.198	0.0001	3.238%
Fat-free mass	256758.0	1	256758.0	6.165	0.0137	1.314%
Subtotal	9399783.5	3				48.094%
Covariates						
Fat-free mass	7509186.9	1	7509186.9	180.314	0.0000	38.421%
Stature	1719340.7	1	1719340.7	41.286	0.0000	8.797%
Iso strength at 850 mm	171255.9	1	171255.9	4.112	0.0437	0.876%
Subtotal	9399783.5	3				48.094%
Covariates						
Fat-free mass	7509186.9	1	7509186.9	180.314	0.0000	38.421%
Iso strength at 850 mm	489419.5	1	489419.5	11.752	0.0007	2.504%
Stature	1401177.1	1	1401177.1	33.646	0.0000	7.169%
Subtotal	9399783.5	3				48.094%
Covariates						
Iso strength at 850 mm	6381180.3	1	6381180.3	153.228	0.0000	32.650%
Stature	2761845.2	1	2761845.2	66.319	0.0000	14.131%
Fat-free mass	256758.0	1	256758.0	6.165	0.0137	1.314%
Subtotal	9399783.5	3				48.095%
Covariates						
Iso strength at 850 mm	6381180.3	1	6381180.3	153.228	0.0000	32.650%
Fat-free mass	1617426.1	1	1617426.1	38.838	0.0000	8.276%
Stature	1401177.1	1	1401177.1	33.646	0.0000	7.169%
Subtotal	9399783.5	3				48.095%
Main Effects						
Gender	108151.3	1	108151.3	2.597	0.1084	0.553%
Residual	10036477	241	41645.1			
Total (Corrected)	19544412	245				48.648%

Table A3.22: One-way Ancova of power at 30% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	3145835.4	1	3145835.4	153.220	0.0000	27.968%
Fat-free mass	2359772.5	1	2359772.5	114.935	0.0000	20.979%
Iso strength at 850 mm	275190.1	1	275190.1	13.403	0.0003	2.447%
Subtotal	5780798.0	3				51.394%
Covariates						
Stature	3145835.4	1	3145835.4	153.220	0.0000	27.968%
Iso strength at 850 mm	1547507.9	1	1547507.9	75.373	0.0000	13.758%
Fat-free mass	1087454.7	1	1087454.7	52.965	0.0000	9.668%
Subtotal	5780798.0	3				51.394%
Covariates						
Fat-free mass	5465015.5	1	5465015.5	266.178	0.0000	48.586%
Stature	40592.4	1	40592.4	1.977	0.1609	0.361%
Iso strength at 850 mm	275190.1	1	275190.1	13.403	0.0003	2.447%
Subtotal	5780798.0	3				51.394%
Covariates						
Fat-free mass	5465015.5	1	5465015.5	266.178	0.0000	48.586%
Iso strength at 850 mm	200983.7	1	200983.7	9.789	0.0020	1.787%
Stature	114798.9	1	114798.9	5.591	0.0188	1.021%
Subtotal	5780798.1	3				51.394%
Covariates						
Iso strength at 850 mm	4635203.5	1	4635203.5	225.761	0.0000	41.209%
Stature	58139.9	1	58139.9	2.832	0.0936	0.517%
Fat-free mass	1087454.7	1	1087454.7	52.965	0.0000	9.668%
Subtotal	5780798.1	3				51.394%
Covariates						
Iso strength at 850 mm	4635203.5	1	4635203.5	225.761	0.0000	41.209%
Fat-free mass	1030795.7	1	1030795.7	50.206	0.0000	9.164%
Stature	114798.9	1	114798.9	5.591	0.0188	1.021%
Subtotal	5780798.1	3				51.394%
Main Effects						
Gender	26427.2	1	26427.2	1.287	0.2576	0.235%
Residual	5440828.6	265	20531.4			
Total (Corrected)	11248054	269				51.629%

Table A3.23: One-way Ancova of power at 35% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	3293734.8	1	3293734.8	181.430	0.0000	30.840%
Fat-free mass	2400158.2	1	2400158.2	132.209	0.0000	22.473%
Iso strength at 850 mm	159959.8	1	159959.8	8.811	0.0033	1.498%
Covariates						
Stature	3293734.8	1	3293734.8	181.430	0.0000	30.840%
Iso strength at 850 mm	1309020.6	1	1309020.6	72.105	0.0000	12.257%
Fat-free mass	1251097.3	1	1251097.3	68.915	0.0000	11.714%
Covariates						
Fat-free mass	5658601.1	1	5658601.1	311.695	0.0000	52.982%
Stature	35291.8	1	35291.8	1.944	0.1644	0.330%
Iso strength at 850 mm	159959.8	1	159959.8	8.811	0.0033	1.498%
Covariates						
Fat-free mass	5658601.1	1	5658601.1	311.695	0.0000	52.982%
Iso strength at 850 mm	110433.6	1	110433.6	6.083	0.0143	1.034%
Stature	84818	1	84818	4.672	0.0316	0.794%
Covariates						
Iso strength at 850 mm	4484924.1	1	4484924.1	247.045	0.0000	41.993%
Stature	117831.3	1	117831.3	6.491	0.0114	1.103%
Fat-free mass	1251097.3	1	1251097.3	68.915	0.0000	11.714%
Covariates						
Iso strength at 850 mm	4484924.1	1	4484924.1	247.045	0.0000	41.993%
Fat-free mass	1284110.6	1	1284110.6	70.733	0.0000	12.023%
Stature	84818	1	84818	4.672	0.0316	0.794%
Main Effects						
Gender	15434.7	1	15434.7	0.850	0.3672	0.145%
Residual	4810888	265	18154.3			
Total (Corrected)	10680175	269				54.955%

Table A3.24: One-way Ancova of power at 40% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	3800466.4	1	3800466.4	166.754	0.0000	28.806%
Fat-free mass	2981025.9	1	2981025.9	130.8	0.0000	22.595%
Iso strength at 850 mm	302446.8	1	302446.8	13.271	0.0003	2.292%
Covariates						
Stature	3800466.4	1	3800466.4	166.754	0.0000	28.806%
Iso strength at 850 mm	1861184.5	1	1861184.5	81.664	0.0000	14.107%
Fat-free mass	1422288.1	1	1422288.1	62.406	0.0000	10.780%
Covariates						
Fat-free mass	6717834.8	1	6717834.8	294.761	0.0000	50.919%
Stature	63657.5	1	63657.5	2.793	0.0959	0.483%
Iso strength at 850 mm	302446.8	1	302446.8	13.271	0.0003	2.292%
Covariates						
Fat-free mass	6717834.8	1	6717834.8	294.761	0.0000	50.919%
Iso strength at 850 mm	210328.7	1	210328.7	9.229	0.0026	1.594%
Stature	155775.5	1	155775.5	6.835	0.0095	1.181%
Covariates						
Iso strength at 850 mm	5590192.3	1	5590192.3	245.283	0.0000	42.372%
Stature	71458.6	1	71458.6	3.135	0.0778	0.542%
Fat-free mass	1422288.1	1	1422288.1	62.406	0.0000	10.780%
Covariates						
Iso strength at 850 mm	5590192.3	1	5590192.3	245.283	0.0000	42.372%
Fat-free mass	1337971.2	1	1337971.2	58.707	0.0000	10.141%
Stature	155775.5	1	155775.5	6.835	0.0095	1.181%
Main Effects						
Gender	69748.2	1	69748.2	3.06	0.0814	0.529%
Residual	6039559.9	265	22790.8			
Total (Corrected)	13193247	269				54.222%

Table A3.25: One-way Ancova of power at 45% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	3014761.8	1	3014761.8	149.247	0.0000	25.550%
Fat-free mass	2985685.5	1	2985685.5	147.808	0.0000	25.304%
Iso strength at 850 mm	296140.9	1	296140.9	14.661	0.0002	2.510%
Covariates						
Stature	3014761.8	1	3014761.8	149.247	0.0000	25.550%
Iso strength at 850 mm	1849653	1	1849653	91.568	0.0000	15.676%
Fat-free mass	1432173.5	1	1432173.5	70.900	0.0000	12.138%
Covariates						
Fat-free mass	5857105.8	1	5857105.8	289.959	0.0000	49.640%
Stature	143341.5	1	143341.5	7.096	0.0082	1.215%
Iso strength at 850 mm	296140.9	1	296140.9	14.661	0.0002	2.510%
Covariates						
Fat-free mass	5857105.8	1	5857105.8	289.959	0.0000	49.640%
Iso strength at 850 mm	174820.3	1	174820.3	8.655	0.0036	1.482%
Stature	264662.1	1	264662.1	13.102	0.0004	2.243%
Covariates						
Iso strength at 850 mm	4847665.2	1	4847665.2	239.986	0.0000	41.085%
Stature	16749.6	1	16749.6	0.829	0.3731	0.142%
Fat-free mass	1432173.5	1	1432173.5	70.900	0.0000	12.138%
Covariates						
Iso strength at 850 mm	4847665.2	1	4847665.2	239.986	0.0000	41.085%
Fat-free mass	1184261	1	1184261	58.627	0.0000	10.037%
Stature	264662.1	1	264662.1	13.102	0.0004	2.243%
Main Effects						
Gender	149720.1	1	149720.1	7.412	0.0069	1.269%
Residual	5352946.5	265	20199.8			
Total (Corrected)	11799255	269				54.633%

Table A3.26: One-way Ancova of power at 50% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Stature	2373966.3	1	2373966.3	193.315	0.0000	29.955%
Fat-free mass	2086651.5	1	2086651.5	169.919	0.0000	26.330%
Iso strength at 850 mm	157041.6	1	157041.6	12.788	0.0004	1.982%
Covariates						
Stature	2373966.3	1	2373966.3	193.315	0.0000	29.955%
Iso strength at 850 mm	1181097.9	1	1181097.9	96.178	0.0000	14.903%
Fat-free mass	1062595.2	1	1062595.2	86.529	0.0000	13.408%
Covariates						
Fat-free mass	4390867.5	1	4390867.5	357.554	0.0000	55.404%
Stature	69750.3	1	69750.3	5.68	0.0179	0.880%
Iso strength at 850 mm	157041.6	1	157041.6	12.788	0.0004	1.982%
Covariates						
Fat-free mass	4390867.5	1	4390867.5	357.554	0.0000	55.404%
Iso strength at 850 mm	94672.1	1	94672.1	7.709	0.0059	1.195%
Stature	132119.7	1	132119.7	10.759	0.0012	1.667%
Covariates						
Iso strength at 850 mm	3513094.2	1	3513094.2	286.076	0.0000	44.328%
Stature	41969.9	1	41969.9	3.418	0.0656	0.530%
Fat-free mass	1062595.2	1	1062595.2	86.529	0.0000	13.408%
Covariates						
Iso strength at 850 mm	3513094.2	1	3513094.2	286.076	0.0000	44.328%
Fat-free mass	972445.3	1	972445.3	79.188	0.0000	12.270%
Stature	132119.7	1	132119.7	10.759	0.0012	1.667%
Main Effects						
Gender	53203.235	1	53203.2	4.332	0.0384	0.671%
Residual	3254275.6	265	12280.3			
Total (Corrected)	7925138.2	269				58.937%

Table A3.27: One-way Ancova of power at 55% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Stature	1138582.6	1	1138582.6	137.726	0.0000	25.603%
Fat-free mass	1041327.6	1	1041327.6	125.962	0.0000	23.416%
Iso strength at 850 mm	52629.2	1	52629.2	6.366	0.0122	1.183%
Covariates						
Stature	1138582.6	1	1138582.6	137.726	0.0000	25.603%
Iso strength at 850 mm	524894.6	1	524894.6	63.493	0.0000	11.803%
Fat-free mass	569062.3	1	569062.3	68.835	0.0000	12.796%
Covariates						
Fat-free mass	2140253.7	1	2140253.7	258.891	0.0000	48.128%
Stature	39656.5	1	39656.5	4.797	0.0294	0.892%
Iso strength at 850 mm	52629.2	1	52629.2	6.366	0.0122	1.183%
Covariates						
Fat-free mass	2140253.7	1	2140253.7	258.891	0.0000	48.128%
Iso strength at 850 mm	27330.3	1	27330.3	3.306	0.0702	0.615%
Stature	64955.4	1	64955.4	7.857	0.0054	1.461%
Covariates						
Iso strength at 850 mm	1636915.3	1	1636915.3	198.006	0.0000	36.809%
Stature	26561.9	1	26561.9	3.213	0.0742	0.597%
Fat-free mass	569062.3	1	569062.3	68.835	0.0000	12.796%
Covariates						
Iso strength at 850 mm	1636915.3	1	1636915.3	198.006	0.0000	36.809%
Fat-free mass	530668.7	1	530668.7	64.191	0.0000	11.933%
Stature	64955.4	1	64955.4	7.857	0.0054	1.461%
Main Effects						
Gender	23744.0	1	23744.0	2.872	0.0913	0.534%
Residual	2190754.0	265	8267.0			
Total (Corrected)	4447037.4	269				50.737%

Table A3.28: One-way Ancova of power at 60% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	295441.68	1	295441.68	35.758	0.0000	10.047%
Fat-free mass	432704.6	1	432704.6	52.371	0.0000	14.715%
Iso strength at 850 mm	7054.46	1	7054.46	0.854	0.3662	0.240%
Covariates						
Stature	295441.68	1	295441.68	35.758	0.0000	10.047%
Iso strength at 850 mm	170038.18	1	170038.18	20.58	0.0000	5.782%
Fat-free mass	269720.87	1	269720.87	32.645	0.0000	9.172%
Covariates						
Fat-free mass	682726.62	1	682726.62	82.632	0.0000	23.217%
Stature	45419.65	1	45419.65	5.497	0.0198	1.545%
Iso strength at 850 mm	7054.46	1	7054.46	0.854	0.3662	0.240%
Covariates						
Fat-free mass	682726.62	1	682726.62	82.632	0.0000	23.217%
Iso strength at 850 mm	471.42	1	471.42	0.057	0.8139	0.016%
Stature	52002.69	1	52002.69	6.294	0.0127	1.768%
Covariates						
Iso strength at 850 mm	462924.01	1	462924.01	56.029	0.0000	15.742%
Stature	2555.85	1	2555.85	0.309	0.5845	0.087%
Fat-free mass	269720.87	1	269720.87	32.645	0.0000	9.172%
Covariates						
Iso strength at 850 mm	462924.01	1	462924.01	56.029	0.0000	15.742%
Fat-free mass	220274.03	1	220274.03	26.66	0.0000	7.491%
Stature	52002.69	1	52002.69	6.294	0.0127	1.768%
Main Effects						
Gender	15956.37	1	15956.37	1.931	0.1658	0.543%
Residual	2189502.70	265	8262.27			
Total (Corrected)	2940659.8	269				25.544%

Table A3.29: One-way Ancova of power at 65% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	131778.56	1	131778.56	17.918	0.0000	5.742%
Fat-free mass	190115.58	1	190115.58	25.850	0.0000	8.284%
Iso strength at 850 mm	21.95	1	21.95	0.003	0.9571	0.001%
Covariates						
Stature	131778.56	1	131778.56	17.918	0.0000	5.742%
Iso strength at 850 mm	52763.61	1	52763.61	7.174	0.0079	2.299%
Fat-free mass	137373.92	1	137373.92	18.679	0.0000	5.986%
Covariates						
Fat-free mass	302388.08	1	302388.08	41.116	0.0000	13.176%
Stature	19506.06	1	19506.06	2.652	0.1046	0.850%
Iso strength at 850 mm	21.95	1	21.95	0.003	0.9571	0.001%
Covariates						
Fat-free mass	302388.08	1	302388.08	41.116	0.0000	13.176%
Iso strength at 850 mm	1166.95	1	1166.95	0.159	0.6950	0.051%
Stature	18361.05	1	18361.05	2.497	0.1153	0.800%
Covariates						
Iso strength at 850 mm	179915.29	1	179915.29	24.463	0.0000	7.839%
Stature	4626.88	1	4626.88	0.629	0.4369	0.202%
Fat-free mass	137373.92	1	137373.92	18.679	0.0000	5.986%
Covariates						
Iso strength at 850 mm	179915.29	1	179915.29	24.463	0.0000	7.839%
Fat-free mass	123639.75	1	123639.75	16.812	0.0001	5.387%
Stature	18361.05	1	18361.05	2.497	0.1153	0.800%
Main Effects						
Gender	24139.92	1	24139.92	3.282	0.0712	1.052%
Residual	1948935.40	265	7354.47			
Total (Corrected)	2294991.40	269				15.079%

Table A3.30: One-way Ancova of power at 70% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	50149.61	1	50149.61	5.135	0.0243	1.792%
Fat-free mass	84390.61	1	84390.61	8.642	0.0036	3.016%
Iso strength at 850 mm	21879.98	1	21879.98	2.24	0.1356	0.782%
Covariates						
Stature	50149.61	1	50149.61	5.135	0.0243	1.792%
Iso strength at 850 mm	76690.41	1	76690.41	7.853	0.0054	2.740%
Fat-free mass	29580.17	1	29580.17	3.029	0.0829	1.057%
Covariates						
Fat-free mass	123812.40	1	123812.40	12.678	0.0004	4.424%
Stature	10727.81	1	10727.81	1.099	0.2955	0.383%
Iso strength at 850 mm	21879.98	1	21879.98	2.24	0.1356	0.782%
Covariates						
Fat-free mass	123812.40	1	123812.40	12.678	0.0004	4.424%
Iso strength at 850 mm	12874.58	1	12874.58	1.318	0.2519	0.460%
Stature	19733.21	1	19733.21	2.021	0.1563	0.705%
Covariates						
Iso strength at 850 mm	123309.40	1	123309.40	12.627	0.0005	4.406%
Stature	3530.62	1	3530.62	0.362	0.5546	0.126%
Fat-free mass	29580.17	1	29580.17	3.029	0.0829	1.057%
Covariates						
Iso strength at 850 mm	123309.40	1	123309.40	12.627	0.0005	4.406%
Fat-free mass	13377.58	1	13377.58	1.37	0.2429	0.478%
Stature	19733.21	1	19733.21	2.021	0.1563	0.705%
Main Effects						
Gender	54125.21	1	54125.21	5.542	0.0193	1.934%
Residual	2587907.70	265	9765.69			
Total (Corrected)	2798453.10	269				7.524%

Table A3.31: One-way Ancova of power at 75% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	251828.87	1	251828.87	16.511	0.0001	5.625%
Fat-free mass	140572.46	1	140572.46	9.217	0.0026	3.140%
Iso strength at 850 mm	23298.90	1	23298.90	1.528	0.2176	0.520%
Covariates						
Stature	251828.87	1	251828.87	16.511	0.0001	5.625%
Iso strength at 850 mm	105412.01	1	105412.01	6.911	0.0091	2.354%
Fat-free mass	58459.35	1	58459.35	3.833	0.0513	1.306%
Covariates						
Fat-free mass	392325.86	1	392325.86	25.723	0.0000	8.763%
Stature	75.47	1	75.47	0.005	0.9447	0.002%
Iso strength at 850 mm	23298.90	1	23298.90	1.528	0.2176	0.520%
Covariates						
Fat-free mass	392325.86	1	392325.86	25.723	0.0000	8.763%
Iso strength at 850 mm	20813.79	1	20813.79	1.365	0.2438	0.465%
Stature	2560.58	1	2560.58	0.168	0.6867	0.057%
Covariates						
Iso strength at 850 mm	349375.98	1	349375.98	22.907	0.0000	7.803%
Stature	7864.90	1	7864.90	0.516	0.4810	0.176%
Fat-free mass	58459.35	1	58459.35	3.833	0.0513	1.306%
Covariates						
Iso strength at 850 mm	349375.98	1	349375.98	22.907	0.0000	7.803%
Fat-free mass	63763.67	1	63763.67	4.181	0.0419	1.424%
Stature	2560.58	1	2560.58	0.168	0.6867	0.057%
Main Effects						
Gender	19828.37	1	19828.37	1.300	0.2552	0.443%
Residual	4041798.40	265	15252.07			
Total (Corrected)	4477327.00	269				9.727%

Table A3.32: One-way Ancova of power at 80% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	296440.19	1	296440.19	14.583	0.0002	5.003%
Fat-free mass	219988.14	1	219988.14	10.822	0.0011	3.713%
Iso strength at 850 mm	20752.90	1	20752.90	1.021	0.3132	0.350%
Covariates						
Stature	296440.19	1	296440.19	14.583	0.0002	5.003%
Iso strength at 850 mm	133983.69	1	133983.69	6.591	0.0108	2.261%
Fat-free mass	106757.35	1	106757.35	5.252	0.0227	1.802%
Covariates						
Fat-free mass	512852.25	1	512852.25	25.229	0.0000	8.655%
Stature	3576.08	1	3576.08	0.176	0.6797	0.060%
Iso strength at 850 mm	20752.90	1	20752.90	1.021	0.3132	0.350%
Covariates						
Fat-free mass	512852.25	1	512852.25	25.229	0.0000	8.655%
Iso strength at 850 mm	14853.47	1	14853.47	0.731	0.4026	0.251%
Stature	9475.51	1	9475.51	0.466	0.5027	0.160%
Covariates						
Iso strength at 850 mm	423047.05	1	423047.05	20.811	0.0000	7.140%
Stature	7376.83	1	7376.83	0.363	0.5539	0.124%
Fat-free mass	106757.35	1	106757.35	5.252	0.0227	1.802%
Covariates						
Iso strength at 850 mm	423047.05	1	423047.05	20.811	0.0000	7.140%
Fat-free mass	104658.66	1	104658.66	5.148	0.0241	1.766%
Stature	9475.51	1	9475.51	0.466	0.5027	0.160%
Main Effects						
Gender	1146.37	1	1146.37	0.056	0.8150	0.019%
Residual	5386932.40	265	20328.05			
Total (Corrected)	5925260.00	269				9.085%

Table A3.33: One-way Ancova of power at 85% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	522353.75	1	522353.75	30.418	0.0000	9.572%
Fat-free mass	302594.86	1	302594.86	17.621	0.0000	5.545%
Iso strength at 850 mm	80130.63	1	80130.63	4.666	0.0317	1.468%
Covariates						
Stature	522353.75	1	522353.75	30.418	0.0000	9.572%
Iso strength at 850 mm	277662.93	1	277662.93	16.169	0.0001	5.088%
Fat-free mass	105062.56	1	105062.56	6.118	0.0140	1.925%
Covariates						
Fat-free mass	824520.58	1	824520.58	48.014	0.0000	15.110%
Stature	428.03	1	428.03	0.025	0.8764	0.008%
Iso strength at 850 mm	80130.63	1	80130.63	4.666	0.0317	1.468%
Covariates						
Fat-free mass	824520.58	1	824520.58	48.014	0.0000	15.110%
Iso strength at 850 mm	70907.19	1	70907.19	4.129	0.0431	1.299%
Stature	9651.47	1	9651.47	0.562	0.4621	0.177%
Covariates						
Iso strength at 850 mm	793087.85	1	793087.85	46.184	0.0000	14.534%
Stature	6928.83	1	6928.83	0.403	0.5326	0.127%
Fat-free mass	105062.56	1	105062.56	6.118	0.0140	1.925%
Covariates						
Iso strength at 850 mm	793087.85	1	793087.85	46.184	0.0000	14.534%
Fat-free mass	102339.92	1	102339.92	5.960	0.0153	1.875%
Stature	9651.47	1	9651.47	0.562	0.4621	0.177%
Main Effects						
Gender	1053.98	1	1053.98	0.061	0.8072	0.019%
Residual	4550695.3	265	17172.44			
Total (Corrected)	5456828.5	269				16.605%

Table A3.34: One-way Ancova of power at 90% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Stature	608787.79	1	608787.79	82.476	0.0000	19.415%
Fat-free mass	517688.54	1	517688.54	70.134	0.0000	16.510%
Iso strength at 850 mm	52997.52	1	52997.52	7.18	0.0078	1.690%
Covariates						
Stature	608787.79	1	608787.79	82.476	0.0000	19.415%
Iso strength at 850 mm	324220.65	1	324220.65	43.924	0.0000	10.340%
Fat-free mass	246465.41	1	246465.41	33.39	0.0000	7.860%
Covariates						
Fat-free mass	1111093.80	1	1111093.8	150.526	0.0000	35.435%
Stature	15382.50	1	15382.5	2.084	0.1500	0.491%
Iso strength at 850 mm	52997.50	1	52997.5	7.18	0.0078	1.690%
Covariates						
Fat-free mass	1111093.80	1	1111093.8	150.526	0.0000	35.435%
Iso strength at 850 mm	34924.90	1	34924.9	4.731	0.0305	1.114%
Stature	33455.20	1	33455.2	4.532	0.0342	1.067%
Covariates						
Iso strength at 850 mm	925005.47	1	925005.47	125.316	0.0000	29.500%
Stature	8002.98	1	8002.98	1.084	0.2987	0.255%
Fat-free mass	246465.41	1	246465.41	33.39	0.0000	7.860%
Covariates						
Iso strength at 850 mm	925005.47	1	925005.47	125.316	0.0000	29.500%
Fat-free mass	221013.18	1	221013.18	29.942	0.0000	7.049%
Stature	33455.20	1	33455.2	4.532	0.0342	1.067%
Main Effects						
Gender	53.27	1	53.27	0.007	0.9333	0.002%
Residual	1956071.90	265	7381.40			
Total (Corrected)	3135599	269				37.617%

Table A3.35: One-way Ancova of power at 95% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Stature	303284.68	1	303284.68	125.570	0.0000	24.046%
Fat-free mass	302442.43	1	302442.43	125.221	0.0000	23.979%
Iso strength at 850 mm	13745.12	1	13745.12	5.691	0.0178	1.090%
Covariates						
Stature	303284.68	1	303284.68	125.570	0.0000	24.046%
Iso strength at 850 mm	148206.94	1	148206.94	61.362	0.0000	11.751%
Fat-free mass	167980.61	1	167980.61	69.549	0.0000	13.318%
Covariates						
Fat-free mass	590935.91	1	590935.91	244.667	0.0000	46.852%
Stature	14791.21	1	14791.21	6.124	0.0140	1.173%
Iso strength at 850 mm	13745.12	1	13745.12	5.691	0.0178	1.090%
Covariates						
Fat-free mass	590935.91	1	590935.91	244.667	0.0000	46.852%
Iso strength at 850 mm	6239.57	1	6239.57	2.583	0.1092	0.495%
Stature	22296.76	1	22296.76	9.232	0.0026	1.768%
Covariates						
Iso strength at 850 mm	445742.07	1	445742.07	184.552	0.0000	35.341%
Stature	5749.56	1	5749.56	2.381	0.1241	0.456%
Fat-free mass	167980.61	1	167980.61	69.549	0.0000	13.318%
Covariates						
Iso strength at 850 mm	445742.07	1	445742.07	184.552	0.0000	35.341%
Fat-free mass	151433.40	1	151433.4	62.698	0.0000	12.006%
Stature	22296.76	1	22296.76	9.232	0.0026	1.768%
Main Effects						
Gender	1750.50	1	1750.50	0.725	0.4044	0.139%
Residual	640046.70	265	2415.27			
Total (Corrected)	1261269.40	269				49.254%

Table A3.36: One-way Ancova of power at 100% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	144135.34	1	144135.34	151.397	0.0000	27.312%
Fat-free mass	124012.03	1	124012.03	130.26	0.0000	23.499%
Iso strength at 850 mm	522.93	1	522.93	0.549	0.4672	0.099%
Covariates						
Stature	144135.34	1	144135.34	151.397	0.0000	27.312%
Iso strength at 850 mm	40742.72	1	40742.72	42.795	0.0000	7.720%
Fat-free mass	83792.24	1	83792.24	88.014	0.0000	15.877%
Covariates						
Fat-free mass	264301.64	1	264301.64	277.618	0.0000	50.081%
Stature	3845.74	1	3845.74	4.039	0.0455	0.729%
Iso strength at 850 mm	522.93	1	522.93	0.549	0.4672	0.099%
Covariates						
Fat-free mass	264301.64	1	264301.64	277.618	0.0000	50.081%
Iso strength at 850 mm	23.11	1	23.11	0.024	0.8780	0.004%
Stature	4345.56	1	4345.56	4.564	0.0336	0.823%
Covariates						
Iso strength at 850 mm	174895.03	1	174895.03	183.707	0.0000	33.140%
Stature	9983.03	1	9983.03	10.486	0.0014	1.892%
Fat-free mass	83792.24	1	83792.24	88.014	0.0000	15.877%
Covariates						
Iso strength at 850 mm	174895.03	1	174895.03	183.707	0.0000	33.140%
Fat-free mass	89429.71	1	89429.71	93.935	0.0000	16.946%
Stature	4345.56	1	4345.56	4.564	0.0336	0.823%
Main Effects						
Gender	6784.71	1	6784.71	7.127	0.0081	1.286%
Residual	252288.86	265	952.03			
Total (Corrected)	527743.87	269				52.195%

Table A3.37: One-way Ancova of power at 105% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	73264.538	1	73264.538	132.087	0.0000	24.127%
Fat-free mass	76817.404	1	76817.404	138.492	0.0000	25.297%
Iso strength at 850 mm	357.376	1	357.376	0.644	0.4314	0.118%
Covariates						
Stature	73264.538	1	73264.538	132.087	0.0000	24.127%
Iso strength at 850 mm	25231.788	1	25231.788	45.490	0.0000	8.309%
Fat-free mass	51942.992	1	51942.992	93.647	0.0000	17.106%
Covariates						
Fat-free mass	145670.59	1	145670.59	262.626	0.0000	47.971%
Stature	4411.35	1	4411.35	7.953	0.0052	1.453%
Iso strength at 850 mm	357.38	1	357.38	0.644	0.4314	0.118%
Covariates						
Fat-free mass	145670.59	1	145670.59	262.626	0.0000	47.971%
Iso strength at 850 mm	0.02	1	0.02	0.000	0.9952	0.000%
Stature	4768.7	1	4768.7	8.597	0.0037	1.570%
Covariates						
Iso strength at 850 mm	94906.71	1	94906.71	171.105	0.0000	31.254%
Stature	3589.616	1	3589.616	6.472	0.0115	1.182%
Fat-free mass	51942.992	1	51942.992	93.647	0.0000	17.106%
Covariates						
Iso strength at 850 mm	94906.71	1	94906.71	171.105	0.0000	31.254%
Fat-free mass	50763.905	1	50763.905	91.521	0.0000	16.717%
Stature	4768.703	1	4768.703	8.597	0.0037	1.570%
Main Effects						
Gender	6789.387	1	6789.387	12.240	0.0005	2.236%
Residual	146432.46	264	554.668			
Total (Corrected)	303661.17	268				51.778%

Table A3.38: One-way Ancova of power at 110% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	30765.223	1	30765.223	41.602	0.0000	10.272%
Fat-free mass	68878.851	1	68878.851	93.14	0.0000	22.998%
Iso strength at 850 mm	2410.257	1	2410.257	3.259	0.0722	0.805%
Covariates						
Stature	30765.223	1	30765.223	41.602	0.0000	10.272%
Iso strength at 850 mm	31664.826	1	31664.826	42.818	0.0000	10.573%
Fat-free mass	39624.281	1	39624.281	53.581	0.0000	13.230%
Covariates						
Fat-free mass	87691.065	1	87691.065	118.578	0.0000	29.280%
Stature	11953.008	1	11953.008	16.163	0.0001	3.991%
Iso strength at 850 mm	2410.257	1	2410.257	3.259	0.0722	0.805%
Covariates						
Fat-free mass	87691.065	1	87691.065	118.578	0.0000	29.280%
Iso strength at 850 mm	321.751	1	321.751	0.435	0.5171	0.107%
Stature	14041.514	1	14041.514	18.987	0.0000	4.688%
Covariates						
Iso strength at 850 mm	62179.08	1	62179.08	84.08	0.0000	20.761%
Stature	250.97	1	250.97	0.339	0.5669	0.084%
Fat-free mass	39624.281	1	39624.281	53.581	0.0000	13.230%
Covariates						
Iso strength at 850 mm	62179.08	1	62179.08	84.08	0.0000	20.761%
Fat-free mass	25833.737	1	25833.737	34.933	0.0000	8.626%
Stature	14041.514	1	14041.514	18.987	0.0000	4.688%
Main Effects						
Gender	4426.673	1	4426.673	5.986	0.0151	1.478%
Residual	193015.19	261	739.522			
Total (Corrected)	299496.2	265				35.553%

Table A3.39: One-way Ancova of power at 115% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	32802.762	1	32802.762	34.778	0.0000	10.391%
Fat-free mass	58935.594	1	58935.594	62.484	0.0000	18.669%
Iso strength at 850 mm	1685.18	1	1685.18	1.787	0.1827	0.534%
Covariates						
Stature	32802.762	1	32802.762	34.778	0.0000	10.391%
Iso strength at 850 mm	27997.129	1	27997.129	29.683	0.0000	8.869%
Fat-free mass	32623.646	1	32623.646	34.588	0.0000	10.334%
Covariates						
Fat-free mass	84365.538	1	84365.538	89.446	0.0000	26.725%
Stature	7372.818	1	7372.818	7.817	0.0056	2.336%
Iso strength at 850 mm	1685.18	1	1685.18	1.787	0.1827	0.534%
Covariates						
Fat-free mass	84365.538	1	84365.538	89.446	0.0000	26.725%
Iso strength at 850 mm	268.474	1	268.474	0.285	0.5999	0.085%
Stature	8789.524	1	8789.524	9.319	0.0025	2.784%
Covariates						
Iso strength at 850 mm	60779.568	1	60779.568	64.439	0.0000	19.253%
Stature	20.323	1	20.323	0.022	0.8850	0.006%
Fat-free mass	32623.646	1	32623.646	34.588	0.0000	10.334%
Covariates						
Iso strength at 850 mm	60779.568	1	60779.568	64.439	0.0000	19.253%
Fat-free mass	23854.444	1	23854.444	25.291	0.0000	7.556%
Stature	8789.524	1	8789.524	9.319	0.0025	2.784%
Main Effects						
Gender	5324.196	1	5324.196	5.645	0.0183	1.687%
Residual	216936.89	230	943.204			
Total (Corrected)	315684.62	234				31.281%

Table A3.40: One-way Ancova of power at 120% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Stature	12304.791	1	12304.791	10.116	0.0017	4.968%
Fat-free mass	20237.662	1	20237.662	16.638	0.0001	8.171%
Iso strength at 850 mm	19.831	1	19.831	0.016	0.8999	0.008%
Covariates						
Stature	12304.791	1	12304.791	10.116	0.0017	4.968%
Iso strength at 850 mm	6798.868	1	6798.868	5.59	0.0192	2.745%
Fat-free mass	13458.625	1	13458.625	11.065	0.0011	5.434%
Covariates						
Fat-free mass	30642.609	1	30642.609	25.192	0.0000	12.372%
Stature	1899.844	1	1899.844	1.562	0.2131	0.767%
Iso strength at 850 mm	19.831	1	19.831	0.016	0.8999	0.008%
Covariates						
Fat-free mass	30642.609	1	30642.609	25.192	0.0000	12.372%
Iso strength at 850 mm	197.733	1	197.733	0.163	0.6916	0.080%
Stature	1721.942	1	1721.942	1.416	0.2357	0.695%
Covariates						
Iso strength at 850 mm	18858.030	1	18858.030	15.504	0.0001	7.614%
Stature	245.629	1	245.629	0.202	0.6585	0.099%
Fat-free mass	13458.625	1	13458.625	11.065	0.0011	5.434%
Covariates						
Iso strength at 850 mm	18858.030	1	18858.030	15.504	0.0001	7.614%
Fat-free mass	11982.312	1	11982.312	9.851	0.0020	4.838%
Stature	1721.942	1	1721.942	1.416	0.2357	0.695%
Main Effects						
Gender	4679.319	1	4679.319	3.847	0.0514	1.889%
Residual	210429.140	173	1216.353			
Total (Corrected)	247670.75	177				15.037%

Table A3.41: One-way Ancova of power at 125% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Stature	66.1761	1	66.1761	0.204	0.6583	0.425%
Fat-free mass	116.1895	1	116.1895	0.358	0.5587	0.746%
Iso strength at 850 mm	398.9018	1	398.9018	1.230	0.2731	2.562%
Covariates						
Stature	66.1761	1	66.1761	0.204	0.6583	0.425%
Iso strength at 850 mm	115.5571	1	115.5571	0.356	0.5598	0.742%
Fat-free mass	399.5342	1	399.5342	1.232	0.2727	2.566%
Covariates						
Fat-free mass	0.0172	1	0.0172	0.000	0.9943	0.000%
Stature	182.3485	1	182.3485	0.562	0.4650	1.171%
Iso strength at 850 mm	398.9018	1	398.9018	1.230	0.2731	2.562%
Covariates						
Fat-free mass	0.0172	1	0.0172	0.000	0.9943	0.000%
Iso strength at 850 mm	555.0889	1	555.0889	1.712	0.1972	3.565%
Stature	26.1614	1	26.1614	0.081	0.7806	0.168%
Covariates						
Iso strength at 850 mm	168.8510	1	168.8510	0.521	0.4818	1.084%
Stature	12.8822	1	12.8822	0.040	0.8450	0.083%
Fat-free mass	399.5342	1	399.5342	1.232	0.2727	2.566%
Covariates						
Iso strength at 850 mm	168.8510	1	168.8510	0.521	0.4818	1.084%
Fat-free mass	386.2550	1	386.2550	1.191	0.2807	2.481%
Stature	26.1614	1	26.1614	0.081	0.7806	0.168%
Main Effects						
Gender	77.3108	1	77.3108	0.238	0.6328	0.497%
Residual	14912.245	46	324.1793			
Total (Corrected)	15570.824	50				4.230%

A3.2.4 One-way analyses at absolute heights

Table A3.42: One-way Ancova of power at 450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	2860195.7	1	2860195.7	63.926	0.0000	16.969%
Fat-free mass	1565964.6	1	1565964.6	35.000	0.0000	9.291%
Iso strength at 850 mm	344048.1	1	344048.1	7.690	0.0059	2.041%
Subtotal	4770208.4	3				28.301%
Covariates						
Stature	2860195.7	1	2860195.7	63.926	0.0000	16.969%
Iso strength at 850 mm	1321598.3	1	1321598.3	29.538	0.0000	7.841%
Fat-free mass	588414.5	1	588414.5	13.151	0.0003	3.491%
Subtotal	4770208.5	3				28.301%
Covariates						
Fat-free mass	4425782.9	1	4425782.9	98.917	0.0000	26.257%
Stature	377.4	1	377.4	0.008	0.9279	0.002%
Iso strength at 850 mm	344048.1	1	344048.1	7.690	0.0059	2.041%
Subtotal	4770208.4	3				28.300%
Covariates						
Fat-free mass	4425782.9	1	4425782.9	98.917	0.0000	26.257%
Iso strength at 850 mm	311650.4	1	311650.4	6.965	0.0088	1.849%
Stature	32775.1	1	32775.1	0.733	0.4020	0.194%
Subtotal	4770208.4	3				28.300%
Covariates						
Iso strength at 850 mm	4115578.1	1	4115578.1	91.984	0.0000	24.417%
Stature	66215.8	1	66215.8	1.480	0.2249	0.393%
Fat-free mass	588414.5	1	588414.5	13.151	0.0003	3.491%
Subtotal	4770208.4	3				28.301%
Covariates						
Iso strength at 850 mm	4115578.1	1	4115578.1	91.984	0.0000	24.417%
Fat-free mass	621855.2	1	621855.2	13.899	0.0002	3.689%
Stature	32775.1	1	32775.1	0.733	0.4020	0.194%
Subtotal	4770208.4	3				28.301%
Main Effects						
Gender	228409.2	1	228409.2	5.105	0.0247	1.355%
Residual	11856719	265	44742.3			
Total (Corrected)	16855337	269				29.656%

Table A3.43: One-way Ancova of power at 550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	1952641	1	1952641	107.938	0.0000	21.043%
Fat-free mass	2267713.4	1	2267713.4	125.354	0.0000	24.439%
Iso strength at 850 mm	240794.4	1	240794.4	13.311	0.0003	2.595%
Covariates						
Stature	1952641	1	1952641	107.938	0.0000	21.043%
Iso strength at 850 mm	1438412.4	1	1438412.4	79.512	0.0000	15.501%
Fat-free mass	1070095.4	1	1070095.4	59.153	0.0000	11.532%
Covariates						
Fat-free mass	4061953.2	1	4061953.2	224.536	0.0000	43.775%
Stature	158401.2	1	158401.2	8.756	0.0034	1.707%
Iso strength at 850 mm	240794.4	1	240794.4	13.311	0.0003	2.595%
Covariates						
Fat-free mass	4061953.2	1	4061953.2	224.536	0.0000	43.775%
Iso strength at 850 mm	130578.7	1	130578.7	7.218	0.0077	1.407%
Stature	268616.9	1	268616.9	14.849	0.0001	2.895%
Covariates						
Iso strength at 850 mm	3390398.7	1	3390398.7	187.414	0.0000	36.538%
Stature	654.6	1	654.6	0.036	0.8513	0.007%
Fat-free mass	1070095.4	1	1070095.4	59.153	0.0000	11.532%
Covariates						
Iso strength at 850 mm	3390398.7	1	3390398.7	187.414	0.0000	36.538%
Fat-free mass	802133.1	1	802133.1	44.340	0.0000	8.644%
Stature	268616.9	1	268616.9	14.849	0.0001	2.895%

Main Effects						
Gender	24065.9	1	24065.9	1.330	0.2498	0.259%
Residual	4793968.9	265	18090.4			
Total (Corrected)	9279183.5	269				48.336%

Table A3.44: One-way Ancova of power at 650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	3510788.5	1	3510788.5	163.847	0.0000	28.565%
Fat-free mass	2811666.1	1	2811666.1	131.219	0.0000	22.877%
Iso strength at 850 mm	202433.1	1	202433.1	9.447	0.0023	1.647%
Covariates						
Stature	3510788.5	1	3510788.5	163.847	0.0000	28.565%
Iso strength at 850 mm	1569786.3	1	1569786.3	73.261	0.0000	12.773%
Fat-free mass	1444312.9	1	1444312.9	67.406	0.0000	11.752%
Covariates						
Fat-free mass	6256644.9	1	6256644.9	291.995	0.0000	50.907%
Stature	65809.7	1	65809.7	3.071	0.0808	0.535%
Iso strength at 850 mm	202433.1	1	202433.1	9.447	0.0023	1.647%
Covariates						
Fat-free mass	6256644.9	1	6256644.9	291.995	0.0000	50.907%
Iso strength at 850 mm	130558.1	1	130558.1	6.093	0.0142	1.062%
Stature	137684.7	1	137684.7	6.426	0.0118	1.120%
Covariates						
Iso strength at 850 mm	4990184.8	1	4990184.8	232.890	0.0000	40.603%
Stature	90390	1	90390	4.218	0.0410	0.735%
Fat-free mass	1444312.9	1	1444312.9	67.406	0.0000	11.752%
Covariates						
Iso strength at 850 mm	4990184.8	1	4990184.8	232.890	0.0000	40.603%
Fat-free mass	1397018.3	1	1397018.3	65.198	0.0000	11.367%
Stature	137684.7	1	137684.7	6.426	0.0118	1.120%
Main Effects						
Gender	87238.7	1	87238.7	4.071	0.0446	0.710%
Residual	5678208.4	265	21427.2			
Total (Corrected)	12290335	269				53.799%

Table A3.45: One-way Ancova of power at 750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	6158480.7	1	6158480.7	291.984	0.0000	40.161%
Fat-free mass	3205688.7	1	3205688.7	151.987	0.0000	20.905%
Iso strength at 850 mm	258219.6	1	258219.6	12.243	0.0005	1.684%
Covariates						
Stature	6158480.7	1	6158480.7	291.984	0.0000	40.161%
Iso strength at 850 mm	1853830.4	1	1853830.4	87.893	0.0000	12.089%
Fat-free mass	1610077.9	1	1610077.9	76.336	0.0000	10.500%
Covariates						
Fat-free mass	9364096.1	1	9364096.1	443.967	0.0000	61.065%
Stature	73.3	1	73.3	0.003	0.9537	0.000%
Iso strength at 850 mm	258219.6	1	258219.6	12.243	0.0005	1.684%
Covariates						
Fat-free mass	9364096.1	1	9364096.1	443.967	0.0000	61.065%
Iso strength at 850 mm	240751.9	1	240751.9	11.414	0.0008	1.570%
Stature	17540.9	1	17540.9	0.832	0.3724	0.114%
Covariates						
Iso strength at 850 mm	7626047.2	1	7626047.2	361.563	0.0000	49.731%
Stature	386263.8	1	386263.8	18.313	0.0000	2.519%
Fat-free mass	1610077.9	1	1610077.9	76.336	0.0000	10.500%
Covariates						
Iso strength at 850 mm	7626047.2	1	7626047.2	361.563	0.0000	49.731%
Fat-free mass	1978800.8	1	1978800.8	93.818	0.0000	12.904%
Stature	17540.9	1	17540.9	0.832	0.3724	0.114%
Main Effects						
Gender	122844.6	1	122844.6	5.824	0.0165	0.801%
Residual	5589346.1	265	21091.9			
Total (Corrected)	15334580	269				63.551%

Table A3.46: One-way Ancova of power at 850 mm

Source of variation	**Sum of squares**	**D.F.**	**Mean squares**	**F ratio**	**Probability**	**R^2**
Covariates						
Stature	6267193.1	1	6267193.1	404.349	0.0000	49.460%
Fat-free mass	2068636.2	1	2068636.2	133.465	0.0000	16.325%
Iso strength at 850 mm	211037.7	1	211037.7	13.616	0.0003	1.665%
Covariates						
Stature	6267193.1	1	6267193.1	404.349	0.0000	49.460%
Iso strength at 850 mm	1293998.8	1	1293998.8	83.487	0.0000	10.212%
Fat-free mass	985675.2	1	985675.2	63.594	0.0000	7.779%
Covariates						
Fat-free mass	8241955.3	1	8241955.3	531.758	0.0000	65.044%
Stature	93874	1	93874	6.057	0.0145	0.741%
Iso strength at 850 mm	211037.7	1	211037.7	13.616	0.0003	1.665%
Covariates						
Fat-free mass	8241955.3	1	8241955.3	531.758	0.0000	65.044%
Iso strength at 850 mm	276940.6	1	276940.6	17.868	0.0000	2.186%
Stature	27971.1	1	27971.1	1.805	0.1803	0.221%
Covariates						
Iso strength at 850 mm	6914972.8	1	6914972.8	446.143	0.0000	54.572%
Stature	646219	1	646219	41.693	0.0000	5.100%
Fat-free mass	985675.2	1	985675.2	63.594	0.0000	7.779%
Covariates						
Iso strength at 850 mm	6914972.8	1	6914972.8	446.143	0.0000	54.572%
Fat-free mass	1603923.1	1	1603923.1	103.483	0.0000	12.658%
Stature	27971.1	1	27971.1	1.805	0.1803	0.221%
Main Effects						
Gender	17043.9	1	17043.9	1.100	0.2953	0.135%
Residual	4107353.3	265	15499.4			
Total (Corrected)	12671264	269				67.585%

Table A3.47: One-way Ancova of power at 950 mm

Source of variation	**Sum of squares**	**D.F.**	**Mean squares**	**F ratio**	**Probability**	**R^2**
Covariates						
Stature	3646364.6	1	3646364.6	410.918	0.0000	51.258%
Fat-free mass	1071536.7	1	1071536.7	120.754	0.0000	15.063%
Iso strength at 850 mm	39705.6	1	39705.6	4.475	0.0353	0.558%
Covariates						
Stature	3646364.6	1	3646364.6	410.918	0.0000	51.258%
Iso strength at 850 mm	498871.2	1	498871.2	56.219	0.0000	7.013%
Fat-free mass	612371.1	1	612371.1	69.010	0.0000	8.608%
Covariates						
Fat-free mass	4637347.8	1	4637347.8	522.595	0.0000	65.189%
Stature	80553.5	1	80553.5	9.078	0.0028	1.132%
Iso strength at 850 mm	39705.6	1	39705.6	4.475	0.0353	0.558%
Covariates						
Fat-free mass	4637347.8	1	4637347.8	522.595	0.0000	65.189%
Iso strength at 850 mm	72923.5	1	72923.5	8.218	0.0045	1.025%
Stature	47335.6	1	47335.6	5.334	0.0217	0.665%
Covariates						
Iso strength at 850 mm	3606250.2	1	3606250.2	406.397	0.0000	50.694%
Stature	538985.5	1	538985.5	60.740	0.0000	7.577%
Fat-free mass	612371.1	1	612371.1	69.010	0.0000	8.608%
Covariates						
Iso strength at 850 mm	3606250.2	1	3606250.2	406.397	0.0000	50.694%
Fat-free mass	1104021.1	1	1104021.1	124.415	0.0000	15.520%
Stature	47335.6	1	47335.6	5.334	0.0217	0.665%
Main Effects						
Gender	4558.0	1	4558.0	0.514	0.4818	0.064%
Residual	2351531	265	8873.7			
Total (Corrected)	7113695.9	269				66.944%

Table A3.48: One-way Ancova of power at 1050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Stature	1062412.9	1	1062412.9	124.418	0.0000	28.291%
Fat-free mass	429997.5	1	429997.5	50.356	0.0000	11.450%
Iso strength at 850 mm	10.5	1	10.5	0.001	0.9725	0.000%
Covariates						
Stature	1062412.9	1	1062412.9	124.418	0.0000	28.291%
Iso strength at 850 mm	113339.2	1	113339.2	13.273	0.0003	3.018%
Fat-free mass	316668.8	1	316668.8	37.085	0.0000	8.433%
Covariates						
Fat-free mass	1486829.7	1	1486829.7	174.121	0.0000	39.593%
Stature	5580.8	1	5580.8	0.654	0.4282	0.149%
Iso strength at 850 mm	10.5	1	10.5	0.001	0.9725	0.000%
Covariates						
Fat-free mass	1486829.7	1	1486829.7	174.121	0.0000	39.593%
Iso strength at 850 mm	308.8	1	308.8	0.036	0.8514	0.008%
Stature	5282.5	1	5282.5	0.619	0.4407	0.141%
Covariates						
Iso strength at 850 mm	991098.3	1	991098.3	116.066	0.0000	26.392%
Stature	184653.85	1	184653.85	21.625	0.0000	4.917%
Fat-free mass	316668.8	1	316668.8	37.085	0.0000	8.433%
Covariates						
Iso strength at 850 mm	991098.3	1	991098.3	116.066	0.0000	26.392%
Fat-free mass	496040.15	1	496040.15	58.091	0.0000	13.209%
Stature	5282.51	1	5282.51	0.619	0.4407	0.141%
Main Effects						
Gender	35.6	1	35.6	0.004	0.9493	0.001%
Residual	2262855.9	265	8539.1			
Total (Corrected)	3755312.4	269				39.743%

Table A3.49: One-way Ancova of power at 1150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Stature	170397.06	1	170397.06	21.039	0.0000	6.853%
Fat-free mass	140162	1	140162	17.306	0.0000	5.637%
Iso strength at 850 mm	12591.3	1	12591.3	1.555	0.2136	0.506%
Covariates						
Stature	170397.06	1	170397.06	21.039	0.0000	6.853%
Iso strength at 850 mm	83982.51	1	83982.51	10.369	0.0014	3.378%
Fat-free mass	68770.79	1	68770.79	8.491	0.0039	2.766%
Covariates						
Fat-free mass	306894.09	1	306894.09	37.892	0.0000	12.343%
Stature	3664.97	1	3664.97	0.453	0.5089	0.147%
Iso strength at 850 mm	12591.3	1	12591.3	1.555	0.2136	0.506%
Covariates						
Fat-free mass	306894.09	1	306894.09	37.892	0.0000	12.343%
Iso strength at 850 mm	8293.24	1	8293.24	1.024	0.3125	0.334%
Stature	7963.04	1	7963.04	0.983	0.3329	0.320%
Covariates						
Iso strength at 850 mm	251253.62	1	251253.62	31.022	0.0000	10.105%
Stature	3125.96	1	3125.96	0.386	0.5416	0.126%
Fat-free mass	68770.79	1	68770.79	8.491	0.0039	2.766%
Covariates						
Iso strength at 850 mm	251253.62	1	251253.62	31.022	0.0000	10.105%
Fat-free mass	63933.71	1	63933.71	7.894	0.0053	2.571%
Stature	7963.04	1	7963.04	0.983	0.3329	0.320%
Main Effects						
Gender	16990.48	1	16990.48	2.098	0.1487	0.683%
Residual	2146289.3	265	8099.20			
Total (Corrected)	2486430.2	269				13.680%

Table A3.50: One-way Ancova of power at 1250 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	4955.43	1	4955.43	0.412	0.5282	0.145%
Fat-free mass	131476.62	1	131476.62	10.942	0.0011	3.841%
Iso strength at 850 mm	66329.71	1	66329.71	5.520	0.0195	1.938%
Covariates						
Stature	4955.43	1	4955.43	0.412	0.5282	0.145%
Iso strength at 850 mm	166502.11	1	166502.11	13.857	0.0002	4.864%
Fat-free mass	31304.21	1	31304.21	2.605	0.1077	0.914%
Covariates						
Fat-free mass	72871.741	1	72871.741	6.064	0.0144	2.129%
Stature	63560.305	1	63560.305	5.290	0.0222	1.857%
Iso strength at 850 mm	66329.708	1	66329.708	5.520	0.0195	1.938%
Covariates						
Fat-free mass	72871.741	1	72871.741	6.064	0.0144	2.129%
Iso strength at 850 mm	31573.874	1	31573.874	2.628	0.1062	0.922%
Stature	98316.139	1	98316.139	8.182	0.0046	2.872%
Covariates						
Iso strength at 850 mm	104205.39	1	104205.39	8.672	0.0035	3.044%
Stature	67252.15	1	67252.15	5.597	0.0187	1.964%
Fat-free mass	31304.21	1	31304.21	2.605	0.1077	0.914%
Covariates						
Iso strength at 850 mm	104205.39	1	104205.39	8.672	0.0035	3.044%
Fat-free mass	240.22	1	240.22	0.020	0.8892	0.007%
Stature	98316.14	1	98316.14	8.182	0.0046	2.872%
Main Effects						
Gender	36381.18	1	36381.18	3.028	0.0830	1.063%
Residual	3184280.1	265	12016.15			
Total (Corrected)	3423423.1	269				6.985%

Table A3.51: One-way Ancova of power at 1350 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	45338.58	1	45338.58	2.631	0.1060	0.939%
Fat-free mass	167471.57	1	167471.57	9.720	0.0020	3.469%
Iso strength at 850 mm	11479.43	1	11479.43	0.666	0.4238	0.238%
Covariates						
Stature	45338.582	1	45338.582	2.631	0.1060	0.939%
Iso strength at 850 mm	92112.191	1	92112.191	5.346	0.0215	1.908%
Fat-free mass	86838.804	1	86838.804	5.040	0.0256	1.799%
Covariates						
Fat-free mass	170317.91	1	170317.91	9.885	0.0019	3.528%
Stature	42492.24	1	42492.24	2.466	0.1175	0.880%
Iso strength at 850 mm	11479.43	1	11479.43	0.666	0.4238	0.238%
Covariates						
Fat-free mass	170317.91	1	170317.91	9.885	0.0019	3.528%
Iso strength at 850 mm	2106.04	1	2106.04	0.122	0.7306	0.044%
Stature	51865.63	1	51865.63	3.010	0.0839	1.074%
Covariates						
Iso strength at 850 mm	129946.68	1	129946.68	7.542	0.0064	2.691%
Stature	7504.09	1	7504.09	0.436	0.5169	0.155%
Fat-free mass	86838.8	1	86838.8	5.040	0.0256	1.799%
Covariates						
Iso strength at 850 mm	129946.68	1	129946.68	7.542	0.0064	2.691%
Fat-free mass	42477.26	1	42477.26	2.465	0.1176	0.880%
Stature	51865.63	1	51865.63	3.010	0.0839	1.074%
Main Effects						
Gender	37875.05	1	37875.05	2.198	0.1394	0.784%
Residual	4565997.5	265	17230.18			
Total (Corrected)	4828162.2	269				5.430%

Table A3.52: One-way Ancova of power at 1450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	598198.31	1	598198.31	33.851	0.0000	10.652%
Fat-free mass	302956.73	1	302956.73	17.144	0.0000	5.395%
Iso strength at 850 mm	22911.96	1	22911.96	1.297	0.2559	0.408%
Covariates						
Stature	598198.31	1	598198.31	33.851	0.0000	10.652%
Iso strength at 850 mm	171742.42	1	171742.42	9.719	0.0020	3.058%
Fat-free mass	154126.27	1	154126.27	8.722	0.0034	2.744%
Covariates						
Fat-free mass	901077.25	1	901077.25	50.990	0.0000	16.045%
Stature	77.79	1	77.79	0.004	0.9479	0.001%
Iso strength at 850 mm	22911.96	1	22911.96	1.297	0.2559	0.408%
Covariates						
Fat-free mass	901077.25	1	901077.25	50.990	0.0000	16.045%
Iso strength at 850 mm	21872.38	1	21872.38	1.238	0.2669	0.389%
Stature	1117.36	1	1117.36	0.063	0.8043	0.020%
Covariates						
Iso strength at 850 mm	729482.36	1	729482.36	41.280	0.0000	12.989%
Stature	40458.37	1	40458.37	2.289	0.1314	0.720%
Fat-free mass	154126.27	1	154126.27	8.722	0.0034	2.744%
Covariates						
Iso strength at 850 mm	729482.36	1	729482.36	41.280	0.0000	12.989%
Fat-free mass	193467.27	1	193467.27	10.948	0.0011	3.445%
Stature	1117.36	1	1117.36	0.063	0.8043	0.020%
Main Effects						
Gender	8936.12	1	8936.12	0.506	0.4852	0.159%
Residual	4682990.4	265	17671.66			
Total (Corrected)	5615993.5	269				16.613%

Table A3.53: One-way Ancova of power at 1550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	1429265.5	1	1429265.5	137.901	0.0000	31.205%
Fat-free mass	348506.2	1	348506.2	33.625	0.0000	7.609%
Iso strength at 850 mm	47792.9	1	47792.9	4.611	0.0327	1.043%
Covariates						
Stature	1429265.5	1	1429265.5	137.901	0.0000	31.205%
Iso strength at 850 mm	242679.5	1	242679.5	23.415	0.0000	5.298%
Fat-free mass	153619.6	1	153619.6	14.822	0.0001	3.354%
Covariates						
Fat-free mass	1727407	1	1727407	166.667	0.0000	37.714%
Stature	50364.8	1	50364.8	4.859	0.0284	1.100%
Iso strength at 850 mm	47792.9	1	47792.9	4.611	0.0327	1.043%
Covariates						
Fat-free mass	1727407	1	1727407	166.667	0.0000	37.714%
Iso strength at 850 mm	74091.5	1	74091.5	7.149	0.0080	1.618%
Stature	24066.2	1	24066.2	2.322	0.1287	0.525%
Covariates						
Iso strength at 850 mm	1494000.8	1	1494000.8	144.147	0.0000	32.619%
Stature	177944.3	1	177944.3	17.169	0.0000	3.885%
Fat-free mass	153619.6	1	153619.6	14.822	0.0001	3.354%
Covariates						
Iso strength at 850 mm	1494000.8	1	1494000.8	144.147	0.0000	32.619%
Fat-free mass	307497.7	1	307497.7	29.669	0.0000	6.714%
Stature	24066.2	1	24066.2	2.322	0.1287	0.525%
Main Effects						
Gender	8079.3	1	8079.3	0.780	0.3875	0.176%
Residual	2746576.6	265	10364.4			
Total (Corrected)	4580220.6	269				40.034%

Table A3.54: One-way Ancova of power at 1650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	1137414.1	1	1137414.1	267.280	0.0000	44.033%
Fat-free mass	297839.7	1	297839.7	69.989	0.0000	11.530%
Iso strength at 850 mm	13234.1	1	13234.1	3.110	0.0790	0.512%
Covariates						
Stature	1137414.1	1	1137414.1	267.280	0.0000	44.033%
Iso strength at 850 mm	145100	1	145100	34.097	0.0000	5.617%
Fat-free mass	165973.8	1	165973.8	39.002	0.0000	6.425%
Covariates						
Fat-free mass	1401127.9	1	1401127.9	329.250	0.0000	54.242%
Stature	34125.8	1	34125.8	8.019	0.0050	1.321%
Iso strength at 850 mm	13234.1	1	13234.1	3.110	0.0790	0.512%
Covariates						
Fat-free mass	1401127.9	1	1401127.9	329.250	0.0000	54.242%
Iso strength at 850 mm	26141.1	1	26141.1	6.143	0.0138	1.012%
Stature	21218.8	1	21218.8	4.986	0.0264	0.821%
Covariates						
Iso strength at 850 mm	1105948.4	1	1105948.4	259.886	0.0000	42.815%
Stature	176565.6	1	176565.6	41.491	0.0000	6.835%
Fat-free mass	165973.8	1	165973.8	39.002	0.0000	6.425%
Covariates						
Iso strength at 850 mm	1105948.4	1	1105948.4	259.886	0.0000	42.815%
Fat-free mass	321320.6	1	321320.6	75.507	0.0000	12.439%
Stature	21218.8	1	21218.8	4.986	0.0264	0.821%
Main Effects						
Gender	6883.3	1	6883.3	1.618	0.2046	0.266%
Residual	1127711.8	265	4255.5			
Total (Corrected)	2583083	269				56.342%

Table A3.55: One-way Ancova of power at 1750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	407431.62	1	407431.62	255.942	0.0000	42.356%
Fat-free mass	127959.49	1	127959.49	80.382	0.0000	13.302%
Iso strength at 850 mm	4464.65	1	4464.65	2.805	0.0952	0.464%
Covariates						
Stature	407431.62	1	407431.62	255.942	0.0000	42.356%
Iso strength at 850 mm	58724.36	1	58724.36	36.890	0.0000	6.105%
Fat-free mass	73699.79	1	73699.79	46.297	0.0000	7.662%
Covariates						
Fat-free mass	528096.65	1	528096.65	331.741	0.0000	54.900%
Stature	7294.46	1	7294.46	4.582	0.0332	0.758%
Iso strength at 850 mm	4464.65	1	4464.65	2.805	0.0952	0.464%
Covariates						
Fat-free mass	528096.65	1	528096.65	331.741	0.0000	54.900%
Iso strength at 850 mm	7717.57	1	7717.57	4.848	0.0285	0.802%
Stature	4041.55	1	4041.55	2.539	0.1123	0.420%
Covariates						
Iso strength at 850 mm	408203.56	1	408203.56	256.426	0.0000	42.436%
Stature	57952.42	1	57952.42	36.405	0.0000	6.025%
Fat-free mass	73699.79	1	73699.79	46.297	0.0000	7.662%
Covariates						
Iso strength at 850 mm	408203.56	1	408203.56	256.426	0.0000	42.436%
Fat-free mass	127610.66	1	127610.66	80.163	0.0000	13.266%
Stature	4041.55	1	4041.55	2.539	0.1123	0.420%
Main Effects						
Gender	218.81	1	218.81	0.137	0.7151	0.023%
Residual	421851.75	265	1591.89			
Total (Corrected)	961926.33	269				56.145%

Table A3.56: One-way Ancova of power at 1850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	126835.72	1	126835.72	223.386	0.0000	36.793%
Fat-free mass	68002.31	1	68002.31	119.767	0.0000	19.726%
Iso strength at 850 mm	370.42	1	370.42	0.652	0.4286	0.107%
Covariates						
Stature	126835.72	1	126835.72	223.386	0.0000	36.793%
Iso strength at 850 mm	22994.16	1	22994.16	40.498	0.0000	6.670%
Fat-free mass	45378.57	1	45378.57	79.922	0.0000	13.164%
Covariates						
Fat-free mass	194828.45	1	194828.45	343.136	0.0000	56.517%
Stature	9.58	1	9.58	0.017	0.8981	0.003%
Iso strength at 850 mm	370.42	1	370.42	0.652	0.4286	0.107%
Covariates						
Fat-free mass	194828.45	1	194828.45	343.136	0.0000	56.517%
Iso strength at 850 mm	375.08	1	375.08	0.661	0.4258	0.109%
Stature	4.92	1	4.92	0.009	0.9269	0.001%
Covariates						
Iso strength at 850 mm	133602.44	1	133602.44	235.304	0.0000	38.756%
Stature	16227.44	1	16227.44	28.580	0.0000	4.707%
Fat-free mass	45378.57	1	45378.57	79.922	0.0000	13.164%
Covariates						
Iso strength at 850 mm	133602.44	1	133602.44	235.304	0.0000	38.756%
Fat-free mass	61601.09	1	61601.09	108.493	0.0000	17.869%
Stature	4.92	1	4.92	0.009	0.9269	0.001%
Main Effects						
Gender	191.28	1	191.28	0.337	0.5683	0.055%
Residual	149328.12	263	567.79			
Total (Corrected)	344727.85	267				56.682%

Table A3.57: One-way Ancova of power at 1950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	86950.122	1	86950.122	120.017	0.0000	26.747%
Fat-free mass	53512.756	1	53512.756	73.864	0.0000	16.461%
Iso strength at 850 mm	1.552	1	1.552	0.002	0.9636	0.000%
Covariates						
Stature	86950.122	1	86950.122	120.017	0.0000	26.747%
Iso strength at 850 mm	13967.372	1	13967.372	19.279	0.0000	4.297%
Fat-free mass	39546.935	1	39546.935	54.587	0.0000	12.165%
Covariates						
Fat-free mass	140453.76	1	140453.76	193.868	0.0000	43.205%
Stature	9.12	1	9.12	0.013	0.9120	0.003%
Iso strength at 850 mm	1.55	1	1.55	0.002	0.9636	0.000%
Covariates						
Fat-free mass	140453.76	1	140453.76	193.868	0.0000	43.205%
Iso strength at 850 mm	0.19	1	0.19	0.000	0.9874	0.000%
Stature	10.49	1	10.49	0.014	0.9056	0.003%
Covariates						
Iso strength at 850 mm	85679.238	1	85679.238	118.263	0.0000	26.356%
Stature	15238.256	1	15238.256	21.033	0.0000	4.687%
Fat-free mass	39546.935	1	39546.935	54.587	0.0000	12.165%
Covariates						
Iso strength at 850 mm	85679.238	1	85679.238	118.263	0.0000	26.356%
Fat-free mass	54774.706	1	54774.706	75.606	0.0000	16.849%
Stature	10.485	1	10.485	0.014	0.9056	0.003%
Main Effects						
Gender	2053.344	1	2053.344	2.834	0.0935	0.632%
Residual	182568.88	252	724.480			
Total (Corrected)	325086.65	256				43.840%

Table A3.58: One-way Ancova of power at 2050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	28873.502	1	28873.502	18.866	0.0000	8.026%
Fat-free mass	40921.259	1	40921.259	26.738	0.0000	11.375%
Iso strength at 850 mm	1087.33	1	1087.33	0.710	0.4094	0.302%
Covariates						
Stature	28873.502	1	28873.502	18.866	0.0000	8.026%
Iso strength at 850 mm	5591.286	1	5591.286	3.653	0.0575	1.554%
Fat-free mass	36417.303	1	36417.303	23.795	0.0000	10.123%
Covariates						
Fat-free mass	69384.114	1	69384.114	45.336	0.0000	19.286%
Stature	410.648	1	410.648	0.268	0.6106	0.114%
Iso strength at 850 mm	1087.33	1	1087.33	0.710	0.4094	0.302%
Covariates						
Fat-free mass	69384.114	1	69384.114	45.336	0.0000	19.286%
Iso strength at 850 mm	1364.347	1	1364.347	0.891	0.3564	0.379%
Stature	133.63	1	133.63	0.087	0.7711	0.037%
Covariates						
Iso strength at 850 mm	27150.487	1	27150.487	17.740	0.0000	7.547%
Stature	7314.301	1	7314.301	4.779	0.0301	2.033%
Fat-free mass	36417.303	1	36417.303	23.795	0.0000	10.123%
Covariates						
Iso strength at 850 mm	27150.487	1	27150.487	17.740	0.0000	7.547%
Fat-free mass	43597.974	1	43597.974	28.487	0.0000	12.119%
Stature	133.63	1	133.63	0.087	0.7711	0.037%
Main Effects						
Gender	4217.612	1	4217.612	2.756	0.0986	1.172%
Residual	284660.5	186	1530.433			
Total (Corrected)	359760.2	190				20.875%

Table A3.59: One-way Ancova of power at 2150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Stature	1808.381	1	1808.381	0.963	0.3413	1.694%
Fat-free mass	4241.2342	1	4241.2342	2.259	0.1388	3.972%
Iso strength at 850 mm	819.8281	1	819.8281	0.437	0.5187	0.768%
Covariates						
Stature	1808.381	1	1808.381	0.963	0.3413	1.694%
Iso strength at 850 mm	14.4786	1	14.4786	0.008	0.9313	0.014%
Fat-free mass	5046.5837	1	5046.5837	2.688	0.1071	4.727%
Covariates						
Fat-free mass	6010.8558	1	6010.8558	3.201	0.0793	5.630%
Stature	38.7594	1	38.7594	0.021	0.8878	0.036%
Iso strength at 850 mm	819.8281	1	819.8281	0.437	0.5187	0.768%
Covariates						
Fat-free mass	6010.8558	1	6010.8558	3.201	0.0793	5.630%
Iso strength at 850 mm	858.4294	1	858.4294	0.457	0.5091	0.804%
Stature	0.1582	1	0.1582	0.000	0.9928	0.000%
Covariates						
Iso strength at 850 mm	645.3513	1	645.3513	0.344	0.5664	0.604%
Stature	1177.5084	1	1177.5084	0.627	0.4404	1.103%
Fat-free mass	5046.5837	1	5046.5837	2.688	0.1071	4.727%
Covariates						
Iso strength at 850 mm	645.3513	1	645.3513	0.344	0.5664	0.604%
Fat-free mass	6223.9339	1	6223.9339	3.315	0.0743	5.829%
Stature	0.1582	1	0.1582	0.000	0.9928	0.000%
Main Effects						
Gender	378.0309	1	378.0309	0.201	0.6603	0.354%
Residual	99522.457	53	1877.7822			
Total (Corrected)	106769.93	57				6.788%

APPENDIX 4

ANALYSES OF POWER, WORK AND IMPULSE AT ABSOLUTE HEIGHTS

In all the following tables there were no missing values; all F ratios were calculated using the residual mean square error; R^2 values were calculated by dividing individual sums of squares by the total sum of squares; Total R^2 is the total proportion of variance accounted for by the model, excluding the residual variance.

A4.1 Variance accounted for by Anova and Ancova of power at fixed heights

Table A4.1: Two way Anova of power at 100 mm intervals

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	24324601	1	24324601	1315.422	0.0000	10.243%
Hand height (mm)	135696119	13	10438163	564.473	0.0000	57.142%
Interactions						
Gender × Height	8072891	13	620992	33.582	0.0000	3.399%
Residual	69381454	3752	18492			
Total (Corrected)	237475064	3779				70.784%

Table A4.2: Two way Ancova of power at 100 mm intervals

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	32512584	1	32512584	2033.634	0.0000	13.691%
Iso strength at 850 mm	910220	1	910220	56.933	0.0000	0.383%
Stature	77989	1	77989	4.878	0.0273	0.033%
Main Effects						
Gender	268369	1	268369	16.786	0.0000	0.113%
Hand height (mm)	135696119	13	10438163	652.898	0.0000	57.141%
Interactions						
Gender × Height	8072891	13	6209923	38.842	0.0000	3.399%
Residual	59936892	3749	15987			
Total (Corrected)	237475064	3779				74.761%

A4.1.1 One-way Anova of power at fixed heights

Table A4.3: One-way Anova of power at 450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3977634	1	3977634	82.779	0.0000	23.599%
Residual	12877703	268	48051			
Total (Corrected)	16855337	269				

Table A4.4: One-way Anova of power at 550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2992904	1	2992904	127.595	0.0000	32.254%
Residual	6286280	268	23456			
Total (Corrected)	9279183.5	269				

Table A4.5: One-way Anova of power at 650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	4857268.3	1	4857268.3	175.129	0.0000	39.521%
Residual	7433066.6	268	27735.3			
Total (Corrected)	12290335	269				

Table A4.6: One-way Anova of power at 750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	7230656	1	7230656	239.121	0.0000	47.153%
Residual	8103923.7	268	30238.5			
Total (Corrected)	15334580	269				

Table A4.7: One-way Anova of power at 850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	5786449.6	1	5786449.6	225.245	0.0000	45.666%
Residual	6884814.6	268	25689.6			
Total (Corrected)	12671264	269				

Table A4.8: One-way Anova of power at 950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2900671.5	1	2900671.5	184.518	0.0000	40.776%
Residual	4213024.3	268	15720.2			
Total (Corrected)	7113695.9	269				

Table A4.9: One-way Anova of power at 1050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	961256.5	1	961256.5	92.202	0.0000	25.597%
Residual	2794055.9	268	10425.6			
Total (Corrected)	3755312.4	269				

Table A4.10: One-way Anova of power at 1150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	277453.9	1	277453.9	33.662	0.0000	11.159%
Residual	2208976.2	268	8242.4			
Total (Corrected)	2486430.2	269				

Table A4.11: One-way Anova of power at 1250 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	113361.4	1	113361.4	9.178	0.0027	3.311%
Residual	3310061.6	268	12351.0			
Total (Corrected)	3423423.1	269				

Table A4.12: One-way Anova of power at 1350 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	202881.5	1	202881.5	11.755	0.0007	4.202%
Residual	4625280.6	268	17258.5			
Total (Corrected)	4828162.2	269				

Table A4.13: One-way Anova of power at 1450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	681628.67	1	681628.67	37.021	0.0000	12.137%
Residual	4934364.9	268	18411.81			
Total (Corrected)	5615993.5	269				

Table A4.14: One-way Anova of power at 1550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	1252813.2	1	1252813.2	100.906	0.0000	27.353%
Residual	3327407.4	268	12415.7			
Total (Corrected)	4580220.6	269				

Table A4.15: One-way Anova of power at 1650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	826766.67	1	826766.67	126.158	0.0000	32.007%
Residual	1756316.3	268	6553.42			
Total (Corrected)	2583083	269				

Table A4.16: One-way Anova of power at 1750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	335747.1	1	335747.1	143.697	0.0000	34.904%
Residual	626179.23	268	2336.5			
Total (Corrected)	961926.33	269				

Table A4.17: One-way Anova of power at 1850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	131645.45	1	131645.45	164.339	0.0000	38.188%
Residual	213082.4	266	801.06			
Total (Corrected)	344727.85	267				

Table A4.18: One-way Anova of power at 1950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	104000.79	1	104000.79	119.954	0.0000	31.992%
Residual	221085.86	255	867.00			
Total (Corrected)	325086.65	256				

Table A4.19: One-way Anova of power at 2050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	58046.527	1	58046.527	36.362	0.0000	16.135%
Residual	301713.67	189	1596.369			
Total (Corrected)	359760.2	190				

Table A4.20: One-way Anova of power at 2150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3179.337	1	3179.337	1.719	0.195	2.978%
Residual	103590.59	56	1849.832			
Total (Corrected)	106769.93	57				

A4.1.2 One-way Ancova of power at fixed heights

Table A4.21: One-way Ancova of power at 450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	4425782.9	1	4425782.9	98.917	0.0000	26.257%
Iso strength at 850 mm	311650.4	1	311650.4	6.965	0.0088	1.849%
Stature	32775.1	1	32775.1	0.733	0.4020	0.194%
Main Effects						
Gender	228409.22	1	228409.22	5.105	0.0247	1.355%
Residual	11856719	265	44742.34			
Total (Corrected)	16855337	269				29.656%

Table A4.22: One-way Ancova of power at 550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	4061953.2	1	4061953.2	224.536	0.0000	43.775%
Iso strength at 850 mm	130578.7	1	130578.7	7.218	0.0077	1.407%
Stature	268616.9	1	268616.9	14.849	0.0001	2.895%
Main Effects						
Gender	24065.887	1	24065.887	1.33	0.2498	0.259%
Residual	4793968.9	265	18090.449			
Total (Corrected)	9279183.5	269				48.336%

Table A4.23: One-way Ancova of power at 650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	6256644.9	1	6256644.9	291.995	0.0000	50.907%
Iso strength at 850 mm	130558.1	1	130558.1	6.093	0.0142	1.062%
Stature	137684.7	1	137684.7	6.426	0.0118	1.120%
Main Effects						
Gender	87238.743	1	87238.743	4.071	0.0446	0.710%
Residual	5678208.4	265	21427.202			
Total (Corrected)	12290335	269				53.799%

Table A4.24: One-way Ancova of power at 750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	9364096.1	1	9364096.1	443.967	0.0000	61.065%
Iso strength at 850 mm	240751.9	1	240751.9	11.414	0.0008	1.570%
Stature	17540.9	1	17540.9	0.832	0.3724	0.114%
Main Effects						
Gender	122844.61	1	122844.61	5.824	0.0165	0.801%
Residual	5589346.1	265	21091.872			
Total (Corrected)	15334580	269				63.551%

Table A4.25: One-way Ancova of power at 850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	8241955.3	1	8241955.3	531.758	0.0000	65.044%
Iso strength at 850 mm	276940.6	1	276940.6	17.868	0.0000	2.186%
Stature	27971.1	1	27971.1	1.805	0.1803	0.221%
Main Effects						
Gender	17043.869	1	17043.869	1.1	0.2953	0.135%
Residual	4107353.3	265	15499.446			
Total (Corrected)	12671264	269				67.585%

Table A4.26: One-way Ancova of power at 950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	4637347.8	1	4637347.8	522.595	0.0000	65.189%
Iso strength at 850 mm	72923.5	1	72923.5	8.218	0.0045	1.025%
Stature	47335.6	1	47335.6	5.334	0.0217	0.665%
Main Effects						
Gender	4557.971	1	4557.971	0.514	0.4818	0.064%
Residual	2351531	265	8873.702			
Total (Corrected)	7113695.9	269				66.944%

Table A4.27: One-way Ancova of power at 1050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1486829.7	1	1486829.7	174.121	0.0000	39.593%
Iso strength at 850 mm	308.8	1	308.8	0.036	0.8514	0.008%
Stature	5282.5	1	5282.5	0.619	0.4407	0.141%
Main Effects						
Gender	35.561	1	35.561	0.004	0.9493	0.001%
Residual	2262855.9	265	8539.079			
Total (Corrected)	3755312.4	269				39.743%

Table A4.28: One-way Ancova of power at 1150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	306894.09	1	306894.09	37.892	0.0000	12.343%
Iso strength at 850 mm	8293.24	1	8293.24	1.024	0.3125	0.334%
Stature	7963.04	1	7963.04	0.983	0.3329	0.320%
Main Effects						
Gender	16990.483	1	16990.483	2.098	0.1487	0.683%
Residual	2146289.3	265	8099.205			
Total (Corrected)	2486430.2	269				13.680%

Table A4.29: One-way Ancova of power at 1250 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	72871.741	1	72871.741	6.064	0.0144	2.129%
Iso strength at 850 mm	31573.874	1	31573.874	2.628	0.1062	0.922%
Stature	98316.139	1	98316.139	8.182	0.0046	2.872%
Main Effects						
Gender	36381.179	1	36381.179	3.028	0.0830	1.063%
Residual	3184280.1	265	12016.151			
Total (Corrected)	3423423.1	269				6.985%

Table A4.30: One-way Ancova of power at 1350 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	170317.91	1	170317.91	9.885	0.0019	3.528%
Iso strength at 850 mm	2106.04	1	2106.04	0.122	0.7306	0.044%
Stature	51865.63	1	51865.63	3.01	0.0839	1.074%
Main Effects						
Gender	37875.052	1	37875.052	2.198	0.1394	0.784%
Residual	4565997.5	265	17230.179			
Total (Corrected)	4828162.2	269				5.430%

Table A4.31: One-way Ancova of power at 1450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	901077.25	1	901077.25	50.99	0.0000	16.045%
Iso strength at 850 mm	21872.38	1	21872.38	1.238	0.2669	0.389%
Stature	1117.36	1	1117.36	0.063	0.8043	0.020%
Main Effects						
Gender	8936.116	1	8936.116	0.506	0.4852	0.159%
Residual	4682990.4	265	17671.662			
Total (Corrected)	5615993.5	269				16.613%

Table A4.32: One-way Ancova of power at 1550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1727407	1	1727407	166.667	0.0000	37.714%
Iso strength at 850 mm	74091.5	1	74091.5	7.149	0.0080	1.618%
Stature	24066.2	1	24066.2	2.322	0.1287	0.525%
Main Effects						
Gender	8079.32	1	8079.32	0.78	0.3875	0.176%
Residual	2746576.6	265	10364.44			
Total (Corrected)	4580220.6	269				40.034%

Table A4.33: One-way Ancova of power at 1650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1401127.9	1	1401127.9	329.25	0.0000	54.242%
Iso strength at 850 mm	26141.1	1	26141.1	6.143	0.0138	1.012%
Stature	21218.8	1	21218.8	4.986	0.0264	0.821%
Main Effects						
Gender	6883.334	1	6883.334	1.618	0.2046	0.266%
Residual	1127711.8	265	4255.516			
Total (Corrected)	2583083	269				56.342%

Table A4.34: One-way Ancova of power at 1750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	528096.65	1	528096.65	331.741	0.0000	54.900%
Iso strength at 850 mm	7717.57	1	7717.57	4.848	0.0285	0.802%
Stature	4041.55	1	4041.55	2.539	0.1123	0.420%
Main Effects						
Gender	218.814	1	218.814	0.137	0.7151	0.023%
Residual	421851.75	265	1591.893			
Total (Corrected)	961926.33	269				56.145%

Table A4.35: One-way Ancova of power at 1850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	194828.45	1	194828.45	343.136	0.0000	56.517%
Iso strength at 850 mm	375.08	1	375.08	0.661	0.4258	0.109%
Stature	4.92	1	4.92	0.009	0.9269	0.001%
Main Effects						
Gender	191.281	1	191.281	0.337	0.5683	0.055%
Residual	149328.12	263	567.788			
Total (Corrected)	344727.85	267				56.682%

Table A4.36: One-way Ancova of power at 1950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	140453.76	1	140453.76	193.868	0.0000	43.205%
Iso strength at 850 mm	0.19	1	0.19	0	0.9874	0.000%
Stature	10.49	1	10.49	0.014	0.9056	0.003%
Main Effects						
Gender	2053.344	1	2053.344	2.834	0.0935	0.632%
Residual	182568.88	252	724.480			
Total (Corrected)	325086.65	256				43.840%

Table A4.37: One-way Ancova of power at 2050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	69384.114	1	69384.114	45.336	0.0000	19.286%
Iso strength at 850 mm	1364.347	1	1364.347	0.891	0.3564	0.379%
Stature	133.63	1	133.63	0.087	0.7711	0.037%
Main Effects						
Gender	4217.612	1	4217.612	2.756	0.0986	1.172%
Residual	284660.5	186	1530.433			
Total (Corrected)	359760.2	190				20.875%

Table A4.38: One-way Ancova of power at 2150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	6010.856	1	6010.856	3.201	0.0793	5.630%
Iso strength at 850 mm	858.429	1	858.429	0.457	0.5091	0.804%
Stature	0.158	1	0.158	0	0.9928	0.000%
Main Effects						
Gender	378.031	1	378.031	0.201	0.6603	0.354%
Residual	99522.457	53	1877.782			
Total (Corrected)	106769.93	57				6.788%

A4.1.3 Mean powers at fixed heights

Table A4.39: Least squares means for power before correction for covariates

mm	Gender	n	Mean (W)	Std. error	95% confidence interval	
450	male	201	586.43	15.46	555.98	616.88
550	male	201	635.19	10.80	613.92	656.47
650	male	201	711.33	11.75	688.20	734.47
750	male	201	682.46	12.27	658.31	706.62
850	male	201	523.69	11.31	501.43	545.95
950	male	201	353.71	8.84	336.29	371.12
1050	male	201	217.52	7.20	203.34	231.71
1150	male	201	164.39	6.40	151.78	177.00
1250	male	201	162.06	7.84	146.63	177.50
1350	male	201	196.70	9.27	178.45	214.95
1450	male	201	220.22	9.57	201.38	239.07
1550	male	201	218.59	7.86	203.11	234.07
1650	male	201	166.77	5.71	155.52	178.01
1750	male	201	116.40	3.41	109.68	123.11
1850	male	201	85.89	2.00	81.95	89.82
1950	male	199	81.07	2.09	76.96	85.18
2050	male	161	68.31	3.15	62.10	74.52
2150	male	55	46.76	5.80	35.14	58.38
450	female	69	308.16	26.39	256.19	360.13
550	female	69	393.81	18.44	357.50	430.12
650	female	69	403.83	20.05	364.34	443.31
750	female	69	307.28	20.93	266.05	348.50
850	female	69	188.06	19.30	150.06	226.06
950	female	69	116.07	15.09	86.35	145.80
1050	female	69	80.72	12.29	56.52	104.93
1150	female	69	90.90	10.93	69.38	112.42
1250	female	69	115.09	13.38	88.74	141.43
1350	female	69	133.86	15.82	102.71	165.00
1450	female	69	105.03	16.34	72.86	137.20
1550	female	69	62.42	13.41	36.00	88.84
1650	female	69	39.90	9.75	20.71	59.09
1750	female	69	35.55	5.82	24.09	47.01
1850	female	67	34.70	3.46	27.89	41.51

1950	female	58	32.95	3.87	25.33	40.56
2050	female	30	20.40	7.29	6.01	34.79
2150	female	3	13.33	24.83	-36.42	63.09

Table A4.40: Least squares means for power after correction for covariates

mm	Gender	n	Mean (W)	Std. error	95% confidence interval	
450	male	201	544.20	18.14	508.47	579.93
550	male	201	582.88	11.54	560.16	605.60
650	male	201	650.60	12.55	625.87	675.32
750	male	201	607.76	12.46	583.23	632.29
850	male	201	445.81	10.68	424.78	466.84
950	male	201	288.90	8.08	272.99	304.81
1050	male	201	182.20	7.93	166.59	197.81
1150	male	201	153.49	7.72	138.29	168.69
1250	male	201	161.59	9.40	143.07	180.10
1350	male	201	192.40	11.26	170.23	214.57
1450	male	201	196.50	11.40	174.04	218.95
1550	male	201	184.11	8.73	166.92	201.31
1650	male	201	129.33	5.59	118.31	140.35
1750	male	201	94.84	3.42	88.10	101.58
1850	male	201	73.91	2.03	69.92	77.90
1950	male	199	72.68	2.23	68.29	77.07
2050	male	161	63.90	3.40	57.20	70.60
2150	male	55	45.77	5.92	33.89	57.65
450	female	69	431.19	39.40	353.60	508.78
550	female	69	546.20	25.05	496.86	595.54
650	female	69	580.75	27.26	527.06	634.45
750	female	69	524.88	27.05	471.61	578.16
850	female	69	414.94	23.19	369.27	460.60
950	female	69	304.86	17.55	270.31	339.42
1050	female	69	183.61	17.21	149.72	217.51
1150	female	69	122.67	16.76	89.65	155.68
1250	female	69	116.48	20.42	76.27	156.69
1350	female	69	146.38	24.45	98.23	194.53
1450	female	69	174.14	24.76	125.38	222.91
1550	female	69	162.86	18.96	125.51	200.20
1650	female	69	148.95	12.15	125.02	172.88
1750	female	69	98.34	7.43	83.71	112.98
1850	female	67	70.64	4.47	61.83	79.44
1950	female	58	61.73	5.31	51.28	72.19
2050	female	30	44.07	10.46	23.43	64.71
2150	female	3	31.56	30.57	-29.76	92.88

A4.2 Variance accounted for by Anova and Ancova of work done to fixed heights

Table A4.41: Two way Anova of work done to 100 mm intervals

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	18844902	1	18844902	3867.551	0.0000	10.236%
Hand height (mm)	141745513	13	10903501	2237.732	0.0000	76.992%
Interactions						
Gender x Height	5233009.2	13	402539.17	82.613	0.0000	2.842%
Residual	18281873	3752	4872.57			
Total (Corrected)	184105297	3779				90.070%

Table A4.42: Two way Ancova of work done to 100 mm intervals

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	23549906	1	23549906	7129.024	0.0000	12.792%
Iso strength at 850 mm	671010	1	671010	203.128	0.0000	0.364%
Stature	53659	1	53659	16.244	0.0001	0.029%
Main Effects						
Gender	467811	1	467811	141.616	0.0000	0.254%
Hand height (mm)	141745513	13	10903501	3300.706	0.0000	76.992%
Interactions						
Gender x Height	5233009.2	13	402539.17	121.857	0.0000	2.842%
Residual	12384388	3749	3303.38			
Total (Corrected)	184105297	3779				93.273%

A4.2.1 One-way Anova of work done to fixed heights

Table A4.43: One-way Anova of work done to 450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	1326.962	1	1326.962	63.371	0.0000	19.124%
Residual	5611.812	268	20.940			
Total (Corrected)	6938.774	269				

Table A4.44: One-way Anova of work done to 550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	47910.331	1	47910.331	132.736	0.0000	33.123%
Residual	96733.165	268	360.945			
Total (Corrected)	144643.5	269				

Table A4.45: One-way Anova of work done to 650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	151565.26	1	151565.26	176.141	0.0000	39.659%
Residual	230607.71	268	860.477			
Total (Corrected)	382172.97	269				

Table A4.46: One-way Anova of work done to 750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	380429.78	1	380429.78	219.8	0.0000	45.059%
Residual	463855.19	268	1730.803			
Total (Corrected)	844284.97	269				

Table A4.47: One-way Anova of work done to 850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	784477.13	1	784477.13	276.687	0.0000	50.797%
Residual	759846.58	268	2835.248			
Total (Corrected)	1544323.7	269				

Table A4.48: One-way Anova of work done to 950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	1271686.9	1	1271686.9	322.34	0.0000	54.602%
Residual	1057305.2	268	3945.169			
Total (Corrected)	2328992.1	269				

Table A4.49: One-way Anova of work done to 1050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	1708611.3	1	1708611.3	356.142	0.0000	57.061%
Residual	1285745.3	268	4797.557			
Total (Corrected)	2994356.7	269				

Table A4.50: One-way Anova of work done to 1150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	1999666.4	1	1999666.4	379.917	0.0000	58.637%
Residual	1410597.9	268	5263.425			
Total (Corrected)	3410264.3	269				

Table A4.51: One-way Anova of work done to 1250 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2175792.2	1	2175792.2	385.947	0.0000	59.018%
Residual	1510860.4	268	5637.539			
Total (Corrected)	3686652.6	269				

Table A4.52: One-way Anova of work done to 1350 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2317408.6	1	2317408.6	378.336	0.0000	58.536%
Residual	1641570.4	268	6125.3			
Total (Corrected)	3958979	269				

Table A4.53: One-way Anova of work done to 1450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2557650	1	2557650	353.857	0.0000	56.903%
Residual	1937082	268	7227.9			
Total (Corrected)	4494731.9	269				

Table A4.54: One-way Anova of work done to 1550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3016708	1	3016708	352.331	0.0000	56.797%
Residual	2294652.7	268	8562.1			
Total (Corrected)	5311360.7	269				

Table A4.55: One-way Anova of work done to 1650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3586842.2	1	3586842.2	362.964	0.0000	57.525%
Residual	2648401.8	268	9882.1			
Total (Corrected)	6235243.9	269				

Table A4.56: One-way Anova of work done to 1750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	4077835.8	1	4077835.8	371.847	0.0000	58.115%
Residual	2939002.5	268	10966.4			
Total (Corrected)	7016838.3	269				

Table A4.57: One-way Anova of work done to 1850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	4278969.8	1	4278969.8	365.622	0.0000	57.886%
Residual	3113069.5	266	11703.3			
Total (Corrected)	7392039.3	267				

Table A4.58: One-way Anova of work done to 1950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3975274.9	1	3975274.9	320.631	0.0000	55.701%
Residual	3161565.6	255	12398.3			
Total (Corrected)	7136840.5	256				

Table A4.59: One-way Anova of work done to 2050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2440597.3	1	2440597.3	212.716	0.0000	52.952%
Residual	2168492.4	189	11473.5			
Total (Corrected)	4609089.8	190				

Table A4.60: One-way Anova of work done to 2150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	327316.3	1	327316.3	26.346	0.0000	31.994%
Residual	695724.8	56	12423.7			
Total (Corrected)	1023041.1	57				

A4.2.2 One-way Ancova of work done to fixed heights

Table A4.61: One-way Ancova of work done to 450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1187.7039	1	1187.704	57.363	0.0000	17.117%
Iso strength at 850 mm	45.798	1	45.798	2.212	0.1381	0.660%
Stature	14.4502	1	14.450	0.698	0.4132	0.208%
Main Effects						
Gender	204.018	1	204.018	9.854	0.0019	2.940%
Residual	5486.804	265	20.705			
Total (Corrected)	6938.7741	269				20.925%

Table A4.62: One-way Ancova of work done to 550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	55846.098	1	55846.098	181.015	0.0000	38.609%
Iso strength at 850 mm	3523.583	1	3523.583	11.421	0.0008	2.436%
Stature	1501.063	1	1501.063	4.865	0.0283	1.038%
Main Effects						
Gender	2015.942	1	2015.942	6.534	0.0111	1.394%
Residual	81756.811	265	308.517			
Total (Corrected)	144643.5	269				43.477%

Table A4.63: One-way Ancova of work done to 650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	182899.09	1	182899.09	267.87	0.0000	47.858%
Iso strength at 850 mm	7627.86	1	7627.86	11.172	0.0010	1.996%
Stature	5737.24	1	5737.24	8.403	0.0041	1.501%
Main Effects						
Gender	4969.16	1	4969.16	7.278	0.0074	1.300%
Residual	180939.6	265	682.79			
Total (Corrected)	382172.97	269				52.655%

Table A4.64: One-way Ancova of work done to 750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	457565.74	1	457565.74	347.109	0.0000	54.196%
Iso strength at 850 mm	16057.92	1	16057.92	12.182	0.0006	1.902%
Stature	8338.62	1	8338.62	6.326	0.0125	0.988%
Main Effects						
Gender	12995.08	1	12995.08	9.858	0.0019	1.539%
Residual	349327.61	265	1318.22			
Total (Corrected)	844284.97	269				58.624%

Table A4.65: One-way Ancova of work done to 850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	951138.55	1	951138.55	476.984	0.0000	61.589%
Iso strength at 850 mm	32572.94	1	32572.94	16.335	0.0001	2.109%
Stature	6925.3	1	6925.3	3.473	0.0635	0.448%
Main Effects						
Gender	25259.44	1	25259.44	12.667	0.0004	1.636%
Residual	528427.49	265	1994.07			
Total (Corrected)	1544323.7	269				65.783%

Table A4.66: One-way Ancova of work done to 950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	1587927.8	1	1587927.8	642.711	0.0000	68.181%
Iso strength at 850 mm	51864.6	1	51864.6	20.992	0.0000	2.227%
Stature	2852.8	1	2852.8	1.155	0.2836	0.122%
Main Effects						
Gender	31618.56	1	31618.6	12.798	0.0004	1.358%
Residual	654728.34	265	2470.7			
Total (Corrected)	2328992.1	269				71.888%

Table A4.67: One-way Ancova of work done to 1050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	2195905	1	2195905	824.737	0.0000	73.335%
Iso strength at 850 mm	59828.2	1	59828.2	22.47	0.0000	1.998%
Stature	1297.4	1	1297.4	0.487	0.4932	0.043%
Main Effects						
Gender	31750.3	1	31750.3	11.925	0.0006	1.060%
Residual	705575.8	265	2662.6			
Total (Corrected)	2994356.7	269				76.436%

Table A4.68: One-way Ancova of work done to 1150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	2568153.9	1	2568153.9	916.552	0.0000	75.307%
Iso strength at 850 mm	61034.5	1	61034.5	21.783	0.0000	1.790%
Stature	767.1	1	767.1	0.274	0.6068	0.022%
Main Effects						
Gender	37785.7	1	37785.7	13.485	0.0003	1.108%
Residual	742523.1	265	2802.0			
Total (Corrected)	3410264.3	269				78.227%

Table A4.69: One-way Ancova of work done to 1250 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	2752585	1	2752585	900.696	0.0000	74.664%
Iso strength at 850 mm	73197	1	73197	23.951	0.0000	1.985%
Stature	3005.4	1	3005.4	0.983	0.3328	0.082%
Main Effects						
Gender	48007.9	1	48007.9	15.709	0.0001	1.302%
Residual	809857.2	265	3056.1			
Total (Corrected)	3686652.6	269				78.033%

Table A4.70: One-way Ancova of work done to 1350 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	2874274.2	1	2874274.2	813.027	0.0000	72.601%
Iso strength at 850 mm	77717.5	1	77717.5	21.983	0.0000	1.963%
Stature	8216.6	1	8216.6	2.324	0.1286	0.208%
Main Effects						
Gender	61923.0	1	61923.0	17.516	0.0000	1.564%
Residual	936847.7	265	3535.3			
Total (Corrected)	3958979	269				76.336%

Table A4.71: One-way Ancova of work done to 1450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	3168363.1	1	3168363.1	723.262	0.0000	70.491%
Iso strength at 850 mm	86034	1	86034	19.64	0.0000	1.914%
Stature	10384.1	1	10384.1	2.37	0.1248	0.231%
Main Effects						
Gender	69076.9	1	69076.9	15.769	0.0001	1.537%
Residual	1160873.8	265	4380.7			
Total (Corrected)	4494731.9	269				74.173%

Table A4.72: One-way Ancova of work done to 1550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	3746138.9	1	3746138.9	722.884	0.0000	70.531%
Iso strength at 850 mm	103823	1	103823	20.035	0.0000	1.955%
Stature	8436.6	1	8436.6	1.628	0.2031	0.159%
Main Effects						
Gender	79676.67	1	79676.7	15.375	0.0001	1.500%
Residual	1373285.6	265	5182.2			
Total (Corrected)	5311360.7	269				74.144%

Table A4.73: One-way Ancova of work done to 1650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	4496442.4	1	4496442.4	781.449	0.0000	72.113%
Iso strength at 850 mm	122813.6	1	122813.6	21.344	0.0000	1.970%
Stature	4448.7	1	4448.7	0.773	0.3894	0.071%
Main Effects						
Gender	86735.3	1	86735.3	15.074	0.0001	1.391%
Residual	1524803.9	265	5754.0			
Total (Corrected)	6235243.9	269				75.545%

Table A4.74: One-way Ancova of work done to 1750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	5164250.4	1	5164250.4	842.585	0.0000	73.598%
Iso strength at 850 mm	136624.2	1	136624.2	22.291	0.0000	1.947%
Stature	2587.2	1	2587.2	0.422	0.5234	0.037%
Main Effects						
Gender	89176.9	1	89176.9	14.55	0.0002	1.271%
Residual	1624199.5	265	6129.1			
Total (Corrected)	7016838.3	269				76.853%

Table A4.75: One-way Ancova of work done to 1850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	5468070.2	1	5468070.2	852.748	0.0000	73.972%
Iso strength at 850 mm	141039.8	1	141039.8	21.995	0.0000	1.908%
Stature	2230.1	1	2230.1	0.348	0.5622	0.030%
Main Effects						
Gender	94265.3	1	94265.3	14.701	0.0002	1.275%
Residual	1686433.9	263	6412.3			
Total (Corrected)	7392039.3	267				77.186%

Table A4.76: One-way Ancova of work done to 1950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	5217366	1	5217366	785.72	0.0000	73.105%
Iso strength at 850 mm	148577.3	1	148577.3	22.375	0.0000	2.082%
Stature	2753	1	2753	0.415	0.5271	0.039%
Main Effects						
Gender	94805.0	1	94805.0	14.277	0.0002	1.328%
Residual	1673339.1	252	6640.2			
Total (Corrected)	7136840.5	256				76.554%

Table A4.77: One-way Ancova of work done to 2050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	3092291.7	1	3092291.7	455.496	0.0000	67.091%
Iso strength at 850 mm	131641.9	1	131641.9	19.391	0.0000	2.856%
Stature	4055.5	1	4055.5	0.597	0.4488	0.088%
Main Effects						
Gender	118375.4	1	118375.4	17.437	0.0000	2.568%
Residual	1262725.3	186	6788.8			
Total (Corrected)	4609089.8	190				72.604%

Table A4.78: One-way Ancova of work done to 2150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	513094.46	1	513094.46	62.378	0.0000	50.154%
Iso strength at 850 mm	27711.53	1	27711.53	3.369	0.0720	2.709%
Stature	9157.24	1	9157.24	1.113	0.2962	0.895%
Main Effects						
Gender	37125.88	1	37125.88	4.514	0.0383	3.629%
Residual	435952	53	8225.51			
Total (Corrected)	1023041.1	57				57.387%

A4.2.3 Mean work done to fixed heights

Table A4.79: Least squares means for work before correction for covariates

mm	Gender	n	Mean (J)	Standard error	95% confidence interval	
450	male	201	20.85	0.32	20.22	21.49
550	male	201	102.31	1.34	99.67	104.95
650	male	201	188.87	2.07	184.80	192.95
750	male	201	279.20	2.93	273.43	284.98
850	male	201	361.86	3.76	354.46	369.25
950	male	201	427.36	4.43	418.63	436.08
1050	male	201	476.16	4.89	466.54	485.79
1150	male	201	512.19	5.12	502.11	522.27
1250	male	201	544.64	5.30	534.21	555.07
1350	male	201	579.07	5.52	568.20	589.94
1450	male	201	618.04	5.60	606.23	629.85
1550	male	201	658.75	6.53	645.89	671.60
1650	male	201	696.47	7.01	682.66	710.28
1750	male	201	727.10	7.39	712.56	741.65
1850	male	201	752.24	7.63	737.22	767.27
1950	male	199	776.41	7.89	760.86	791.96
2050	male	161	809.40	8.44	792.74	826.05
2150	male	55	834.20	15.03	804.09	864.31
450	female	69	15.77	0.55	14.68	16.85
550	female	69	71.77	2.29	67.26	76.27
650	female	69	134.55	3.53	127.60	141.51
750	female	69	193.14	5.01	183.28	203.01
850	female	69	238.28	6.41	225.65	250.90
950	female	69	270.01	7.56	255.12	284.91
1050	female	69	293.78	8.34	277.36	310.20
1150	female	69	314.88	8.73	297.68	332.08
1250	female	69	338.83	9.04	321.03	356.63
1350	female	69	366.67	9.42	348.11	385.22
1450	female	69	394.90	10.23	374.74	415.05
1550	female	69	416.41	11.14	394.47	438.34
1650	female	69	432.22	11.97	408.65	455.78
1750	female	69	445.35	12.61	420.52	470.17
1850	female	67	460.43	13.22	434.40	486.46
1950	female	58	478.90	14.62	450.10	507.70
2050	female	30	498.73	19.56	460.15	537.32
2150	female	3	495.00	64.35	366.06	623.94

Table A4.80: Least squares means for work after correction for covariates

mm	Gender	n	Mean (J)	Std. error	95% confidence interval	
450	male	201	20.42	0.39	19.65	21.18
550	male	201	97.22	1.51	94.25	100.18
650	male	201	179.25	2.24	174.84	183.66
750	male	201	264.10	3.11	257.97	270.23
850	male	201	339.88	3.83	332.34	347.42
950	male	201	397.89	4.26	389.50	406.29
1050	male	201	440.32	4.43	431.61	449.04
1150	male	201	473.51	4.54	464.57	482.45
1250	male	201	505.28	4.74	495.94	514.62
1350	male	201	539.83	5.10	529.78	549.87
1450	male	201	576.90	5.68	565.72	588.08
1550	male	201	613.87	6.17	601.71	626.03
1650	male	201	646.73	6.51	633.92	659.55
1750	male	201	673.15	6.71	659.92	686.37
1850	male	201	697.44	6.81	684.04	710.85
1950	male	199	726.05	6.75	712.76	739.35
2050	male	161	777.10	7.15	762.99	791.22
2150	male	55	823.94	12.39	799.08	848.80
450	female	69	17.04	0.85	15.37	18.71
550	female	69	86.60	3.27	80.16	93.04
650	female	69	162.58	4.87	152.99	172.16
750	female	69	237.14	6.76	223.83	250.46
850	female	69	302.30	8.32	285.92	318.68
950	female	69	355.85	9.26	337.61	374.08
1050	female	69	398.19	9.61	379.26	417.12
1150	female	69	427.55	9.86	408.13	446.96
1250	female	69	453.47	10.30	433.19	473.75
1350	female	69	480.98	11.07	459.17	502.79
1450	female	69	514.75	12.33	490.47	539.03
1550	female	69	547.13	13.41	520.72	573.53
1650	female	69	577.09	14.13	549.27	604.92
1750	female	69	602.53	14.58	573.81	631.25
1850	female	67	624.83	15.02	595.25	654.42
1950	female	58	651.67	16.07	620.02	683.33
2050	female	30	672.04	22.03	628.57	715.51
2150	female	3	683.12	63.97	554.78	811.46

A4.3 Variance accounted for by Anova and Ancova of impulse to fixed heights

Table A4.81: Two way Anova of impulse to 100 mm intervals

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	11134209	1	11134209	4631.111	0.0000	2.481%
Hand height (mm)	424719035	13	32670695	13588.896	0.0000	94.624%
Interactions						
Gender x Height	3976401.9	13	305877.07	127.225	0.0000	0.886%
Residual	9020633.1	3752	2404.22			
Total (Corrected)	448850279	3779				97.991%

Table A4.82: Two way Ancova of impulse to 100 mm intervals

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	12866455	1	12866455	7465.128	0.0000	2.867%
Iso strength at 850 mm	291359	1	291359	169.047	0.0000	0.065%
Stature	8113	1	8113	4.707	0.0301	0.002%
Main Effects						
Gender	527358	1	527358	305.974	0.0000	0.117%
Hand height (mm)	424719035	13	32670695	18955.563	0.0000	94.624%
Interactions						
Gender x Height	3976401.9	13	305877.07	177.47	0.0000	0.886%
Residual	6461556.1	3749	1723.54			
Total (Corrected)	448850279	3779				98.560%

A4.3.1 One-way Anova of impulse to fixed heights

Table A4.83: One-way Anova of impulse to 450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	1.184	1	1.184	0.26	0.616	0.097%
Residual	1222.016	268	4.560			
Total (Corrected)	1223.2	269				

Table A4.84: One-way Anova of impulse to 550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	14875.961	1	14875.961	131.815	0.0000	32.969%
Residual	30245.036	268	112.855			
Total (Corrected)	45120.996	269				

Table A4.85: One-way Anova of impulse to 650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	52777.395	1	52777.395	200.947	0.0000	42.851%
Residual	70388.591	268	262.644			
Total (Corrected)	123165.99	269				

Table A4.86: One-way Anova of impulse to 750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	140253.08	1	140253.08	265.045	0.0000	49.723%
Residual	141816.64	268	529.167			
Total (Corrected)	282069.72	269				

Table A4.87: One-way Anova of impulse to 850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	335937.57	1	335937.57	358.394	0.0000	57.215%
Residual	251207.8	268	937.34			
Total (Corrected)	587145.37	269				

Table A4.88: One-way Anova of impulse to 950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	630200.43	1	630200.43	423.914	0.0000	61.267%
Residual	398414.85	268	1486.62			
Total (Corrected)	1028615.3	269				

Table A4.89: One-way Anova of impulse to 1050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	953511.2	1	953511.19	465.288	0.0000	63.452%
Residual	549210.9	268	2049.30			
Total (Corrected)	1502722.1	269				

Table A4.90: One-way Anova of impulse to 1150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	1187920.8	1	1187920.8	486.357	0.0000	64.473%
Residual	654586.7	268	2442.5			
Total (Corrected)	1842507.5	269				

Table A4.91: One-way Anova of impulse to 1250 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	1330777.8	1	1330777.8	482.501	0.0000	64.291%
Residual	739166.1	268	2758.1			
Total (Corrected)	2069943.9	269				

Table A4.92: One-way Anova of impulse to 1350 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	1436037	1	1436037	470.276	0.0000	63.699%
Residual	818365.9	268	3053.6			
Total (Corrected)	2254402.9	269				

Table A4.93: One-way Anova of impulse to 1450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	1601762.4	1	1601762.4	431.756	0.0000	61.701%
Residual	994246.6	268	3709.9			
Total (Corrected)	2596009	269				

Table A4.94: One-way Anova of impulse to 1550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	1959822.7	1	1959822.7	428.918	0.0000	61.545%
Residual	1224551.2	268	4569.2			
Total (Corrected)	3184373.9	269				

Table A4.95: One-way Anova of impulse to 1650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	2468860.4	1	2468860.4	453.464	0.0000	62.853%
Residual	1459110.7	268	5444.4			
Total (Corrected)	3927971.1	269				

Table A4.96: One-way Anova of impulse to 1750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	2997872.7	1	2997872.7	475.937	0.0000	63.975%
Residual	1688100	268	6298.9			
Total (Corrected)	4685972.7	269				

Table A4.97: One-way Anova of impulse to 1850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	3317805.9	1	3317805.9	477.032	0.0000	64.201%
Residual	1850058.6	266	6955.1			
Total (Corrected)	5167864.4	267				

Table A4.98: One-way Anova of impulse to 1950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	3249417.4	1	3249417.4	428.48	0.0000	62.691%
Residual	1933816	255	7583.6			
Total (Corrected)	5183233.4	256				

Table A4.99: One-way Anova of impulse to 2050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	2108869	1	2108869	317.153	0.0000	62.660%
Residual	1256730.5	189	6649.4			
Total (Corrected)	3365599.5	190				

Table A4.100: One-way Anova of impulse to 2150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	277282.04	1	277282.04	47.323	0.0000	45.801%
Residual	328122.8	56	5859.34			
Total (Corrected)	605404.84	57				

A4.3.2 One-way Ancova of impulse to fixed heights

Table A4.101: One-way Ancova of impulse to 450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	23.242	1	23.242	5.262	0.0226	1.900%
Iso strength at 850 mm	5.408	1	5.408	1.224	0.2695	0.442%
Stature	0.588	1	0.588	0.133	0.7195	0.048%
Main Effects						
Gender	23.393	1	23.393	5.296	0.0222	1.912%
Residual	1170.570	265	4.417			
Total (Corrected)	1223.2	269				4.303%

Table A4.102: One-way Ancova of impulse to 550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	15090.033	1	15090.033	144.547	0.0000	33.443%
Iso strength at 850 mm	719.727	1	719.727	6.894	0.0092	1.595%
Stature	245.501	1	245.501	2.352	0.1263	0.544%
Main Effects						
Gender	1400.975	1	1400.975	13.42	0.0003	3.105%
Residual	27664.761	265	104.395			
Total (Corrected)	45120.996	269				38.688%

Table A4.103: One-way Ancova of impulse to 650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	57435.587	1	57435.587	259.158	0.0000	46.633%
Iso strength at 850 mm	2062.047	1	2062.047	9.304	0.0025	1.674%
Stature	1420.957	1	1420.957	6.412	0.0119	1.154%
Main Effects						
Gender	3517.105	1	3517.105	15.87	0.0001	2.856%
Residual	58730.289	265	221.624			
Total (Corrected)	123165.99	269				52.316%

Table A4.104: One-way Ancova of impulse to 750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	152869.93	1	152869.93	357.425	0.0000	54.196%
Iso strength at 850 mm	4495.67	1	4495.67	10.511	0.0013	1.594%
Stature	2008.03	1	2008.03	4.695	0.0311	0.712%
Main Effects						
Gender	9356.10	1	9356.10	21.875	0.0000	3.317%
Residual	113339.99	265	427.70			
Total (Corrected)	282069.72	269				59.818%

Table A4.105: One-way Ancova of impulse to 850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	364707.99	1	364707.99	516.393	0.0000	62.115%
Iso strength at 850 mm	10773.79	1	10773.79	15.255	0.0001	1.835%
Stature	1501.91	1	1501.91	2.127	0.1459	0.256%
Main Effects						
Gender	23002.61	1	23002.61	32.57	0.0000	3.918%
Residual	187159.06	265	706.26			
Total (Corrected)	587145.37	269				68.124%

Table A4.106: One-way Ancova of impulse to 950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	711907.25	1	711907.25	722.76	0.0000	69.210%
Iso strength at 850 mm	21241.12	1	21241.12	21.565	0.0000	2.065%
Stature	92.96	1	92.96	0.094	0.7622	0.009%
Main Effects						
Gender	34353.24	1	34353.24	34.877	0.0000	3.340%
Residual	261020.71	265	984.98			
Total (Corrected)	1028615.3	269				74.624%

Table A4.107: One-way Ancova of impulse to 1050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1130573	1	1130573	970.513	0.0000	75.235%
Iso strength at 850 mm	25736.3	1	25736.3	22.093	0.0000	1.713%
Stature	14.6	1	14.6	0.013	0.9121	0.001%
Main Effects						
Gender	37693.69	1	37693.69	32.357	0.0000	2.508%
Residual	308704.52	265	1164.92			
Total (Corrected)	1502722.1	269				79.457%

Table A4.108: One-way Ancova of impulse to 1150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1418121	1	1418121	1058.826	0.0000	76.967%
Iso strength at 850 mm	24278	1	24278	18.127	0.0000	1.318%
Stature	148.1	1	148.1	0.111	0.7433	0.008%
Main Effects						
Gender	45036.913	1	45036.913	33.626	0.0000	2.444%
Residual	354923.39	265	1339.3336			
Total (Corrected)	1842507.5	269				80.737%

Table A4.109: One-way Ancova of impulse to 1250 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1568273	1	1568273	1003.9	0.0000	75.764%
Iso strength at 850 mm	32396.9	1	32396.9	20.738	0.0000	1.565%
Stature	155.1	1	155.1	0.099	0.7563	0.007%
Main Effects						
Gender	55141.066	1	55141.066	35.298	0.0000	2.664%
Residual	413977.82	265	1562.1805			
Total (Corrected)	2069943.9	269				80.001%

Table A4.110: One-way Ancova of impulse to 1350 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1652521.7	1	1652521.7	885.013	0.0000	73.302%
Iso strength at 850 mm	34691.7	1	34691.7	18.579	0.0000	1.539%
Stature	2348.2	1	2348.2	1.258	0.2631	0.104%
Main Effects						
Gender	70025.506	1	70025.506	37.502	0.0000	3.106%
Residual	494815.81	265	1867.2295			
Total (Corrected)	2254402.9	269				78.051%

Table A4.111: One-way Ancova of impulse to 1450 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1844742.2	1	1844742.2	774.989	0.0000	71.061%
Iso strength at 850 mm	39168.3	1	39168.3	16.455	0.0001	1.509%
Stature	3710.5	1	3710.5	1.559	0.2129	0.143%
Main Effects						
Gender	77596.194	1	77596.194	32.599	0.0000	2.989%
Residual	630791.85	265	2380.3466			
Total (Corrected)	2596009	269				75.701%

Table A4.112: One-way Ancova of impulse to 1550 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	2262638	1	2262638	773.916	0.0000	71.054%
Iso strength at 850 mm	50956.2	1	50956.2	17.429	0.0000	1.600%
Stature	2688.3	1	2688.3	0.92	0.3487	0.084%
Main Effects						
Gender	93331.066	1	93331.066	31.923	0.0000	2.931%
Residual	774760.35	265	2923.624			
Total (Corrected)	3184373.9	269				75.670%

Table A4.113: One-way Ancova of impulse to 1650 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	2871950.9	1	2871950.9	865.112	0.0000	73.115%
Iso strength at 850 mm	63747.2	1	63747.2	19.202	0.0000	1.623%
Stature	624.4	1	624.4	0.188	0.6695	0.016%
Main Effects						
Gender	111916.3	1	111916.3	33.712	0.0000	2.849%
Residual	879732.27	265	3319.7444			
Total (Corrected)	3927971.1	269				77.603%

Table A4.114: One-way Ancova of impulse to 1750 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	3518995.1	1	3518995.1	967.573	0.0000	75.096%
Iso strength at 850 mm	75373.8	1	75373.8	20.725	0.0000	1.608%
Stature	49.2	1	49.2	0.014	0.9088	0.001%
Main Effects						
Gender	127768.09	1	127768.09	35.131	0.0000	2.727%
Residual	963786.55	265	3636.9304			
Total (Corrected)	4685972.7	269				79.433%

Table A4.115: One-way Ancova of impulse to 1850 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	3918236.5	1	3918236.5	1004.265	0.0000	75.819%
Iso strength at 850 mm	79172.1	1	79172.1	20.292	0.0000	1.532%
Stature	15.5	1	15.5	0.004	0.9504	0.000%
Main Effects						
Gender	144320.22	1	144320.22	36.99	0.0000	2.793%
Residual	1026120.1	263	3901.5972			
Total (Corrected)	5167864.4	267				80.144%

Table A4.116: One-way Ancova of impulse to 1950 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	3889372.5	1	3889372.5	936.155	0.0000	75.038%
Iso strength at 850 mm	87238.2	1	87238.2	20.998	0.0000	1.683%
Stature	6.8	1	6.8	0.002	0.9682	0.000%
Main Effects						
Gender	159650.33	1	159650.33	38.427	0.0000	3.080%
Residual	1046965.5	252	4154.6251			
Total (Corrected)	5183233.4	256				79.801%

Table A4.117: One-way Ancova of impulse to 2050 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	2352094.2	1	2352094.2	579.039	0.0000	69.886%
Iso strength at 850 mm	65467.5	1	65467.5	16.117	0.0001	1.945%
Stature	533.3	1	533.3	0.131	0.7214	0.016%
Main Effects						
Gender	191960.87	1	191960.87	47.257	0.0000	5.704%
Residual	755543.69	186	4062.0629			
Total (Corrected)	3365599.5	190				77.551%

Table A4.118: One-way Ancova of impulse to 2150 mm

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	335995.19	1	335995.19	88.171	0.0000	55.499%
Iso strength at 850 mm	10623.53	1	10623.53	2.788	0.1009	1.755%
Stature	1724.14	1	1724.14	0.452	0.5113	0.285%
Main Effects						
Gender	55093.432	1	55093.432	14.457	0.0004	9.100%
Residual	201968.55	53	3810.7274			
Total (Corrected)	605404.84	57				66.639%

A4.3.3 Mean impulses to fixed heights

Table A4.119: Least squares means for impulse before correction for covariates

mm	Gender	n	Mean (N·s)	Std. error	95% confidence interval	
450	male	201	28.76	0.15	28.46	29.06
550	male	201	134.95	0.75	133.47	136.42
650	male	201	247.20	1.14	244.95	249.45
750	male	201	363.08	1.62	359.88	366.27
850	male	201	477.19	2.16	472.94	481.44
950	male	201	577.36	2.72	572.00	582.71
1050	male	201	664.64	3.19	658.35	670.92
1150	male	201	739.36	3.49	732.50	746.23
1250	male	201	810.04	3.70	802.75	817.34
1350	male	201	881.48	3.90	873.80	889.15
1450	male	201	958.41	4.30	949.95	966.87
1550	male	201	1036.53	4.77	1027.14	1045.92
1650	male	201	1110.57	5.20	1100.32	1120.82
1750	male	201	1180.44	5.60	1169.41	1191.46
1850	male	201	1245.90	5.88	1234.31	1257.48
1950	male	199	1310.26	6.17	1298.10	1322.42
2050	male	161	1379.45	6.43	1366.77	1392.13
2150	male	55	1439.20	10.32	1418.52	1459.88
450	female	69	28.91	0.26	28.41	29.42
550	female	69	117.93	1.28	115.41	120.45
650	female	69	215.14	1.95	211.30	218.99
750	female	69	310.83	2.77	305.37	316.28
850	female	69	396.32	3.69	389.06	403.58
950	female	69	466.59	4.64	457.45	475.74
1050	female	69	528.39	5.45	517.66	539.12
1150	female	69	587.29	5.95	575.57	599.01
1250	female	69	649.09	6.32	636.64	661.54
1350	female	69	714.28	6.65	701.17	727.38
1450	female	69	781.83	7.33	767.39	796.27
1550	female	69	841.20	8.14	825.18	857.23
1650	female	69	891.33	8.88	873.84	908.83
1750	female	69	938.86	9.55	920.04	957.67
1850	female	67	988.94	10.19	968.88	1009.01
1950	female	58	1041.28	11.43	1018.75	1063.80
2050	female	30	1090.67	14.89	1061.29	1120.04
2150	female	3	1127.00	44.19	1038.45	1215.55

Table A4.120: Least squares means for impulse after correction for covariates

mm	Gender	n	Mean (N·s)	Std. error	95% confidence interval	
450	male	201	29.09	0.18	28.74	29.45
550	male	201	132.86	0.88	131.13	134.58
650	male	201	242.59	1.28	240.08	245.11
750	male	201	355.57	1.77	352.08	359.06
850	male	201	465.69	2.28	461.20	470.18
950	male	201	560.25	2.69	554.95	565.55
1050	male	201	641.55	2.93	635.79	647.32
1150	male	201	713.32	3.14	707.14	719.51
1250	male	201	783.10	3.39	776.43	789.78
1350	male	201	854.74	3.71	847.44	862.04
1450	male	201	930.12	4.18	921.88	938.36
1550	male	201	1005.08	4.64	995.94	1014.21
1650	male	201	1074.76	4.94	1065.03	1084.49
1750	male	201	1140.30	5.17	1130.11	1150.49
1850	male	201	1204.12	5.31	1193.66	1214.58
1950	male	199	1271.34	5.34	1260.82	1281.86
2050	male	161	1355.10	5.53	1344.19	1366.02
2150	male	55	1431.92	8.43	1415.00	1448.85
450	female	69	27.95	0.39	27.18	28.72
550	female	69	124.01	1.90	120.26	127.76
650	female	69	228.57	2.77	223.11	234.03
750	female	69	332.70	3.85	325.11	340.28
850	female	69	429.82	4.95	420.08	439.57
950	female	69	516.42	5.85	504.91	527.94
1050	female	69	595.64	6.36	583.12	608.16
1150	female	69	663.14	6.82	649.72	676.57
1250	female	69	727.57	7.36	713.08	742.07
1350	female	69	792.17	8.05	776.31	808.02
1450	female	69	864.25	9.09	846.35	882.15
1550	female	69	932.84	10.07	913.00	952.67
1650	female	69	995.65	10.73	974.52	1016.78
1750	female	69	1055.78	11.23	1033.66	1077.90
1850	female	67	1114.27	11.72	1091.20	1137.35
1950	female	58	1174.82	12.71	1149.78	1199.85
2050	female	30	1221.31	17.04	1187.69	1254.94
2150	female	3	1260.38	43.54	1173.03	1347.74

APPENDIX 5

ANALYSES OF POWER, WORK AND IMPULSE AT RELATIVE HAND HEIGHTS

In all the following tables there were no missing values; all F ratios were calculated using the residual mean square error; R^2 values were calculated by dividing individual sums of squares by the total sum of squares; Total R^2 is the total proportion of variance accounted for by the model, excluding the residual variance.

A5.1 Variance accounted for by Anova and Ancova of power at relative hand heights

Table A5.1: Two way Anova of power at 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	19696170	1	19696170	1287.164	0.0000	8.325%
Hand height	148472492	14	10605178	693.058	0.0000	62.757%
Interactions						
Gender x Height	6900847.7	14	492917.7	32.213	0.0000	2.917%
Residual	61514021	4020	15302.0			
Total (Corrected)	236583531	4049				73.999%

Table A5.2: Two way Ancova of power at 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	25616997	1	25616997	1907.761	0.0000	10.828%
Iso strength at 850 mm	613876	1	613876	45.717	0.0000	0.259%
Stature	728595	1	728595	54.26	0.0000	0.308%
Main Effects						
Gender	311319	1	311319	23.185	0.0000	0.132%
Hand height	148472492	14	10605178	789.794	0.0000	62.757%
Interactions						
Gender x Height	6900847.7	14	492917.7	36.709	0.0000	2.917%
Residual	53939403	4017	13427.8			
Total (Corrected)	236583530	4049				77.201%

A5.1.1 One-way Anova of power at relative hand heights

Table A5.3: One-way Anova of power at 25% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	5188048.9	1	5188048.9	88.176	0.0000	26.545%
Residual	14356363	244	58837.6			
Total (Corrected)	19544412	245				

Table A5.4: One-way Anova of power at 30% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3981871.1	1	3981871.1	146.864	0.0000	35.401%
Residual	7266182.8	268	27112.6			
Total (Corrected)	11248054	269				

Table A5.5: One-way Anova of power at 35% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	4011388.8	1	4011388.8	161.207	0.0000	37.559%
Residual	6668786.7	268	24883.5			
Total (Corrected)	10680175	269				

Table A5.6: One-way Anova of power at 40% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	5112402.3	1	5112402.3	169.552	0.0000	38.750%
Residual	8080844.8	268	30152.4			
Total (Corrected)	13193247	269				

Table A5.7: One-way Anova of power at 45% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	4816843.8	1	4816843.8	184.881	0.0000	40.823%
Residual	6982411	268	26053.8			
Total (Corrected)	11799255	269				

Table A5.8: One-way Anova of power at 50% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3374010.4	1	3374010.4	198.684	0.0000	42.574%
Residual	4551127.8	268	16981.8			
Total (Corrected)	7925138.2	269				

Table A5.9: One-way Anova of power at 55% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	1631047.6	1	1631047.6	155.228	0.0000	36.677%
Residual	2815989.8	268	10507.4			
Total (Corrected)	4447037.4	269				

Table A5.10: One-way Anova of power at 60% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	552470.86	1	552470.9	61.998	0.0000	18.787%
Residual	2388188.9	268	8911.2			
Total (Corrected)	2940659.8	269				

Table A5.11: One-way Anova of power at 65% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	286711.8	1	286711.8	38.261	0.0000	12.493%
Residual	2008279.6	268	7493.6			
Total (Corrected)	2294991.4	269				

Table A5.12: One-way Anova of power at 70% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	180517.19	1	180517.2	18.48	0.0000	6.451%
Residual	2617935.9	268	9768.4			
Total (Corrected)	2798453.1	269				

Table A5.13: One-way Anova of power at 75% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	350905.31	1	350905.3	22.79	0.0000	7.837%
Residual	4126421.7	268	15397.1			
Total (Corrected)	4477327	269				

Table A5.14: One-way Anova of power at 80% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	361756.59	1	361756.6	17.426	0.0000	6.105%
Residual	5563503.4	268	20759.3			
Total (Corrected)	5925260	269				

Table A5.15: One-way Anova of power at 85% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	576101.06	1	576101.1	31.634	0.0000	10.557%
Residual	4880727.5	268	18211.7			
Total (Corrected)	5456828.5	269				

Table A5.16: One-way Anova of power at 90% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	725928.52	1	725928.5	80.737	0.0000	23.151%
Residual	2409670.5	268	8991.3			
Total (Corrected)	3135599	269				

Table A5.17: One-way Anova of power at 95% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	419764.16	1	419764.2	133.685	0.0000	33.281%
Residual	841505.28	268	3139.9			
Total (Corrected)	1261269.4	269				

Table A5.18: One-way Anova of power at 100% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	215298.61	1	215298.61	184.672	0.0000	40.796%
Residual	312445.26	268	1165.84			
Total (Corrected)	527743.87	269				

Table A5.19: One-way Anova of power at 105% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	127384	1	127384	192.943	0.0000	41.949%
Residual	176277.16	267	660.21			
Total (Corrected)	303661.17	268				

Table A5.20: One-way Anova of power at 110% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	78534.75	1	78534.75	93.832	0.0000	26.222%
Residual	220961.44	264	836.98			
Total (Corrected)	299496.2	265				

Table A5.21: One-way Anova of power at 115% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	79839.472	1	79839.472	78.876	0.0000	25.291%
Residual	235845.15	233	1012.211			
Total (Corrected)	315684.62	234				

Table A5.22: One-way Anova of power at 120% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	33618.79	1	33618.79	27.642	0.0000	13.574%
Residual	214051.96	176	1216.204			
Total (Corrected)	247670.75	177				

Table A5.23: One-way Anova of power at 125% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3.147	1	3.147	0.01	0.9222	0.020%
Residual	15567.676	49	317.708			
Total (Corrected)	15570.824	50				

A5.1.2 One-way Ancova of power at relative hand heights

Table A5.24: One-way Ancova of power at 25% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	7509186.9	1	7509186.9	180.314	0.0000	38.421%
Iso strength at 850 mm	489419.5	1	489419.5	11.752	0.0007	2.504%
Stature	1401177.1	1	1401177.1	33.646	0.0000	7.169%
Main Effects						
Gender	108151.3	1	108151.34	2.597	0.1084	0.553%
Residual	10036477	241	41645.13			
Total (Corrected)	19544412	245				48.648%

Table A5.25: One-way Ancova of power at 30% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	5465015.5	1	5465015.5	266.178	0.0000	48.586%
Iso strength at 850 mm	200983.7	1	200983.7	9.789	0.0020	1.787%
Stature	114798.9	1	114798.9	5.591	0.0188	1.021%
Main Effects						
Gender	26427.225	1	26427.225	1.287	0.2576	0.235%
Residual	5440828.6	265	20531.429			
Total (Corrected)	11248054	269				51.629%

Table A5.26: One-way Ancova of power at 35% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	5658601.1	1	5658601.1	311.695	0.0000	52.982%
Iso strength at 850 mm	110433.6	1	110433.6	6.083	0.0143	1.034%
Stature	84818	1	84818	4.672	0.0316	0.794%
Main Effects						
Gender	15434.695	1	15434.695	0.85	0.3672	0.145%
Residual	4810888	265	18154.294			
Total (Corrected)	10680175	269				54.955%

Table A5.27: One-way Ancova of power at 40% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	6717834.8	1	6717834.8	294.761	0.0000	50.919%
Iso strength at 850 mm	210328.7	1	210328.7	9.229	0.0026	1.594%
Stature	155775.5	1	155775.5	6.835	0.0095	1.181%
Main Effects						
Gender	69748.173	1	69748.173	3.06	0.0814	0.529%
Residual	6039559.9	265	22790.792			
Total (Corrected)	13193247	269				54.222%

Table A5.28: One-way Ancova of power at 45% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	5857105.8	1	5857105.8	289.959	0.0000	49.640%
Iso strength at 850 mm	174820.3	1	174820.3	8.655	0.0036	1.482%
Stature	264662.1	1	264662.1	13.102	0.0004	2.243%
Main Effects						
Gender	149720.13	1	149720.13	7.412	0.0069	1.269%
Residual	5352946.5	265	20199.798			
Total (Corrected)	11799255	269				54.633%

Table A5.29: One-way Ancova of power at 50% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	4390867.5	1	4390867.5	357.554	0.0000	55.404%
Iso strength at 850 mm	94672.1	1	94672.1	7.709	0.0059	1.195%
Stature	132119.7	1	132119.7	10.759	0.0012	1.667%
Main Effects						
Gender	53203.235	1	53203.235	4.332	0.0384	0.671%
Residual	3254275.6	265	12280.285			
Total (Corrected)	7925138.2	269				58.937%

Table A5.30: One-way Ancova of power at 55% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	2140253.7	1	2140253.7	258.891	0.0000	48.128%
Iso strength at 850 mm	27330.3	1	27330.3	3.306	0.0702	0.615%
Stature	64955.4	1	64955.4	7.857	0.0054	1.461%
Main Effects						
Gender	23743.954	1	23743.954	2.872	0.0913	0.534%
Residual	2190754	265	8266.996			
Total (Corrected)	4447037.4	269				50.737%

Table A5.31: One-way Ancova of power at 60% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	682726.62	1	682726.62	82.632	0.0000	23.217%
Iso strength at 850 mm	471.42	1	471.42	0.057	0.8139	0.016%
Stature	52002.69	1	52002.69	6.294	0.0127	1.768%
Main Effects						
Gender	15956.371	1	15956.371	1.931	0.1658	0.543%
Residual	2189502.7	265	8262.274			
Total (Corrected)	2940659.8	269				25.544%

Table A5.32: One-way Ancova of power at 65% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	302388.08	1	302388.08	41.116	0.0000	13.176%
Iso strength at 850 mm	1166.95	1	1166.95	0.159	0.6950	0.051%
Stature	18361.05	1	18361.05	2.497	0.1153	0.800%
Main Effects						
Gender	24139.915	1	24139.915	3.282	0.0712	1.052%
Residual	1948935.4	265	7354.473			
Total (Corrected)	2294991.4	269				15.079%

Table A5.33: One-way Ancova of power at 70% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	123812.4	1	123812.4	12.678	0.0004	4.424%
Iso strength at 850 mm	12874.58	1	12874.58	1.318	0.2519	0.460%
Stature	19733.21	1	19733.21	2.021	0.1563	0.705%
Main Effects						
Gender	54125.21	1	54125.21	5.542	0.0193	1.934%
Residual	2587907.7	265	9765.689			
Total (Corrected)	2798453.1	269				7.524%

Table A5.34: One-way Ancova of power at 75% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	392325.86	1	392325.86	25.723	0.0000	8.763%
Iso strength at 850 mm	20813.79	1	20813.79	1.365	0.2438	0.465%
Stature	2560.58	1	2560.58	0.168	0.6867	0.057%
Main Effects						
Gender	19828.372	1	19828.372	1.3	0.2552	0.443%
Residual	4041798.4	265	15252.069			
Total (Corrected)	4477327	269				9.727%

Table A5.35: One-way Ancova of power at 80% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	512852.25	1	512852.25	25.229	0.0000	8.655%
Iso strength at 850 mm	14853.47	1	14853.47	0.731	0.4026	0.251%
Stature	9475.51	1	9475.51	0.466	0.5027	0.160%
Main Effects						
Gender	1146.367	1	1146.367	0.056	0.8150	0.019%
Residual	5386932.4	265	20328.047			
Total (Corrected)	5925260	269				9.085%

Table A5.36: One-way Ancova of power at 85% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	824520.58	1	824520.58	48.014	0.0000	15.110%
Iso strength at 850 mm	70907.19	1	70907.19	4.129	0.0431	1.299%
Stature	9651.47	1	9651.47	0.562	0.4621	0.177%
Main Effects						
Gender	1053.985	1	1053.985	0.061	0.8072	0.019%
Residual	4550695.3	265	17172.435			
Total (Corrected)	5456828.5	269				16.605%

Table A5.37: One-way Ancova of power at 90% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1111093.8	1	1111093.8	150.526	0.0000	35.435%
Iso strength at 850 mm	34924.9	1	34924.9	4.731	0.0305	1.114%
Stature	33455.2	1	33455.2	4.532	0.0342	1.067%
Main Effects						
Gender	53.269	1	53.269	0.007	0.9333	0.002%
Residual	1956071.9	265	7381.403			
Total (Corrected)	3135599	269				37.617%

Table A5.38: One-way Ancova of power at 95% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	590935.91	1	590935.91	244.667	0.0000	46.852%
Iso strength at 850 mm	6239.57	1	6239.57	2.583	0.1092	0.495%
Stature	22296.76	1	22296.76	9.232	0.0026	1.768%
Main Effects						
Gender	1750.500	1	1750.500	0.725	0.4044	0.139%
Residual	640046.7	265	2415.271			
Total (Corrected)	1261269.4	269				49.254%

Table A5.39: One-way Ancova of power at 100% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	264301.64	1	264301.64	277.618	0.0000	50.081%
Iso strength at 850 mm	23.11	1	23.11	0.024	0.8780	0.004%
Stature	4345.56	1	4345.56	4.564	0.0336	0.823%
Main Effects						
Gender	6784.706	1	6784.70	7.127	0.0081	1.286%
Residual	252288.86	265	952.033			
Total (Corrected)	527743.87	269				52.195%

Table A5.40: One-way Ancova of power at 105% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	145670.59	1	145670.59	262.626	0.0000	47.971%
Iso strength at 850 mm	0.02	1	0.02	0	0.9952	0.000%
Stature	4768.7	1	4768.7	8.597	0.0037	1.570%
Main Effects						
Gender	6789.387	1	6789.387	12.24	0.0005	2.236%
Residual	146432.46	264	554.668			
Total (Corrected)	303661.17	268				51.778%

Table A5.41: One-way Ancova of power at 110% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	87691.065	1	87691.065	118.578	0.0000	29.280%
Iso strength at 850 mm	321.751	1	321.751	0.435	0.5171	0.107%
Stature	14041.514	1	14041.514	18.987	0.0000	4.688%
Main Effects						
Gender	4426.673	1	4426.673	5.986	0.0151	1.478%
Residual	193015.19	261	739.522			
Total (Corrected)	299496.2	265				35.553%

Table A5.42: One-way Ancova of power at 115% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	84365.538	1	84365.538	89.446	0.0000	26.725%
Iso strength at 850 mm	268.474	1	268.474	0.285	0.5999	0.085%
Stature	8789.524	1	8789.524	9.319	0.0025	2.784%
Main Effects						
Gender	5324.196	1	5324.196	5.645	0.0183	1.687%
Residual	216936.89	230	943.204			
Total (Corrected)	315684.62	234				31.281%

Table A5.43: One-way Ancova of power at 120% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	30642.609	1	30642.609	25.192	0.0000	12.372%
Iso strength at 850 mm	197.733	1	197.733	0.163	0.6916	0.080%
Stature	1721.942	1	1721.942	1.416	0.2357	0.695%
Main Effects						
Gender	4679.319	1	4679.319	3.847	0.0514	1.889%
Residual	210429.14	173	1216.353			
Total (Corrected)	247670.75	177				15.037%

Table A5.44: One-way Ancova of power at 125% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	0.017	1	0.017	0	0.9943	0.000%
Iso strength at 850 mm	555.089	1	555.089	1.712	0.1972	3.565%
Stature	26.161	1	26.161	0.081	0.7806	0.168%
Main Effects						
Gender	77.311	1	77.311	0.238	0.6328	0.497%
Residual	14912.245	46	324.179			
Total (Corrected)	15570.824	50				4.230%

A5.1.3 Mean powers at relative hand heights

Table A5.45: Least squares means for power before correction for covariates

% stature	Gender	n	Mean (W)	Std. error	95% confidence interval	
25	male	198	508.22	17.24	474.26	542.18
30	male	201	625.04	11.61	602.17	647.92
35	male	201	689.25	11.13	667.34	711.16
40	male	201	719.73	12.25	695.61	743.85
45	male	201	629.09	11.39	606.67	651.52
50	male	201	473.86	9.19	455.75	491.96
55	male	201	317.02	7.23	302.78	331.26
60	male	201	203.27	6.66	190.16	216.39
65	male	201	156.01	6.11	143.99	168.04
70	male	201	151.21	6.97	137.48	164.94
75	male	201	192.33	8.75	175.10	209.57
80	male	201	220.25	10.16	200.24	240.27
85	male	201	235.99	9.52	217.24	254.74
90	male	201	209.84	6.69	196.66	223.01
95	male	201	147.59	3.95	139.80	155.37
100	male	201	104.57	2.41	99.82	109.31
105	male	200	84.56	1.82	80.98	88.13
110	male	197	76.49	2.06	72.43	80.55
115	male	167	76.84	2.46	71.99	81.69
120	male	113	55.74	3.28	49.27	62.22
125	male	21	17.76	3.89	9.94	25.58
25	female	48	141.77	35.01	72.79	210.75
30	female	69	346.62	19.82	307.59	385.66
35	female	69	409.80	18.99	372.40	447.19
40	female	69	404.25	20.90	363.08	445.41
45	female	69	322.87	19.43	284.60	361.14
50	female	69	217.57	15.69	186.67	248.46
55	female	69	138.83	12.34	114.52	163.13
60	female	69	99.57	11.36	77.19	121.94
65	female	69	81.30	10.42	60.78	101.83
70	female	69	91.93	11.90	68.50	115.36
75	female	69	109.68	14.94	80.26	139.10
80	female	69	136.33	17.35	102.18	170.49
85	female	69	130.09	16.25	98.09	162.08
90	female	69	90.96	11.42	68.48	113.44
95	female	69	57.19	6.75	43.90	70.47
100	female	69	39.83	4.11	31.73	47.92
105	female	69	34.72	3.09	28.63	40.82
110	female	69	37.29	3.48	30.43	44.15
115	female	68	36.19	3.86	28.59	43.79
120	female	65	27.20	4.33	18.66	35.74
125	female	30	18.27	3.25	11.73	24.81

Table A5.46: Least squares means for power after correction for covariates

% stature	Gender	n	Mean (W)	Std. error	95% confidence interval	
25	male	198	452.66	16.34	420.46	484.86
30	male	201	563.72	12.29	539.51	587.92
35	male	201	625.34	11.56	602.58	648.10
40	male	201	655.06	12.95	629.56	680.56
45	male	201	574.22	12.19	550.21	598.23
50	male	201	422.30	9.50	403.58	441.02
55	male	201	280.79	7.80	265.44	296.15
60	male	201	184.40	7.80	169.05	199.76
65	male	201	146.31	7.35	131.83	160.80
70	male	201	150.12	8.48	133.43	166.81
75	male	201	179.72	10.59	158.86	200.58
80	male	201	200.85	12.23	176.77	224.94
85	male	201	210.89	11.24	188.75	233.02
90	male	201	179.01	7.37	164.50	193.53
95	male	201	127.01	4.21	118.71	135.31
100	male	201	93.00	2.65	87.79	98.21
105	male	200	76.77	2.03	72.78	80.76
110	male	197	70.44	2.37	65.77	75.10
115	male	167	70.50	3.04	64.51	76.48
120	male	113	52.33	4.43	43.59	61.07
125	male	21	14.98	6.80	1.29	28.66
25	female	48	370.97	42.82	286.59	455.35
30	female	69	525.28	26.69	472.72	577.84
35	female	69	595.96	25.10	546.54	645.39
40	female	69	592.61	28.12	537.24	647.99
45	female	69	482.72	26.47	430.59	534.86
50	female	69	367.76	20.64	327.11	408.40
55	female	69	244.36	16.94	211.00	277.71
60	female	69	154.53	16.93	121.19	187.88
65	female	69	109.57	15.97	78.11	141.03
70	female	69	95.10	18.41	58.86	131.35
75	female	69	146.42	23.00	101.12	191.72
80	female	69	192.85	26.56	140.55	245.15
85	female	69	203.21	24.41	155.14	251.28
90	female	69	180.74	16.00	149.23	212.26
95	female	69	117.12	9.15	99.09	135.15
100	female	69	73.52	5.75	62.20	84.84
105	female	69	57.29	4.38	48.65	65.92
110	female	69	54.57	5.08	44.56	64.59
115	female	68	51.77	5.95	40.05	63.49
120	female	65	33.13	6.74	19.82	46.44
125	female	30	20.22	5.09	9.97	30.46

A5.2 Variance accounted for by Anova and Ancova of work done to relative hand heights

Table A5.47: Two way Anova of work done to 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	29440468	1	29440468	4737.298	0.0000	16.295%
Hand height	121808134	14	8700581	1400.020	0.0000	67.421%
Interactions						
Gender × Height	4443514.6	14	317393.90	51.072	0.0000	2.459%
Residual	24982738	4020	6214.612			
Total (Corrected)	180674851	4049				86.175%

Table A5.48: Two way Ancova of work done to 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	39250250	1	39250250	11830.90	0.0000	21.724%
Iso strength at 850 mm	1236649	1	1236649	372.754	0.0000	0.684%
Stature	264827	1	264827	79.825	0.0000	0.147%
Main Effects						
Gender	344672	1	344671.7	103.892	0.0000	0.191%
Hand height	121808130	14	8700580.7	2622.551	0.0000	67.418%
Interactions						
Gender × Height	4443514.6	14	317393.9	95.67	0.0000	2.459%
Residual	13326809	4017	3317.603			
Total (Corrected)	180674851	4049				92.624%

A5.2.1 One-way Anova of work done to relative hand heights

Table A5.49: One-way Anova of work done to 25% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	6011.611	1	6011.611	78.316	0.0000	24.298%
Residual	18729.641	244	76.761			
Total (Corrected)	24741.252	245				

Table A5.50: One-way Anova of work done to 30% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	112268.96	1	112268.96	215.392	0.0000	44.558%
Residual	139690.01	268	521.231			
Total (Corrected)	251958.97	269				

Table A5.51: One-way Anova of work done to 35% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	272700.59	1	272700.59	254.289	0.0000	48.687%
Residual	287404.47	268	1072.405			
Total (Corrected)	560105.05	269				

Table A5.52: One-way Anova of work done to 40% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	521135.85	1	521135.85	270.99	0.0000	50.277%
Residual	515385.2	268	1923.079			
Total (Corrected)	1036521	269				

Table A5.53: One-way Anova of work done to 45% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	869151.43	1	869151.43	286.324	0.0000	51.653%
Residual	813528.14	268	3035.553			
Total (Corrected)	1682679.6	269				

Table A5.54: One-way Anova of work done to 50% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	1296619.3	1	1296619.3	314.43	0.0000	53.986%
Residual	1105156.2	268	4123.717			
Total (Corrected)	2401775.5	269				

Table A5.55: One-way Anova of work done to 55% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	1731391.3	1	1731391.3	339.377	0.0000	55.876%
Residual	1367249.4	268	5101.677			
Total (Corrected)	3098640.6	269				

Table A5.56: One-way Anova of work done to 60% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	2092600.2	1	2092600.2	365.317	0.0000	57.683%
Residual	1535149.3	268	5728.169			
Total (Corrected)	3627749.5	269				

Table A5.57: One-way Anova of work done to 65% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2362084.9	1	2362084.9	382.929	0.0000	58.828%
Residual	1653149.4	268	6168.468			
Total (Corrected)	4015234.3	269				

Table A5.58: One-way Anova of work done to 70% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2591235.7	1	2591235.7	397.805	0.0000	59.748%
Residual	1745707.7	268	6513.835			
Total (Corrected)	4336943.4	269				

Table A5.59: One-way Anova of work done to 75% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2812825.6	1	2812825.6	404.646	0.0000	60.157%
Residual	1862957.2	268	6951.333			
Total (Corrected)	4675782.8	269				

Table A5.60: One-way Anova of work done to 80% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3099955.8	1	3099955.8	391.842	0.0000	59.384%
Residual	2120214.1	268	7911.247			
Total (Corrected)	5220169.9	269				

Table A5.61: One-way Anova of work done to 85% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3415863.5	1	3415863.5	370.179	0.0000	58.005%
Residual	2472998.4	268	9227.606			
Total (Corrected)	5888861.9	269				

Table A5.62: One-way Anova of work done to 90% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3821672.2	1	3821672.2	359.125	0.0000	57.265%
Residual	2851956.2	268	10641.628			
Total (Corrected)	6673628.5	269				

Table A5.63: One-way Anova of work done to 95% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	4248935.9	1	4248935.9	360.526	0.0000	57.361
Residual	3158483.3	268	11785.385			
Total (Corrected)	7407419.2	269				

Table A5.64: One-way Anova of work done to 100% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	4635541.8	1	4635541.8	370.433	0.0000	58.022%
Residual	3353709.4	268	12513.841			
Total (Corrected)	7989251.2	269				

Table A5.65: One-way Anova of work done to 105% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	4944337.5	1	4944337.5	378.85	0.0000	58.659%
Residual	3484595.1	267	13050.918			
Total (Corrected)	8428932.6	268				

Table A5.66: One-way Anova of work done to 110% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	5140899.1	1	5140899.1	383.701	0.0000	59.240%
Residual	3537119.9	264	13398.182			
Total (Corrected)	8678019	265				

Table A5.67: One-way Anova of work done to 115% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	4791011.4	1	4791011.4	384.834	0.0000	62.288%
Residual	2900743.1	233	12449.541			
Total (Corrected)	7691754.5	234				

Table A5.68: One-way Anova of work done to 120% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	4146860.4	1	4146860.4	315.384	0.0000	64.183%
Residual	2314152.5	176	13148.594			
Total (Corrected)	6461012.9	177				

Table A5.69: One-way Anova of work done to 125% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	1332454	1	1332454	137.201	0.0000	73.684%
Residual	475874.48	49	9711.724			
Total (Corrected)	1808328.5	50				

A5.2.2 One-way Ancova of work done to relative hand heights

Table A5.70: One-way Ancova of work done to 25% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	11760.957	1	11760.957	662.536	0.0000	47.536%
Iso strength at 850 mm	821.421	1	821.421	46.274	0.0000	3.320%
Stature	7860.847	1	7860.847	442.829	0.0000	31.772%
Main Effects						
Gender	19.935	1	19.935	1.123	0.2903	0.081%
Residual	4278.091	241	17.751			
Total (Corrected)	24741.252	245				82.709%

Table A5.71: One-way Ancova of work done to 30% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	161215.19	1	161215.19	678.827	0.0000	63.985%
Iso strength at 850 mm	9082.37	1	9082.37	38.243	0.0000	3.605%
Stature	18462.01	1	18462.01	77.738	0.0000	7.327%
Main Effects						
Gender	264.301	1	264.301	1.113	0.2924	0.105%
Residual	62935.092	265	237.491			
Total (Corrected)	251958.97	269				75.022%

Table A5.72: One-way Ancova of work done to 35% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	388573.22	1	388573.22	784.081	0.0000	69.375%
Iso strength at 850 mm	17530.32	1	17530.32	35.373	0.0000	3.130%
Stature	21854.14	1	21854.14	44.098	0.0000	3.902%
Main Effects						
Gender	819.188	1	819.188	1.653	0.1997	0.146%
Residual	131328.19	265	495.578			
Total (Corrected)	560105.05	269				76.553%

Table A5.73: One-way Ancova of work done to 40% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	733354.56	1	733354.56	786.179	0.0000	70.752%
Iso strength at 850 mm	28846.24	1	28846.24	30.924	0.0000	2.783%
Stature	24921.93	1	24921.93	26.717	0.0000	2.404%
Main Effects						
Gender	2204.141	1	2204.141	2.363	0.1254	0.213%
Residual	247194.18	265	932.808			
Total (Corrected)	1036521	269				76.152%

Table A5.74: One-way Ancova of work done to 45% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	1198454.9	1	1198454.9	778.894	0.0000	71.223%
Iso strength at 850 mm	45437	1	45437	29.53	0.0000	2.700%
Stature	25309.3	1	25309.3	16.449	0.0001	1.504%
Main Effects						
Gender	5732.855	1	5732.855	3.726	0.0546	0.341%
Residual	407745.55	265	1538.663			
Total (Corrected)	1682679.6	269				75.768%

Table A5.75: One-way Ancova of work done to 50% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	1749291.1	1	1749291.1	836.517	0.0000	72.833%
Iso strength at 850 mm	64212.8	1	64212.8	30.707	0.0000	2.674%
Stature	21547.8	1	21547.8	10.304	0.0015	0.897%
Main Effects						
Gender	12566.395	1	12566.395	6.009	0.0149	0.523%
Residual	554157.39	265	2091.16			
Total (Corrected)	2401775.5	269				76.927%

Table A5.76: One-way Ancova of work done to 55% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	2333083.9	1	2333083.9	952.714	0.0000	75.294%
Iso strength at 850 mm	79246.4	1	79246.4	32.36	0.0000	2.557%
Stature	20209.5	1	20209.5	8.253	0.0044	0.652%
Main Effects						
Gender	17147.372	1	17147.372	7.002	0.0086	0.553%
Residual	648953.46	265	2448.881			
Total (Corrected)	3098640.6	269				79.057%

Table A5.77: One-way Ancova of work done to 60% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	2809684.9	1	2809684.9	1080.058	0.0000	77.450%
Iso strength at 850 mm	89834.5	1	89834.5	34.533	0.0000	2.476%
Stature	16886.9	1	16886.9	6.491	0.0114	0.465%
Main Effects						
Gender	21966.817	1	21966.817	8.444	0.0040	0.606%
Residual	689376.4	265	2601.420			
Total (Corrected)	3627749.5	269				80.997%

Table A5.78: One-way Ancova of work done to 65% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	3149835.7	1	3149835.7	1133.418	0.0000	78.447%
Iso strength at 850 mm	87208.8	1	87208.8	31.381	0.0000	2.172%
Stature	14000.8	1	14000.8	5.038	0.0256	0.349%
Main Effects						
Gender	27738.158	1	27738.158	9.981	0.0018	0.691%
Residual	736450.86	265	2779.060			
Total (Corrected)	4015234.3	269				81.659%

Table A5.79: One-way Ancova of work done to 70% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	3416502	1	3416502	1165.619	0.0000	78.777%
Iso strength at 850 mm	95677.5	1	95677.5	32.643	0.0000	2.206%
Stature	12440	1	12440	4.244	0.0404	0.287%
Main Effects						
Gender	35592.066	1	35592.066	12.143	0.0006	0.821%
Residual	776731.82	265	2931.064			
Total (Corrected)	4336943.4	269				82.090%

Table A5.80: One-way Ancova of work done to 75% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	3672788.9	1	3672788.9	1159.029	0.0000	78.549%
Iso strength at 850 mm	106911.8	1	106911.8	33.738	0.0000	2.287%
Stature	12616.3	1	12616.3	3.981	0.0470	0.270%
Main Effects						
Gender	43720.322	1	43720.322	13.797	0.0002	0.935%
Residual	839745.53	265	3168.851			
Total (Corrected)	4675782.8	269				82.041%

Table A5.81: One-way Ancova of work done to 80% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	4048216.4	1	4048216.4	1084.879	0.0000	77.550%
Iso strength at 850 mm	119596.9	1	119596.9	32.051	0.0000	2.291%
Stature	15421.6	1	15421.6	4.133	0.0431	0.295%
Main Effects						
Gender	48089.644	1	48089.644	12.888	0.0004	0.921%
Residual	988845.36	265	3731.492			
Total (Corrected)	5220169.9	269				81.057%

Table A5.82: One-way Ancova of work done to 85% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	4482718.2	1	4482718.2	985.731	0.0000	76.122%
Iso strength at 850 mm	134164	1	134164	29.502	0.0000	2.278%
Stature	17148.7	1	17148.7	3.771	0.0532	0.291%
Main Effects						
Gender	49714.305	1	49714.305	10.932	0.0011	0.844%
Residual	1205116.6	265	4547.61			
Total (Corrected)	5888861.9	269				79.536%

Table A5.83: One-way Ancova of work done to 90% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	5036458.1	1	5036458.1	945.48	0.0000	75.468%
Iso strength at 850 mm	155222.3	1	155222.3	29.139	0.0000	2.326%
Stature	17858.4	1	17858.4	3.353	0.0682	0.268%
Main Effects						
Gender	52466.071	1	52466.071	9.849	0.0019	0.786%
Residual	1411623.7	265	5326.882			
Total (Corrected)	6673628.5	269				78.848%

Table A5.84: One-way Ancova of work done to 95% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	5631744.1	1	5631744.1	969.485	0.0000	76.028%
Iso strength at 850 mm	167382.9	1	167382.9	28.814	0.0000	2.260%
Stature	14949.5	1	14949.5	2.574	0.1099	0.202%
Main Effects						
Gender	53956.573	1	53956.573	9.288	0.0025	0.728%
Residual	1539386.1	265	5809.004			
Total (Corrected)	7407419.2	269				79.218%

Table A5.85: One-way Ancova of work done to 100% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	6129626.1	1	6129626.1	1007.622	0.0000	76.723%
Iso strength at 850 mm	172041.7	1	172041.7	28.281	0.0000	2.153%
Stature	14472.8	1	14472.8	2.379	0.1242	0.181%
Main Effects						
Gender	61046.671	1	61046.671	10.035	0.0017	0.764%
Residual	1612063.9	265	6083.26			
Total (Corrected)	7989251.2	269				79.822%

Table A5.86: One-way Ancova of work done to 105% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	6514643.6	1	6514643.6	1034.408	0.0000	77.289%
Iso strength at 850 mm	171043.8	1	171043.8	27.159	0.0000	2.029%
Stature	11704.7	1	11704.7	1.858	0.1740	0.139%
Main Effects						
Gender	68883.199	1	68883.199	10.937	0.0011	0.817%
Residual	1662657.3	264	6297.944			
Total (Corrected)	8428932.6	268				80.274%

Table A5.87: One-way Ancova of work done to 110% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	6737778.1	1	6737778.1	1044.712	0.0000	77.642%
Iso strength at 850 mm	184192.4	1	184192.4	28.56	0.0000	2.123%
Stature	6595.6	1	6595.6	1.023	0.3128	0.076%
Main Effects						
Gender	66156.212	1	66156.212	10.258	0.0015	0.762%
Residual	1683296.6	261	6449.412			
Total (Corrected)	8678019	265				80.603%

Table A5.88: One-way Ancova of work done to 115% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	5964576.6	1	5964576.6	938.623	0.0000	77.545%
Iso strength at 850 mm	195259.4	1	195259.4	30.727	0.0000	2.539%
Stature	1886.2	1	1886.2	0.297	0.5922	0.025%
Main Effects						
Gender	68474.036	1	68474.036	10.776	0.0012	0.890%
Residual	1461558.3	230	6354.601			
Total (Corrected)	7691754.5	234				80.998%

Table A5.89: One-way Ancova of work done to 120% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	5103103.4	1	5103103.4	815.435	0.0000	78.983%
Iso strength at 850 mm	208094.7	1	208094.7	33.252	0.0000	3.221%
Stature	2733.7	1	2733.7	0.437	0.5166	0.042%
Main Effects						
Gender	64423.671	1	64423.671	10.294	0.0016	0.997%
Residual	1082657.5	173	6258.136			
Total (Corrected)	6461012.9	177				83.243%

Table A5.90: One-way Ancova of work done to 125% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1421164	1	1421164	234.76	0.0000	78.590%
Iso strength at 850 mm	68516.4	1	68516.4	11.318	0.0016	3.789%
Stature	10490.9	1	10490.9	1.733	0.1946	0.580%
Main Effects						
Gender	29687.733	1	29687.733	4.904	0.0318	1.642%
Residual	278469.43	46	6053.683			
Total (Corrected)	1808328.5	50				84.601%

A5.2.3 Mean work done to relative hand heights

Table A5.91: Least squares means for work done before correction for covariates

% stature	Gender	n	Mean (J)	Std. error	95% confidence interval	
25	male	198	15.66	0.62	14.43	16.89
30	male	201	84.74	1.61	81.57	87.91
35	male	201	159.08	2.31	154.53	163.63
40	male	201	238.83	3.09	232.73	244.92
45	male	201	316.89	3.89	309.24	324.54
50	male	201	385.31	4.53	376.39	394.23
55	male	201	439.64	5.04	429.72	449.56

60	male	201	479.74	5.34	469.22	490.25
65	male	201	510.70	5.54	499.79	521.61
70	male	201	538.25	5.69	527.04	549.46
75	male	201	567.78	5.88	556.20	579.36
80	male	201	601.49	6.27	589.13	613.84
85	male	201	638.19	6.78	624.85	651.54
90	male	201	674.84	7.28	660.51	689.16
95	male	201	706.27	7.66	691.19	721.35
100	male	201	731.36	7.89	715.82	746.90
105	male	200	752.00	8.08	736.09	767.91
110	male	197	769.28	8.25	753.04	785.52
115	male	167	774.95	8.63	757.93	791.96
120	male	113	786.61	10.79	765.32	807.90
125	male	21	786.76	21.50	743.54	829.99
25	female	48	3.19	1.26	0.70	5.68
30	female	69	37.99	2.75	32.57	43.40
35	female	69	86.22	3.94	78.45	93.98
40	female	69	138.10	5.28	127.71	148.50
45	female	69	186.81	6.63	173.75	199.87
50	female	69	226.43	7.73	211.21	241.66
55	female	69	256.04	8.60	239.11	272.98
60	female	69	277.90	9.11	259.96	295.84
65	female	69	296.26	9.46	277.64	314.88
70	female	69	313.65	9.72	294.52	332.79
75	female	69	333.77	10.04	314.00	353.53
80	female	69	355.83	10.71	334.74	376.91
85	female	69	380.32	11.56	357.55	403.09
90	female	69	402.07	12.42	377.62	426.53
95	female	69	418.67	13.07	392.93	444.40
100	female	69	430.96	13.47	404.44	457.48
105	female	69	441.55	13.75	414.47	468.63
110	female	69	452.10	13.93	424.66	479.54
115	female	68	460.07	13.53	433.41	486.74
120	female	65	469.60	14.22	441.52	497.68
125	female	30	458.33	17.99	422.17	494.50

Table A5.92: Least squares means for work done after correction for covariates

% stature	Gender	n	Mean (J)	Std. error	95% confidence interval	
25	male	198	13.01	0.34	12.35	13.68
30	male	201	73.77	1.32	71.17	76.37
35	male	201	142.19	1.91	138.43	145.95
40	male	201	215.92	2.62	210.76	221.08
45	male	201	288.22	3.36	281.60	294.85
50	male	201	351.49	3.92	343.76	359.21
55	male	201	400.63	4.24	392.27	408.99
60	male	201	437.11	4.37	428.50	445.73
65	male	201	465.96	4.52	457.06	474.87
70	male	201	492.26	4.64	483.11	501.40
75	male	201	520.61	4.83	511.10	530.12
80	male	201	551.96	5.24	541.64	562.28
85	male	201	585.77	5.78	574.38	597.16
90	male	201	618.97	6.26	606.64	631.30
95	male	201	646.81	6.54	633.94	659.68
100	male	201	669.52	6.69	656.35	682.70
105	male	200	688.29	6.83	674.85	701.73
110	male	197	702.92	7.00	689.14	716.69
115	male	167	703.27	7.88	687.74	718.80
120	male	113	696.86	10.04	677.03	716.69
125	male	21	654.00	29.38	594.84	713.15

25	female	48	14.12	0.88	12.38	15.86
30	female	69	69.93	2.87	64.27	75.58
35	female	69	135.42	4.15	127.25	143.59
40	female	69	204.82	5.69	193.62	216.02
45	female	69	270.32	7.31	255.93	284.71
50	female	69	324.98	8.52	308.20	341.75
55	female	69	369.67	9.22	351.51	387.82
60	female	69	402.06	9.50	383.36	420.77
65	female	69	426.58	9.82	407.24	445.92
70	female	69	447.64	10.08	427.79	467.50
75	female	69	471.17	10.48	450.52	491.82
80	female	69	500.10	11.38	477.70	522.51
85	female	69	533.04	12.56	508.31	557.78
90	female	69	564.81	13.59	538.04	591.58
95	female	69	591.88	14.20	563.93	619.84
100	female	69	611.10	14.53	582.49	639.71
105	female	69	626.22	14.77	597.14	655.31
110	female	69	641.57	15.02	612.00	671.14
115	female	68	636.11	15.44	605.68	666.54
120	female	65	625.62	15.29	595.43	655.81
125	female	30	551.27	21.99	507.00	595.54

A5.3 Variance accounted for by Anova and Ancova of impulse to relative hand heights

Table A5.93: Two way Anova of impulse at 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Main Effects						
Gender	26639712	1	26639712	5655.090	0.0000	6.171%
Hand height	381500434	14	27250031	5784.649	0.0000	88.376%
Interactions						
Gender × Height	4601553.2	14	328682.37	69.773	0.0000	1.066%
Residual	18937213	4020	4710.749			
Total (Corrected)	431678912	4049				95.613%

Table A5.94: Two way Ancova of impulse at 5% intervals of stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	34844876	1	34844876	18991.14	0.0000	0.807%
Iso strength at 850 mm	1028921	1	1028921	560.782	0.0000	0.024%
Stature	1913837	1	1913837	1043.079	0.0000	0.044%
Main Effects						
Gender	418913	1	418913	228.316	0.0000	0.010%
Hand height	381500434	14	27250031	14851.8	0.0000	8.837%
Interactions						
Gender × Height	4601553.2	14	328682.37	179.138	0.0000	0.107%
Residual	7370377.8	4017	1834.797			
Total (Corrected)	431678912	4049				9.829%

A5.3.1 One-way Anova of impulse to relative hand heights

Table A5.95: One-way Anova of impulse to 25% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	8439.193	1	8439.19	76.133	0.0000	23.782%
Residual	27046.807	244	110.85			
Total (Corrected)	35486	245				

Table A5.96: One-way Anova of impulse to 30% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	114158.3	1	114158.3	239.212	0.0000	47.162%
Residual	127896.66	268	477.23			
Total (Corrected)	242054.96	269				

Table A5.97: One-way Anova of impulse to 35% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	244894.15	1	244894.15	292.358	0.0000	52.173%
Residual	224490.85	268	837.65			
Total (Corrected)	469385	269				

Table A5.98: One-way Anova of impulse to 40% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	421097.09	1	421097.09	324.255	0.0000	54.749%
Residual	348040.67	268	1298.66			
Total (Corrected)	769137.76	269				

Table A5.99: One-way Anova of impulse to 45% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	665394.43	1	665394.43	348.353	0.0000	56.518%
Residual	511910.89	268	1910.12			
Total (Corrected)	1177305.3	269				

Table A5.100: One-way Anova of impulse to 50% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	988246.59	1	988246.59	393.364	0.0000	59.478%
Residual	673294.62	268	2512.29			
Total (Corrected)	1661541.2	269				

Table A5.101: One-way Anova of impulse to 55% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	1360739.6	1	1360739.6	419.861	0.0000	61.039%
Residual	868568.3	268	3240.93			
Total (Corrected)	2229307.9	269				

Table A5.102: One-way Anova of impulse to 60% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	1748782.2	1	1748782.2	445.926	0.0000	62.461%
Residual	1051012.6	268	3921.69			
Total (Corrected)	2799794.9	269				

Table A5.103: One-way Anova of impulse to 65% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2061245.3	1	2061245.3	458.5	0.0000	63.111%
Residual	1204827.7	268	4495.63			
Total (Corrected)	3266073	269				

Table A5.104: One-way Anova of impulse to 70% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2334199.9	1	2334199.9	470.741	0.0000	63.722%
Residual	1328895.3	268	4958.57			
Total (Corrected)	3663095.2	269				

Table A5.105: One-way Anova of impulse to 75% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2582085	1	2582085	481.182	0.0000	64.228%
Residual	1438121.8	268	5366.13			
Total (Corrected)	4020206.8	269				

Table A5.106: One-way Anova of impulse to 80% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	2908418.3	1	2908418.3	472.198	0.0000	63.793%
Residual	1650698.5	268	6159.32			
Total (Corrected)	4559116.8	269				

Table A5.107: One-way Anova of impulse to 85% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Gender	3263192.9	1	3263192.9	454.55	0.0000	62.909%
Residual	1923959.9	268	7178.96			
Total (Corrected)	5187152.8	269				

Table A5.108: One-way Anova of impulse to 90% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	3660573.1	1	3660573.1	438.625	0.0000	62.073%
Residual	2236612.8	268	8345.57			
Total (Corrected)	5897185.9	269				

Table A5.109: One-way Anova of impulse to 95% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	4154934.9	1	4154934.9	437.256	0.0000	62.000%
Residual	2546615.9	268	9502.30			
Total (Corrected)	6701550.8	269				

Table A5.110: One-way Anova of impulse to 100% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	4733303.6	1	4733303.6	452.678	0.0000	62.813%
Residual	2802265.9	268	10456.22			
Total (Corrected)	7535569.5	269				

Table A5.111: One-way Anova of impulse to 105% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	5289228.4	1	5289228.4	470.806	0.0000	63.812%
Residual	2999587.4	267	11234.41			
Total (Corrected)	8288815.8	268				

Table A5.112: One-way Anova of impulse to 110% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	5695607.7	1	5695607.7	487.875	0.0000	64.888%
Residual	3082020.5	264	11674.32			
Total (Corrected)	8777628.2	265				

Table A5.113: One-way Anova of impulse to 115% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	5404697.5	1	5404697.5	486.278	0.0000	67.606%
Residual	2589658.9	233	11114.42			
Total (Corrected)	7994356.4	234				

Table A5.114: One-way Anova of impulse to 120% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	4605965.5	1	4605965.5	402.371	0.0000	69.570%
Residual	2014684.6	176	11447.07			
Total (Corrected)	6620650.1	177				

Table A5.115: One-way Anova of impulse to 125% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Gender	1473070.1	1	1473070.1	157.45	0.0000	76.265%
Residual	458432.7	49	9355.77			
Total (Corrected)	1931502.8	50				

A5.3.2 One-way Ancova of impulse to relative hand heights

Table A5.116: One-way Ancova of impulse to 25% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	17158.84	1	17158.84	2828.973	0.0000	48.354%
Iso strength at 850 mm	861.582	1	861.58	142.049	0.0000	2.428%
Stature	15954.416	1	15954.42	2630.4	0.0000	44.960%
Main Effects						
Gender	49.402	1	49.40	8.145	0.0047	0.139%
Residual	1461.760	241	6.07			
Total (Corrected)	35486	245				95.881%

Table A5.117: One-way Ancova of impulse to 30% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	165141.8	1	165141.8	2217.774	0.0000	68.225%
Iso strength at 850 mm	7469.25	1	7469.25	100.308	0.0000	3.086%
Stature	49465.97	1	49465.97	664.304	0.0000	20.436%
Main Effects						
Gender	245.279	1	245.28	3.294	0.0707	0.101%
Residual	19732.656	265	74.46			
Total (Corrected)	242054.96	269				91.848%

Table A5.118: One-way Ancova of impulse to 35% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	346266.02	1	346266.02	2242.089	0.0000	73.770%
Iso strength at 850 mm	14426.09	1	14426.09	93.41	0.0000	3.073%
Stature	66760.01	1	66760.01	432.274	0.0000	14.223%
Main Effects						
Gender	1006.53	1	1006.53	6.517	0.0112	0.214%
Residual	40926.34	265	154.44			
Total (Corrected)	469385	269				91.281%

Table A5.119: One-way Ancova of impulse to 40% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	585358.13	1	585358.13	2108.12	0.0000	76.106%
Iso strength at 850 mm	21554.09	1	21554.09	77.625	0.0000	2.802%
Stature	86093.24	1	86093.24	310.058	0.0000	11.193%
Main Effects						
Gender	2550.20	1	2550.20	9.184	0.0027	0.332%
Residual	73582.11	265	277.67			
Total (Corrected)	769137.76	269				90.433%

Table A5.120: One-way Ancova of impulse to 45% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	907232.48	1	907232.48	1901.464	0.0000	77.060%
Iso strength at 850 mm	32279.59	1	32279.59	67.655	0.0000	2.742%
Stature	105599.34	1	105599.34	221.325	0.0000	8.970%
Main Effects						
Gender	5756.28	1	5756.28	12.065	0.0006	0.489%
Residual	126437.63	265	477.12			
Total (Corrected)	1177305.3	269				89.260%

Table A5.121: One-way Ancova of impulse to 50% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1302100.5	1	1302100.5	1826.171	0.0000	78.367%
Iso strength at 850 mm	46282.9	1	46282.9	64.911	0.0000	2.786%
Stature	110079.1	1	110079.1	154.384	0.0000	6.625%
Main Effects						
Gender	14127.871	1	14127.87	19.814	0.0000	0.850%
Residual	188950.91	265	713.02			
Total (Corrected)	1661541.2	269				88.628%

Table A5.122: One-way Ancova of impulse to 55% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	1787383.3	1	1787383.3	1942.548	0.0000	80.177%
Iso strength at 850 mm	59714.7	1	59714.7	64.899	0.0000	2.679%
Stature	118175.1	1	118175.1	128.434	0.0000	5.301%
Main Effects						
Gender	20202.31	1	20202.31	21.956	0.0000	0.906%
Residual	243832.57	265	920.12			
Total (Corrected)	2229307.9	269				89.062%

Table A5.123: One-way Ancova of impulse to 60% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	2286405.4	1	2286405.4	2069.28	0.0000	81.663%
Iso strength at 850 mm	70969.4	1	70969.4	64.23	0.0000	2.535%
Stature	122069.7	1	122069.7	110.478	0.0000	4.360%
Main Effects						
Gender	27544.40	1	27544.40	24.929	0.0000	0.984%
Residual	292805.88	265	1104.93			
Total (Corrected)	2799794.9	269				89.542%

Table A5.124: One-way Ancova of impulse to 65% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	2686643.8	1	2686643.8	2022.301	0.0000	82.259%
Iso strength at 850 mm	69899.2	1	69899.2	52.615	0.0000	2.140%
Stature	123485.9	1	123485.9	92.951	0.0000	3.781%
Main Effects						
Gender	33989.26	1	33989.26	25.585	0.0000	1.041%
Residual	352054.79	265	1328.51			
Total (Corrected)	3266073	269				89.221%

Table A5.125: One-way Ancova of impulse to 70% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	3020726.8	1	3020726.8	2035.669	0.0000	82.464%
Iso strength at 850 mm	78855.3	1	78855.3	53.141	0.0000	2.153%
Stature	128434.2	1	128434.2	86.552	0.0000	3.506%
Main Effects						
Gender	41845.70	1	41845.70	28.2	0.0000	1.142%
Residual	393233.19	265	1483.90			
Total (Corrected)	3663095.2	269				89.265%

Table A5.126: One-way Ancova of impulse to 75% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	3314585.8	1	3314585.8	2060.69	0.0000	82.448%
Iso strength at 850 mm	90716.7	1	90716.7	56.399	0.0000	2.257%
Stature	138054.9	1	138054.9	85.829	0.0000	3.434%
Main Effects						
Gender	50601.24	1	50601.24	31.459	0.0000	1.259%
Residual	426248.21	265	1608.48			
Total (Corrected)	4020206.8	269				89.397%

Table A5.127: One-way Ancova of impulse to 80% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	3739455.1	1	3739455.1	1981.039	0.0000	82.021%
Iso strength at 850 mm	102669.5	1	102669.5	54.391	0.0000	2.252%
Stature	160759.3	1	160759.3	85.165	0.0000	3.526%
Main Effects						
Gender	56012.8	1	56012.80	29.674	0.0000	1.229%
Residual	500220.1	265	1887.62			
Total (Corrected)	4559116.8	269				89.028%

Table A5.128: One-way Ancova of impulse to 85% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	4205022	1	4205022	1772.98	0.0000	81.066%
Iso strength at 850 mm	114836.9	1	114836.9	48.419	0.0000	2.214%
Stature	177514.4	1	177514.4	74.846	0.0000	3.422%
Main Effects						
Gender	61272.08	1	61272.08	25.834	0.0000	1.181%
Residual	628507.42	265	2371.73			
Total (Corrected)	5187152.8	269				87.883%

Table A5.129: One-way Ancova of impulse to 90% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	4729791.1	1	4729791.1	1616.92	0.0000	80.204%
Iso strength at 850 mm	135988	1	135988	46.489	0.0000	2.306%
Stature	189845.3	1	189845.3	64.9	0.0000	3.219%
Main Effects						
Gender	66387.27	1	66387.27	22.695	0.0000	1.126%
Residual	775174.34	265	2925.19			
Total (Corrected)	5897185.9	269				86.855%

Table A5.130: One-way Ancova of impulse to 95% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	5405053.5	1	5405053.5	1624.992	0.0000	80.654%
Iso strength at 850 mm	153238.1	1	153238.1	46.07	0.0000	2.287%
Stature	192365	1	192365	57.833	0.0000	2.870%
Main Effects						
Gender	69450.48	1	69450.48	20.88	0.0000	1.036%
Residual	881443.72	265	3326.20			
Total (Corrected)	6701550.8	269				86.847%

Table A5.131: One-way Ancova of impulse to 100% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	6139233.5	1	6139233.5	1724.843	0.0000	81.470%
Iso strength at 850 mm	163029.1	1	163029.1	45.804	0.0000	2.163%
Stature	207867.8	1	207867.8	58.401	0.0000	2.758%
Main Effects						
Gender	82224.72	1	82224.72	23.101	0.0000	1.091%
Residual	943214.29	265	3559.30			
Total (Corrected)	7535569.5	269				87.483%

Table A5.132: One-way Ancova of impulse to 105% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	6813799.9	1	6813799.9	1803.134	0.0000	82.205%
Iso strength at 850 mm	165122.5	1	165122.5	43.696	0.0000	1.992%
Stature	212489.3	1	212489.3	56.231	0.0000	2.564%
Main Effects						
Gender	99783.60	1	99783.60	26.406	0.0000	1.204%
Residual	997620.52	264	3778.87			
Total (Corrected)	8288815.8	268				87.964%

Table A5.133: One-way Ancova of impulse to 110% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	7255971.8	1	7255971.8	1820.592	0.0000	82.664%
Iso strength at 850 mm	173425.1	1	173425.1	43.514	0.0000	1.976%
Stature	198304.4	1	198304.4	49.756	0.0000	2.259%
Main Effects						
Gender	109710.9	1	109710.9	27.527	0.0000	1.250%
Residual	1040216	261	3985.5			
Total (Corrected)	8777628.2	265				88.149%

Table A5.134: One-way Ancova of impulse to 115% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R^2
Covariates						
Fat-free mass	6585363.3	1	6585363.3	1556.365	0.0000	82.375%
Iso strength at 850 mm	186660.7	1	186660.7	44.115	0.0000	2.335%
Stature	141978.5	1	141978.5	33.555	0.0000	1.776%
Main Effects						
Gender	107167.16	1	107167.16	25.328	0.0000	1.341%
Residual	973186.7	230	4231.25			
Total (Corrected)	7994356.4	234				87.827%

Table A5.135: One-way Ancova of impulse to 120% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	5515178.8	1	5515178.8	1318.354	0.0000	83.303%
Iso strength at 850 mm	171154.3	1	171154.3	40.913	0.0000	2.585%
Stature	103348.3	1	103348.3	24.704	0.0000	1.561%
Main Effects						
Gender	107243.51	1	107243.51	25.636	0.0000	1.620%
Residual	723725.11	173	4183.38			
Total (Corrected)	6620650.1	177				89.069%

Table A5.136: One-way Ancova of impulse to 125% stature

Source of variation	Sum of squares	D.F.	Mean squares	F ratio	Probability	R²
Covariates						
Fat-free mass	1584263.7	1	1584263.7	330.671	0.0000	82.022%
Iso strength at 850 mm	84778.1	1	84778.1	17.695	0.0001	4.389%
Stature	1134.3	1	1134.3	0.237	0.6340	0.059%
Main Effects						
Gender	40938.52	1	40938.52	8.545	0.0054	2.120%
Residual	220388.32	46	4791.05			
Total (Corrected)	1931502.8	50				88.590%

A5.3.3 Mean impulses to relative hand heights

Table A5.137: Least squares means for impulse before correction for covariates

% stature	Gender	n	Mean (N·s)	Std. error	95% confidence interval	
25	male	198	21.88	0.75	20.41	23.36
30	male	201	111.42	1.54	108.38	114.45
35	male	201	208.64	2.04	204.62	212.66
40	male	201	310.37	2.54	305.36	315.37
45	male	201	412.61	3.08	406.54	418.68
50	male	201	509.82	3.54	502.86	516.78
55	male	201	596.21	4.02	588.30	604.12
60	male	201	670.70	4.42	662.00	679.40
65	male	201	735.87	4.73	726.56	745.18
70	male	201	797.07	4.97	787.29	806.85
75	male	201	859.06	5.17	848.88	869.23
80	male	201	925.65	5.54	914.75	936.55
85	male	201	995.44	5.98	983.67	1007.21
90	male	201	1064.36	6.44	1051.67	1077.05
95	male	201	1129.23	6.88	1115.69	1142.77
100	male	201	1189.08	7.21	1174.88	1203.28
105	male	200	1244.94	7.49	1230.18	1259.69
110	male	197	1296.92	7.70	1281.76	1312.08
115	male	167	1334.11	8.16	1318.03	1350.18
120	male	113	1370.93	10.06	1351.06	1390.80
125	male	21	1390.19	21.11	1347.76	1432.62
25	female	48	7.10	1.52	4.11	10.10
30	female	69	64.28	2.63	59.10	69.45
35	female	69	139.59	3.48	132.73	146.46
40	female	69	219.83	4.34	211.28	228.37
45	female	69	298.80	5.26	288.44	309.16
50	female	69	371.12	6.03	359.23	383.00
55	female	69	433.45	6.85	419.95	446.95
60	female	69	486.19	7.54	471.34	501.03
65	female	69	535.55	8.07	519.66	551.45
70	female	69	583.90	8.48	567.20	600.59
75	female	69	634.86	8.82	617.49	652.22
80	female	69	687.70	9.45	669.09	706.30
85	female	69	743.39	10.20	723.30	763.48
90	female	69	797.41	11.00	775.75	819.06

95	female	69	844.83	11.74	821.72	867.94
100	female	69	885.52	12.31	861.28	909.76
105	female	69	923.84	12.76	898.71	948.97
110	female	69	963.07	13.01	937.46	988.69
115	female	68	999.68	12.78	974.48	1024.87
120	female	65	1036.83	13.27	1010.64	1063.03
125	female	30	1044.87	17.66	1009.37	1080.36

Table A5.138: Least squares means for impulse after correction for covariates

% stature	Gender	n	Mean (N·s)	Std. error	95% confidence interval	
25	male	198	18.66	0.20	18.27	19.05
30	male	201	100.32	0.74	98.86	101.77
35	male	201	192.91	1.07	190.81	195.01
40	male	201	290.28	1.43	287.47	293.10
45	male	201	388.11	1.87	384.42	391.80
50	male	201	481.56	2.29	477.05	486.07
55	male	201	563.20	2.60	558.08	568.33
60	male	201	633.58	2.85	627.96	639.19
65	male	201	695.82	3.13	689.66	701.98
70	male	201	754.95	3.30	748.45	761.46
75	male	201	815.36	3.44	808.58	822.13
80	male	201	879.14	3.73	871.80	886.48
85	male	201	945.98	4.18	937.76	954.21
90	male	201	1011.71	4.64	1002.57	1020.84
95	male	201	1072.48	4.95	1062.74	1082.22
100	male	201	1128.83	5.12	1118.76	1138.91
105	male	200	1181.73	5.29	1171.32	1192.15
110	male	197	1230.82	5.50	1219.99	1241.65
115	male	167	1261.65	6.43	1248.98	1274.32
120	male	113	1282.49	8.21	1266.28	1298.71
125	male	21	1258.02	26.14	1205.39	1310.64
25	female	48	20.41	0.52	19.39	21.42
30	female	69	96.61	1.61	93.45	99.78
35	female	69	185.41	2.31	180.85	189.97
40	female	69	278.34	3.10	272.23	284.45
45	female	69	370.17	4.07	362.16	378.18
50	female	69	453.45	4.97	443.66	463.25
55	female	69	529.59	5.65	518.47	540.72
60	female	69	594.33	6.19	582.14	606.53
65	female	69	652.22	6.79	638.85	665.59
70	female	69	706.58	7.17	692.45	720.71
75	female	69	762.16	7.47	747.45	776.88
80	female	69	823.17	8.09	807.24	839.11
85	female	69	887.45	9.07	869.59	905.32
90	female	69	950.78	10.07	930.94	970.62
95	female	69	1010.16	10.74	989.00	1031.32
100	female	69	1061.03	11.11	1039.14	1082.91
105	female	69	1107.03	11.44	1084.50	1129.56
110	female	69	1151.82	11.80	1128.57	1175.06
115	female	68	1177.63	12.60	1152.80	1202.46
120	female	65	1190.58	12.50	1165.89	1215.26
125	female	30	1137.39	19.56	1098.00	1176.77

APPENDIX 6

CORRELATIONS BETWEEN DIFFERENT MEAN VALUES OF RANGES

Table A6.1: Correlation matrix for all event and range variables, with groupings of inter-related correlations highlighted

	R26	**R27**	**R28**	**R29**	**R30**	**R31**	**R32**	**R33**	**R34**	**R35**	**R36**	**R37**	**R38**	**R39**	**R40**	**R41**	**R42**	**R43**	**R44**	**R45**	**R46**	**R47**	**R48**	**R49**	**R50**	**R51**	**R52**	**R53**	**R54**	**R55**	
R26	1.000	0.956	0.924	0.917	0.853	0.966	0.915	0.883	0.875	0.618	0.502	0.696	0.144	0.575	0.995	0.950	0.907	0.902	0.803	0.942	0.905	0.855	0.856	0.621	0.501	0.712	0.062	0.595	0.993	0.955	R26
R27		1.000	0.973	0.976	0.869	0.922	0.977	0.945	0.953	0.585	0.558	0.778	0.117	0.587	0.951	0.994	0.961	0.970	0.816	0.901	0.967	0.925	0.946	0.565	0.535	0.813	0.036	0.616	0.951	0.995	R27
R28			1.000	0.988	0.920	0.889	0.963	0.978	0.959	0.645	0.516	0.763	0.074	0.477	0.921	0.969	0.994	0.981	0.888	0.890	0.962	0.965	0.950	0.622	0.505	0.788	-0.011	0.513	0.919	0.965	R28
R29				1.000	0.924	0.892	0.968	0.973	0.984	0.639	0.531	0.827	0.114	0.533	0.912	0.970	0.981	0.995	0.895	0.892	0.963	0.958	0.975	0.614	0.522	0.847	0.031	0.559	0.912	0.968	R29
R30					1.000	0.876	0.889	0.916	0.914	0.347	0.280	0.632	-0.096	0.514	0.845	0.860	0.902	0.914	0.990	0.898	0.879	0.888	0.900	0.351	0.284	0.670	-0.119	0.526	0.848	0.861	R30
R31						1.000	0.927	0.891	0.886	0.555	0.459	0.679	0.078	0.563	0.960	0.914	0.870	0.877	0.834	0.985	0.914	0.862	0.867	0.558	0.457	0.693	0.020	0.574	0.950	0.915	R31
R32							1.000	0.972	0.976	0.618	0.584	0.800	0.004	0.517	0.907	0.971	0.951	0.960	0.839	0.912	0.991	0.952	0.965	0.591	0.558	0.828	-0.053	0.547	0.906	0.966	R32
R33								1.000	0.980	0.668	0.547	0.791	0.034	0.419	0.879	0.941	0.975	0.969	0.888	0.897	0.973	0.991	0.972	0.637	0.532	0.813	-0.040	0.454	0.870	0.932	R33
R34									1.000	0.654	0.554	0.863	0.100	0.503	0.870	0.946	0.953	0.981	0.889	0.890	0.971	0.968	0.993	0.622	0.543	0.879	0.027	0.525	0.863	0.941	R34
R35												0.880	-0.148	0.027	0.603	0.591	0.651	0.628	0.272	0.471	0.635	0.670	0.636			0.854	-0.229	0.061	0.625	0.574	R35
R36												0.793	0.246	0.035	0.498	0.565	0.538	0.536	0.239	0.409	0.599	0.572	0.556			0.762	0.111	0.069	0.503	0.549	R36
R37												1.000	0.296	0.343	0.689	0.774	0.768	0.832	0.601	0.653	0.797	0.792	0.863	0.828	0.779	0.988	0.177	0.358	0.692	0.769	R37
R38															0.148	0.128	0.107	0.141	-0.092	0.032	0.002	0.085	0.140	-0.115	0.300	0.303			0.147	0.124	R38
R39															0.589	0.589	0.470	0.558	0.506	0.574	0.504	0.409	0.539	0.041	0.041	0.423	0.346		0.562	0.588	R39
R40															1.000	0.954	0.912	0.905	0.803	0.949	0.907	0.861	0.860	0.617	0.500	0.710	0.067	0.612	0.985	0.949	R40
R41																1.000	0.968	0.975	0.815	0.904	0.974	0.933	0.951	0.584	0.553	0.820	0.048	0.624	0.943	0.986	R41
R42																	1.000	0.985	0.878	0.882	0.963	0.976	0.956	0.639	0.532	0.801	0.022	0.512	0.899	0.951	R42
R43																		1.000	0.894	0.889	0.969	0.966	0.985	0.618	0.533	0.863	0.062	0.589	0.893	0.959	R43
R44																			1.000	0.875	0.839	0.869	0.886	0.285	0.247	0.646	-0.107	0.517	0.794	0.804	R44
R45																				1.000	0.913	0.881	0.884	0.486	0.413	0.679	-0.012	0.587	0.918	0.887	R45
R46																					1.000	0.969	0.975	0.625	0.586	0.840	-0.051	0.542	0.892	0.949	R46
R47																						1.000	0.974	0.653	0.564	0.823	0.013	0.450	0.837	0.907	R47
R48																							1.000	0.622	0.551	0.892	0.072	0.566	0.839	0.929	R48
R49																										0.831	-0.173	0.078	0.622	0.552	R49
R50																										0.764	0.190	0.079	0.501	0.526	R50
R51																										1.000	0.204	0.446	0.704	0.800	R51
R52																													0.059	0.040	R52
R53																													0.581	0.615	R53
R54																													1.000	0.960	R54
R55																														1.000	R55
	R26	**R27**	**R28**	**R29**	**R30**	**R31**	**R32**	**R33**	**R34**	**R35**	**R36**	**R37**	**R38**	**R39**	**R40**	**R41**	**R42**	**R43**	**R44**	**R45**	**R46**	**R47**	**R48**	**R49**	**R50**	**R51**	**R52**	**R53**	**R54**	**R55**	

	R56	R57	R58	R59	R60	R61	R62	R63	R64	R65	R66	R67	R68	R69	R70	R71	R72	R73	R74	R75	R76	R77	R78	R79	R80	R81	R82	R83	R84	R85	
R26	0.929	0.922	0.862	0.961	0.905	0.891	0.878	0.591	0.510	0.669	0.232	0.577	0.703	0.866	0.924	0.916	0.856	0.541	0.779	0.882	0.874	0.452	0.346	0.579	0.019	0.252	0.389	0.709	0.897	0.894	R26
R27	0.974	0.977	0.879	0.917	0.969	0.943	0.948	0.585	0.558	0.745	0.195	0.585	0.851	0.890	0.972	0.976	0.873	0.698	0.811	0.942	0.951	0.378	0.297	0.543	-0.015	0.232	0.612	0.713	0.950	0.954	R27
R28	0.993	0.985	0.918	0.880	0.950	0.974	0.954	0.644	0.547	0.743	0.156	0.482	0.872	0.964	0.999	0.988	0.922	0.752	0.907	0.975	0.957	0.486	0.235	0.450	-0.057	0.064	0.642	0.842	0.981	0.970	R28
R29	0.982	0.993	0.920	0.885	0.957	0.973	0.979	0.638	0.565	0.808	0.191	0.538	0.855	0.956	0.988	0.999	0.926	0.741	0.900	0.972	0.983	0.479	0.221	0.497	-0.042	0.133	0.624	0.829	0.967	0.984	R29
R30	0.920	0.922	0.993	0.874	0.883	0.925	0.916	0.321	0.303	0.604	-0.062	0.519	0.913	0.830	0.919	0.923	0.999	0.854	0.790	0.914	0.912	0.148	-0.049	0.244	-0.247	0.131	0.731	0.714	0.896	0.906	R30
R31	0.884	0.886	0.883	0.992	0.919	0.898	0.888	0.525	0.464	0.647	0.150	0.567	0.685	0.836	0.888	0.890	0.879	0.570	0.782	0.891	0.885	0.391	0.309	0.558	-0.046	0.250	0.394	0.694	0.875	0.882	R31
R32	0.958	0.963	0.900	0.925	0.994	0.973	0.975	0.623	0.588	0.770	0.063	0.515	0.839	0.908	0.963	0.968	0.895	0.723	0.867	0.971	0.975	0.427	0.302	0.547	-0.143	0.137	0.619	0.757	0.949	0.953	R32
R33	0.959	0.958	0.914	0.881	0.963	0.992	0.974	0.673	0.579	0.771	0.104	0.427	0.842	0.964	0.977	0.972	0.919	0.760	0.940	0.998	0.979	0.522	0.264	0.474	-0.096	0.002	0.629	0.860	0.973	0.968	R33
R34	0.944	0.967	0.910	0.878	0.967	0.978	0.993	0.658	0.590	0.844	0.166	0.513	0.819	0.951	0.958	0.983	0.916	0.736	0.922	0.979	0.999	0.505	0.236	0.526	-0.064	0.107	0.602	0.839	0.948	0.979	R34
R35	0.638	0.638	0.375	0.570	0.609	0.666	0.659	**0.986**	**0.934**	0.877	-0.046	0.045	0.241	0.707	0.652	0.645	0.358	0.053	0.722	0.676	0.660	**0.903**	**0.811**	0.868	-0.225	-0.257	-0.033	0.689	0.642	0.632	R35
R36	0.501	0.520	0.292	0.465	0.577	0.537	0.552	**0.953**	**0.986**	0.791	0.346	0.054	0.112	0.667	0.520	0.534	0.284	-0.041	0.681	0.551	0.557	**0.889**	**0.809**	0.896	0.327	-0.203	-0.164	0.640	0.514	0.530	R36
R37	0.750	0.807	0.633	0.678	0.792	0.789	0.856	0.896	0.826	0.991	0.385	0.361	0.505	0.827	0.765	0.828	0.635	0.399	0.818	0.794	0.864	0.802	0.475	0.761	0.177	0.046	0.276	0.751	0.750	0.828	R37
R38	0.067	0.098	-0.106	0.056	-0.015	0.006	0.067	-0.169	0.223	0.285	**0.980**	**0.437**	-0.049	-0.129	0.070	0.111	-0.097	-0.144	-0.263	0.029	0.097	-0.220	0.294	0.377	**0.875**	**0.813**	-0.119	-0.286	0.073	0.130	R38
R39	0.485	0.522	0.513	0.543	0.508	0.416	0.480	0.012	0.019	0.288	0.480	**0.991**	0.500	0.295	0.473	0.529	0.508	0.409	0.174	0.413	0.499	-0.194	-0.005	0.233	0.222	**0.799**	0.356	0.076	0.459	0.528	R39
R40	0.922	0.915	0.851	0.950	0.895	0.884	0.870	0.572	0.505	0.661	0.238	0.590	0.704	0.854	0.920	0.911	0.847	0.543	0.763	0.878	0.868	0.425	0.343	0.571	0.004	0.266	0.393	0.693	0.893	0.887	R40
R41	0.967	0.968	0.867	0.905	0.958	0.936	0.938	0.585	0.562	0.737	0.210	0.586	0.846	0.883	0.967	0.969	0.863	0.693	0.804	0.937	0.944	0.373	0.295	0.537	-0.022	0.231	0.609	0.707	0.943	0.944	R41
R42	0.982	0.973	0.897	0.858	0.935	0.965	0.945	0.645	0.568	0.747	0.191	0.475	0.865	0.958	0.992	0.980	0.904	0.748	0.903	0.971	0.951	0.487	0.252	0.450	-0.046	0.050	0.642	0.843	0.974	0.961	R42
R43	0.970	0.982	0.905	0.865	0.944	0.962	0.970	0.621	0.568	0.808	0.218	0.562	0.853	0.944	0.980	0.993	0.915	0.743	0.886	0.966	0.979	0.459	0.218	0.491	-0.043	0.155	0.630	0.819	0.960	0.979	R43
R44	0.882	0.886	0.972	0.826	0.829	0.891	0.885	0.244	0.263	0.572	-0.067	0.509	0.916	0.778	0.886	0.893	0.987	0.873	0.742	0.884	0.887	0.061	-0.121	0.181	-0.270	0.133	0.765	0.672	0.866	0.880	R44
R45	0.878	0.880	0.895	0.967	0.898	0.896	0.884	0.436	0.414	0.620	0.094	0.574	0.733	0.813	0.889	0.891	0.899	0.636	0.761	0.895	0.888	0.278	0.226	0.482	-0.130	0.246	0.470	0.675	0.880	0.886	R45
R46	0.950	0.952	0.884	0.906	0.977	0.966	0.963	0.631	0.598	0.763	0.064	0.501	0.837	0.911	0.960	0.962	0.884	0.722	0.873	0.970	0.969	0.435	0.299	0.538	-0.181	0.109	0.624	0.772	0.946	0.947	R46
R47	0.938	0.937	0.879	0.845	0.936	0.974	0.954	0.669	0.601	0.769	0.157	0.416	0.829	0.954	0.962	0.956	0.890	0.752	0.932	0.988	0.966	0.521	0.284	0.469	-0.077	-0.018	0.629	0.862	0.963	0.954	R47
R48	0.928	0.951	0.890	0.852	0.949	0.962	0.978	0.632	0.587	0.838	0.205	0.545	0.818	0.936	0.948	0.974	0.902	0.739	0.903	0.970	0.991	0.476	0.229	0.514	-0.060	0.137	0.612	0.826	0.940	0.972	R48
R49	0.612	0.609	0.374	0.566	0.577	0.631	0.622	**0.938**	**0.876**	0.810	-0.016	0.060	0.237	0.679	0.627	0.618	0.360	0.051	0.688	0.642	0.626	**0.859**	**0.767**	0.823	-0.266	-0.244	-0.045	0.667	0.610	0.600	R49
R50	0.491	0.511	0.297	0.463	0.548	0.522	0.538	**0.916**	**0.955**	0.768	0.390	0.060	0.114	0.639	0.507	0.523	0.288	-0.036	0.650	0.534	0.543	**0.856**	**0.780**	0.870	0.323	-0.189	-0.169	0.614	0.496	0.515	R50
R51	0.771	0.823	0.666	0.688	0.814	0.805	0.865	0.852	0.786	0.967	0.384	0.436	0.556	0.839	0.788	0.847	0.672	0.454	0.819	0.813	0.879	0.751	0.431	0.713	0.138	0.104	0.332	0.753	0.772	0.846	R51
R52	-0.019	0.013	-0.126	-0.000	-0.066	-0.062	-0.004	-0.263	0.076	0.155	**0.907**	**0.344**	-0.092	-0.195	-0.018	0.026	-0.121	-0.150	-0.306	-0.049	0.022	-0.286	0.184	0.256	**0.828**	**0.714**	-0.139	-0.334	-0.017	0.046	R52
R53	0.519	0.549	0.526	0.553	0.538	0.451	0.502	0.049	0.057	0.305	0.440	**0.959**	0.525	0.334	0.508	0.554	0.521	0.426	0.213	0.448	0.519	-0.159	0.021	0.243	0.165	**0.752**	0.373	0.111	0.491	0.547	R53
R54	0.936	0.929	0.867	0.958	0.905	0.889	0.877	0.605	0.515	0.671	0.243	0.570	0.701	0.863	0.919	0.911	0.851	0.533	0.774	0.869	0.862	0.462	0.341	0.573	0.066	0.250	0.382	0.697	0.876	0.873	R54
R55	0.976	0.979	0.878	0.919	0.966	0.940	0.945	0.579	0.554	0.742	0.208	0.591	0.842	0.879	0.964	0.968	0.865	0.684	0.796	0.930	0.940	0.371	0.299	0.542	0.028	0.248	0.594	0.691	0.930	0.934	R55
R56	1.000	0.992	0.928	0.888	0.955	0.968	0.952	0.641	0.536	0.737	0.156	0.493	0.866	0.954	0.992	0.981	0.922	0.738	0.891	0.957	0.943	0.477	0.222	0.445	-0.028	0.088	0.623	0.815	0.955	0.946	R56
R57		1.000	0.929	0.891	0.961	0.970	0.975	0.643	0.558	0.797	0.183	0.532	0.853	0.949	0.984	0.992	0.924	0.730	0.889	0.957	0.966	0.478	0.217	0.487	-0.017	0.135	0.608	0.809	0.946	0.960	R57
R58			1.000	0.894	0.904	0.935	0.924	0.353	0.316	0.611	-0.069	0.522	0.895	0.838	0.917	0.919	0.993	0.832	0.799	0.912	0.908	0.182	-0.017	0.267	-0.234	0.131	0.695	0.710	0.881	0.889	R58
R59				1.000	0.929	0.902	0.892	0.548	0.473	0.654	0.130	0.553	0.674	0.837	0.881	0.884	0.877	0.556	0.787	0.881	0.877	0.413	0.313	0.564	-0.035	0.231	0.374	0.688	0.852	0.861	R59
R60					1.000	0.975	0.978	0.622	0.588	0.772	0.045	0.512	0.825	0.896	0.951	0.957	0.890	0.712	0.858	0.962	0.967	0.425	0.304	0.547	-0.131	0.139	0.598	0.735	0.925	0.931	R60
R61						1.000	0.985	0.679	0.575	0.777	0.079	0.428	0.835	0.954	0.973	0.972	0.928	0.750	0.932	0.991	0.977	0.521	0.255	0.481	-0.094	0.012	0.608	0.836	0.952	0.951	R61
R62							1.000	0.672	0.593	0.847	0.137	0.494	0.812	0.945	0.954	0.978	0.918	0.726	0.919	0.973	0.992	0.514	0.239	0.529	-0.062	0.091	0.583	0.820	0.929	0.959	R62
	R56	R57	R58	R59	R60	R61	R62	R63	R64	R65	R66	R67	R68	R69	R70	R71	R72	R73	R74	R75	R76	R77	R78	R79	R80	R81	R82	R83	R84	R85	

	R56	**R57**	**R58**	**R59**	**R60**	**R61**	**R62**	**R63**	**R64**	**R65**	**R66**	**R67**	**R68**	**R69**	**R70**	**R71**	**R72**	**R73**	**R74**	**R75**	**R76**	**R77**	**R78**	**R79**	**R80**	**R81**	**R82**	**R83**	**R84**	**R85**	
R63								1.000	0.961	0.911	-0.059	0.027	0.233	0.706	0.652	0.645	0.333	0.049	0.726	0.682	0.665	0.911	0.828	0.880	-0.178	-0.259	-0.028	0.677	0.637	0.627	R63
R64									1.000	0.838	0.340	0.038	0.154	0.667	0.551	0.568	0.307	0.005	0.684	0.584	0.592	0.890	0.786	0.895	0.356	-0.209	-0.109	0.633	0.538	0.557	R64
R65										1.000	0.388	0.309	0.487	0.799	0.745	0.809	0.607	0.382	0.797	0.774	0.846	0.814	0.480	0.755	0.219	0.011	0.262	0.720	0.720	0.797	R65
R66											1.000	0.501	-0.005	-0.053	0.153	0.189	-0.063	-0.133	-0.203	0.100	0.164	-0.130	0.387	0.477	0.872	0.853	-0.107	-0.223	0.141	0.191	R66
R67												1.000	0.498	0.302	0.476	0.535	0.513	0.408	0.185	0.420	0.508	-0.177	0.005	0.248	0.256	0.792	0.347	0.088	0.456	0.528	R67
R68													1.000	0.820	0.869	0.854	0.912	0.966	0.759	0.837	0.818	0.051	-0.255	-0.016	-0.220	0.100	0.922	0.711	0.854	0.837	R68
R69														1.000	0.965	0.957	0.837	0.687	0.981	0.964	0.952	0.613	0.347	0.555	-0.295	-0.157	0.618	0.949	0.958	0.947	R69
R70															1.000	0.989	0.921	0.749	0.909	0.977	0.959	0.495	0.241	0.456	-0.060	0.061	0.638	0.843	0.984	0.972	R70
R71																1.000	0.925	0.740	0.901	0.973	0.984	0.486	0.225	0.499	-0.044	0.130	0.623	0.831	0.970	0.986	R71
R72																	1.000	0.852	0.799	0.917	0.915	0.164	-0.042	0.250	-0.247	0.123	0.728	0.722	0.899	0.908	R72
R73																		1.000	0.661	0.755	0.736	-0.122	-0.426	-0.180	-0.312	0.046	0.967	0.611	0.748	0.736	R73
R74																			1.000	0.941	0.924	0.664	0.353	0.545	-0.441	-0.279	0.584	0.970	0.909	0.899	R74
R75																				1.000	0.981	0.534	0.271	0.482	-0.098	-0.002	0.624	0.861	0.976	0.970	R75
R76																					1.000	0.513	0.240	0.528	-0.067	0.103	0.602	0.840	0.951	0.981	R76
R77																						1.000	0.860	0.861	-0.216	-0.418	-0.194	0.675	0.496	0.484	R77
R78																							1.000	0.888	0.423	-0.084	-0.560	0.323	0.251	0.228	R78
R79																								1.000	0.360	0.093	-0.336	0.485	0.444	0.498	R79
R80																									1.000	0.734	-0.300	-0.513	-0.087	-0.063	R80
R81																										1.000	0.007	-0.398	0.036	0.127	R81
R82																											1.000	0.569	0.648	0.628	R82
R83																												1.000	0.861	0.845	R83
R84																													1.000	0.982	R84
R85																														1.000	R85
	R56	**R57**	**R58**	**R59**	**R60**	**R61**	**R62**	**R63**	**R64**	**R65**	**R66**	**R67**	**R68**	**R69**	**R70**	**R71**	**R72**	**R73**	**R74**	**R75**	**R76**	**R77**	**R78**	**R79**	**R80**	**R81**	**R82**	**R83**	**R84**	**R85**	

	R86	**R87**	**R88**	**R89**	**R90**	**R91**	**R92**	**R93**	**R94**	**R95**	
R26	0.841	0.272	0.635	0.857	0.860	0.377	0.225	0.389	-0.218	0.030	R26
R27	0.857	0.486	0.639	0.926	0.936	0.252	0.103	0.298	-0.244	0.004	R27
R28	0.913	0.543	0.783	0.956	0.945	0.374	0.044	0.164	-0.290	-0.178	R28
R29	0.916	0.528	0.770	0.947	0.969	0.366	0.029	0.197	-0.273	-0.122	R29
R30	0.987	0.661	0.667	0.886	0.897	0.073	-0.196	-0.026	-0.386	-0.101	R30
R31	0.864	0.298	0.637	0.869	0.875	0.320	0.196	0.371	-0.249	0.022	R31
R32	0.877	0.510	0.703	0.951	0.956	0.297	0.093	0.289	-0.336	-0.093	R32
R33	0.907	0.548	0.818	0.982	0.969	0.405	0.066	0.181	-0.310	-0.244	R33
R34	0.905	0.521	0.793	0.956	0.986	0.388	0.039	0.219	-0.281	-0.154	R34
R35	0.344	-0.153	0.679	0.655	0.639	0.834	0.652	0.739	-0.407	-0.396	R35
R36	0.277	-0.260	0.631	0.534	0.544	0.809	0.657	0.787	0.054	-0.329	R36
R37	0.628	0.194	0.721	0.763	0.849	0.693	0.274	0.481	-0.085	-0.166	R37
R38	-0.083	-0.165	-0.382	0.050	0.127	-0.226	0.268	0.363	0.752	0.865	R38
R39	0.498	0.281	-0.016	0.414	0.510	-0.274	-0.025	0.141	0.026	0.624	R39
R40	0.833	0.277	0.617	0.852	0.853	0.351	0.224	0.382	-0.242	0.043	R40
R41	0.846	0.483	0.634	0.918	0.925	0.248	0.100	0.290	-0.265	0.000	R41
R42	0.895	0.545	0.785	0.952	0.938	0.378	0.055	0.159	-0.294	-0.198	R42
R43	0.907	0.536	0.759	0.941	0.965	0.350	0.021	0.187	-0.284	-0.108	R43
R44	0.981	0.703	0.629	0.857	0.873	-0.012	-0.272	-0.096	-0.405	-0.098	R44
R45	0.889	0.381	0.620	0.876	0.880	0.206	0.111	0.283	-0.322	0.017	R45
R46	0.867	0.516	0.720	0.950	0.949	0.310	0.085	0.276	-0.390	-0.128	R46
R47	0.881	0.551	0.822	0.975	0.957	0.408	0.079	0.173	-0.310	-0.271	R47
R48	0.894	0.534	0.779	0.948	0.980	0.364	0.028	0.203	-0.288	-0.134	R48
R49	0.344	-0.164	0.656	0.617	0.602	0.819	0.637	0.718	-0.462	-0.395	R49
R50	0.278	-0.264	0.605	0.513	0.528	0.799	0.648	0.776	0.066	-0.316	R50
R51	0.665	0.251	0.717	0.783	0.865	0.655	0.233	0.428	-0.123	-0.127	R51
R52	-0.117	-0.166	-0.416	-0.036	0.048	-0.264	0.200	0.277	0.708	0.795	R52
R53	0.508	0.292	0.017	0.444	0.523	-0.250	-0.016	0.140	-0.029	0.584	R53
R54	0.826	0.265	0.624	0.832	0.836	0.381	0.218	0.379	-0.176	0.031	R54
R55	0.841	0.467	0.616	0.904	0.915	0.243	0.108	0.299	-0.203	0.023	R55
R56	0.900	0.522	0.754	0.923	0.917	0.362	0.039	0.164	-0.261	-0.146	R56
R57	0.902	0.510	0.748	0.919	0.938	0.361	0.031	0.192	-0.250	-0.110	R57
R58	0.965	0.624	0.663	0.872	0.880	0.103	-0.156	0.005	-0.371	-0.094	R58
R59	0.849	0.279	0.634	0.844	0.853	0.336	0.199	0.375	-0.231	0.011	R59
R60	0.861	0.493	0.682	0.930	0.936	0.290	0.098	0.290	-0.314	-0.083	R60
	R86	**R87**	**R88**	**R89**	**R90**	**R91**	**R92**	**R93**	**R94**	**R95**	

	R86	**R87**	**R88**	**R89**	**R90**	**R91**	**R92**	**R93**	**R94**	**R95**	
R61	0.902	0.526	0.795	0.958	0.952	0.397	0.062	0.190	-0.300	-0.223	R61
R62	0.894	0.502	0.777	0.935	0.965	0.389	0.045	0.223	-0.274	-0.157	R62
R63	0.315	-0.144	0.669	0.655	0.637	0.816	0.641	0.727	-0.357	-0.387	R63
R64	0.297	-0.204	0.625	0.557	0.571	0.787	0.608	0.748	0.056	-0.332	R64
R65	0.592	0.184	0.694	0.733	0.819	0.688	0.272	0.468	-0.058	-0.185	R65
R66	-0.049	-0.171	-0.327	0.110	0.181	-0.154	0.325	0.431	0.727	0.861	R66
R67	0.497	0.275	0.001	0.416	0.513	-0.251	-0.016	0.151	0.050	0.599	R67
R68	0.907	0.867	0.653	0.826	0.810	-0.044	-0.426	-0.317	-0.387	-0.131	R68
R69	0.826	0.503	0.913	0.954	0.942	0.522	0.102	0.284	-0.496	-0.396	R69
R70	0.912	0.539	0.784	0.960	0.948	0.384	0.050	0.170	-0.294	-0.180	R70
R71	0.916	0.527	0.772	0.950	0.971	0.374	0.033	0.199	-0.276	-0.124	R71
R72	0.988	0.657	0.676	0.890	0.899	0.088	-0.188	-0.020	-0.387	-0.110	R72
R73	0.847	0.947	0.575	0.751	0.732	-0.206	-0.586	-0.475	-0.416	-0.164	R73
R74	0.787	0.489	0.957	0.929	0.911	0.579	0.100	0.272	-0.602	-0.512	R74
R75	0.906	0.542	0.820	0.986	0.972	0.416	0.073	0.190	-0.314	-0.246	R75
R76	0.904	0.521	0.795	0.959	0.989	0.396	0.044	0.221	-0.285	-0.157	R76
R77	0.155	-0.298	0.693	0.521	0.500	0.971	0.723	0.775	-0.340	-0.510	R77
R78	-0.051	-0.655	0.317	0.272	0.236	0.814	0.953	0.960	0.232	-0.129	R78
R79	0.238	-0.430	0.461	0.455	0.515	0.793	0.773	0.924	0.117	-0.033	R79
R80	-0.242	-0.327	-0.611	-0.094	-0.062	-0.255	0.387	0.379	0.957	0.919	R80
R81	0.117	-0.024	-0.481	-0.005	0.116	-0.473	0.026	0.131	0.575	0.941	R81
R82	0.742	0.990	0.531	0.635	0.611	-0.283	-0.732	-0.630	-0.410	-0.189	R82
R83	0.728	0.475	0.993	0.871	0.848	0.628	0.075	0.232	-0.688	-0.638	R83
R84	0.909	0.553	0.805	0.986	0.964	0.392	0.062	0.166	-0.307	-0.205	R84
R85	0.917	0.535	0.788	0.971	0.991	0.380	0.036	0.204	-0.280	-0.132	R85
R86	1.000	0.670	0.681	0.897	0.906	0.086	-0.203	-0.031	-0.385	-0.121	R86
R87		1.000	0.452	0.555	0.530	-0.378	-0.814	-0.711	-0.397	-0.199	R87
R88			1.000	0.827	0.801	0.655	0.070	0.215	-0.759	-0.712	R88
R89				1.000	0.973	0.414	0.080	0.175	-0.301	-0.250	R89
R90					1.000	0.394	0.044	0.218	-0.269	-0.149	R90
R91						1.000	0.740	0.769	-0.353	-0.555	R91
R92							1.000	0.950	0.302	0.051	R92
R93								1.000	0.235	0.088	R93
R94									1.000	0.864	R94
R95										1.000	R95
	R86	**R87**	**R88**	**R89**	**R90**	**R91**	**R92**	**R93**	**R94**	**R95**	

	ht6	ht7	ht8	ht9	ht10	ht11	ht12	ht13	ht14	ht15	ht16	ht17	ht18	ht19	ht20	ht21	ht22	ht23	ht24	ht25	ti1	ti2	ti3	ti4	ti5	ti6	ti7	ti8	ti9	ti10	
ht5	0.662	0.261	0.142	0.164	-0.008	-0.029	0.786	0.655	0.245	0.140	0.165	-0.012	-0.105	0.936	0.649	0.268	0.144	0.162	-0.007	-0.033	-0.438	-0.333	-0.443	-0.427	0.842	0.624	0.014	-0.082	-0.170	-0.271	ht5
ht6	1.000	0.386	0.120	0.094	-0.063	-0.080	0.448	0.913	0.353	0.119	0.078	-0.066	-0.126	0.568	0.987	0.364	0.121	0.096	-0.061	-0.081	-0.541	-0.353	-0.462	-0.455	0.337	0.879	0.071	-0.119	-0.262	-0.318	ht6
ht7		1.000	0.115	0.273	0.304	0.359	0.200	0.362	0.954	0.115	0.263	0.307	0.330	0.166	0.372	0.984	0.113	0.276	0.306	0.353	-0.278	-0.349	-0.397	-0.438	0.149	0.338	0.838	-0.130	-0.125	-0.161	ht7
ht8			1.000	0.787	0.225	0.248	0.154	0.144	0.102	1.000	0.790	0.224	0.240	0.090	0.109	0.117	1.000	0.788	0.225	0.251	-0.187	-0.476	-0.307	-0.280	0.122	0.126	0.041	0.787	0.495	-0.001	ht8
ht9				1.000	0.707	0.658	0.129	0.090	0.241	0.786	0.984	0.707	0.655	0.139	0.080	0.271	0.787	0.998	0.709	0.658	-0.300	-0.527	-0.459	-0.469	0.096	0.035	0.131	0.498	0.546	0.280	ht9
ht10					1.000	0.901	0.072	-0.138	0.327	0.226	0.708	1.000	0.901	-0.056	-0.078	0.316	0.224	0.710	1.000	0.901	-0.324	-0.255	-0.488	-0.381	-0.097	-0.171	0.139	0.066	0.374	0.537	ht10
ht11						1.000	0.105	-0.164	0.367	0.248	0.658	0.900	0.993	-0.044	-0.094	0.365	0.248	0.662	0.898	1.000	-0.375	-0.336	-0.534	-0.474	-0.100	-0.170	0.166	0.031	0.259	0.364	ht11
ht12							1.000	0.464	0.233	0.151	0.126	0.066	0.024	0.775	0.412	0.225	0.154	0.122	0.071	0.102	-0.015	-0.115	-0.234	-0.235	0.865	0.610	0.193	0.047	-0.036	-0.154	ht12
ht13								1.000	0.329	0.143	0.086	-0.143	-0.206	0.557	0.903	0.338	0.144	0.093	-0.136	-0.159	-0.461	-0.339	-0.421	-0.404	0.403	0.836	0.093	-0.089	-0.242	-0.351	ht13
ht14									1.000	0.102	0.238	0.330	0.337	0.160	0.347	0.964	0.099	0.243	0.328	0.362	-0.209	-0.291	-0.321	-0.366	0.182	0.352	0.833	-0.094	-0.084	-0.088	ht14
ht15										1.000	0.789	0.224	0.240	0.088	0.108	0.116	1.000	0.787	0.226	0.251	-0.182	-0.472	-0.303	-0.276	0.121	0.125	0.043	0.791	0.500	0.007	ht15
ht16											1.000	0.707	0.655	0.136	0.071	0.260	0.789	0.986	0.709	0.657	-0.293	-0.521	-0.455	-0.466	0.102	0.020	0.127	0.499	0.534	0.283	ht16
ht17												1.000	0.900	-0.060	-0.081	0.319	0.223	0.710	1.000	0.900	-0.321	-0.256	-0.484	-0.378	-0.103	-0.177	0.145	0.065	0.378	0.540	ht17
ht18													1.000	-0.116	-0.135	0.336	0.240	0.659	0.898	0.994	-0.349	-0.306	-0.496	-0.435	-0.169	-0.216	0.153	0.052	0.291	0.399	ht18
ht19														1.000	0.556	0.180	0.091	0.136	-0.056	-0.048	-0.366	-0.279	-0.398	-0.408	0.851	0.577	-0.032	-0.101	-0.167	-0.315	ht19
ht20															1.000	0.351	0.110	0.084	-0.076	-0.092	-0.534	-0.347	-0.447	-0.445	0.324	0.865	0.065	-0.125	-0.267	-0.294	ht20
ht21																1.000	0.114	0.274	0.318	0.359	-0.259	-0.338	-0.385	-0.423	0.174	0.327	0.835	-0.117	-0.111	-0.138	ht21
ht22																	1.000	0.787	0.224	0.251	-0.187	-0.478	-0.306	-0.279	0.122	0.126	0.038	0.788	0.497	0.000	ht22
ht23																		1.000	0.712	0.662	-0.302	-0.528	-0.462	-0.473	0.087	0.029	0.133	0.497	0.541	0.281	ht23
ht24																			1.000	0.898	-0.325	-0.259	-0.489	-0.381	-0.097	-0.172	0.140	0.063	0.375	0.537	ht24
ht25																				1.000	-0.373	-0.335	-0.528	-0.466	-0.103	-0.169	0.162	0.038	0.265	0.369	ht25
ti1																					1.000	0.755	0.774	0.774	0.056	-0.116	0.272	0.311	0.434	0.476	ti1
ti2																						1.000	0.750	0.781	-0.050	-0.115	0.045	0.040	0.212	0.444	ti2
ti3																							1.000	0.952	-0.150	-0.233	0.012	0.274	0.456	0.430	ti3
ti4																								1.000	-0.148	-0.235	-0.034	0.285	0.429	0.542	ti4
ti5																									1.000	0.548	0.182	0.060	-0.003	-0.268	ti5
ti6																										1.000	0.259	0.014	-0.131	-0.340	ti6
ti7																											1.000	0.065	0.127	0.145	ti7
ti8																												1.000	0.784	0.441	ti8
ti9																													1.000	0.822	ti9
ti10																														1.000	ti10
	ht6	**ht7**	**ht8**	**ht9**	**ht10**	**ht11**	**ht12**	**ht13**	**ht14**	**ht15**	**ht16**	**ht17**	**ht18**	**ht19**	**ht20**	**ht21**	**ht22**	**ht23**	**ht24**	**ht25**	**ti1**	**ti2**	**ti3**	**ti4**	**ti5**	**ti6**	**ti7**	**ti8**	**ti9**	**ti10**	

	ti11	ti12	ti13	ti14	ti15	ti16	ti17	ti18	ti19	ti20	ti21	ti22	ti23	ti24	ti25	frc1	frc2	frc3	frc4	frc5	frc6	frc7	frc8	frc9	frc10	frc11	frc12	frc13	frc14	frc15	
ht5	-0.327	0.662	0.607	0.028	-0.080	-0.165	-0.272	-0.362	0.765	0.617	0.025	-0.066	-0.172	-0.272	-0.327	0.486	0.401	0.129	0.261	0.369	0.613	0.491	0.100	0.164	0.248	0.319	0.621	0.577	0.487	0.100	ht5
ht6	-0.401	0.251	0.750	0.074	-0.115	-0.269	-0.312	-0.414	0.271	0.873	0.054	-0.107	-0.263	-0.321	-0.399	0.480	0.297	0.180	0.251	0.651	0.579	0.470	0.134	0.183	0.290	0.440	0.663	0.591	0.474	0.135	ht6
ht7	-0.146	0.140	0.292	0.803	-0.138	-0.122	-0.163	-0.160	0.071	0.322	0.826	-0.135	-0.120	-0.158	-0.149	0.451	0.373	0.304	0.452	0.305	0.254	0.378	0.055	0.360	0.150	0.344	0.276	0.286	0.445	0.068	ht7
ht8	0.012	0.123	0.140	0.039	0.776	0.505	-0.009	0.008	0.076	0.111	0.046	0.798	0.499	0.006	0.014	0.221	0.491	-0.170	0.249	0.037	0.022	0.197	0.104	-0.158	-0.058	0.027	0.202	0.041	0.205	0.082	ht8
ht9	0.244	0.081	0.034	0.118	0.490	0.549	0.265	0.236	0.076	0.023	0.134	0.509	0.549	0.271	0.242	0.363	0.548	0.126	0.432	0.146	0.157	0.338	0.119	0.159	-0.040	-0.048	0.238	0.166	0.341	0.097	ht9
ht10	0.464	0.005	-0.231	0.177	0.086	0.389	0.516	0.451	-0.124	-0.181	0.158	0.078	0.379	0.536	0.460	0.331	0.224	0.440	0.028	0.266	0.089	0.314	-0.100	0.516	0.128	-0.194	0.265	0.140	0.303	-0.075	ht10
ht11	0.471	0.040	-0.244	0.193	0.041	0.274	0.346	0.456	-0.104	-0.181	0.180	0.042	0.265	0.372	0.468	0.398	0.296	0.462	0.119	0.236	0.028	0.362	-0.035	0.513	0.304	-0.105	0.214	0.092	0.361	-0.013	ht11
ht12	-0.177	0.947	0.606	0.216	0.047	-0.034	-0.157	-0.219	0.824	0.572	0.213	0.064	-0.040	-0.151	-0.178	0.120	0.287	0.033	0.107	0.023	0.230	0.128	0.123	0.022	0.470	0.198	0.576	0.180	0.127	0.112	ht12
ht13	-0.408	0.308	0.896	0.091	-0.087	-0.241	-0.345	-0.419	0.325	0.834	0.073	-0.075	-0.242	-0.361	-0.401	0.424	0.330	0.110	0.240	0.531	0.548	0.413	0.148	0.100	0.252	0.301	0.608	0.521	0.420	0.147	ht13
ht14	-0.082	0.191	0.300	0.876	-0.101	-0.078	-0.089	-0.100	0.106	0.341	0.843	-0.103	-0.080	-0.082	-0.085	0.380	0.323	0.288	0.393	0.225	0.165	0.301	0.029	0.314	0.164	0.270	0.228	0.195	0.381	0.042	ht14
ht15	0.020	0.121	0.140	0.041	0.780	0.509	-0.001	0.016	0.075	0.110	0.048	0.802	0.503	0.015	0.022	0.217	0.489	-0.171	0.248	0.036	0.020	0.192	0.095	-0.159	-0.058	0.021	0.200	0.040	0.201	0.073	ht15
ht16	0.249	0.085	0.033	0.120	0.491	0.558	0.269	0.241	0.079	0.016	0.130	0.510	0.540	0.276	0.247	0.366	0.551	0.127	0.424	0.141	0.162	0.338	0.131	0.152	-0.041	-0.043	0.226	0.166	0.342	0.111	ht16
ht17	0.467	-0.003	-0.238	0.182	0.086	0.392	0.521	0.455	-0.130	-0.187	0.163	0.076	0.382	0.540	0.464	0.334	0.220	0.439	0.027	0.270	0.092	0.316	-0.102	0.514	0.125	-0.194	0.265	0.144	0.305	-0.078	ht17
ht18	0.508	-0.033	-0.286	0.177	0.063	0.305	0.382	0.501	-0.168	-0.223	0.166	0.062	0.296	0.406	0.506	0.367	0.262	0.451	0.064	0.226	0.001	0.335	-0.041	0.508	0.282	-0.144	0.189	0.071	0.333	-0.020	ht18
ht19	-0.341	0.693	0.565	-0.014	-0.099	-0.164	-0.321	-0.373	0.870	0.575	-0.016	-0.088	-0.170	-0.318	-0.342	0.447	0.323	0.139	0.261	0.261	0.578	0.446	0.118	0.159	0.309	0.317	0.542	0.517	0.437	0.119	ht19
ht20	-0.363	0.218	0.740	0.074	-0.122	-0.268	-0.286	-0.374	0.252	0.891	0.049	-0.114	-0.267	-0.301	-0.359	0.466	0.285	0.184	0.235	0.643	0.575	0.453	0.133	0.190	0.266	0.397	0.643	0.581	0.457	0.130	ht20
ht21	-0.124	0.170	0.279	0.823	-0.126	-0.110	-0.142	-0.139	0.097	0.313	0.852	-0.124	-0.107	-0.137	-0.128	0.433	0.368	0.301	0.451	0.280	0.240	0.359	0.036	0.356	0.152	0.326	0.269	0.268	0.427	0.049	ht21
ht22	0.015	0.123	0.139	0.036	0.777	0.507	-0.007	0.010	0.075	0.110	0.043	0.798	0.500	0.007	0.016	0.221	0.491	-0.169	0.250	0.040	0.023	0.197	0.098	-0.157	-0.058	0.026	0.203	0.043	0.204	0.076	ht22
ht23	0.246	0.072	0.029	0.119	0.489	0.547	0.267	0.239	0.066	0.019	0.136	0.508	0.548	0.272	0.245	0.365	0.548	0.132	0.435	0.160	0.171	0.342	0.121	0.162	-0.039	-0.045	0.238	0.180	0.344	0.099	ht23
ht24	0.462	0.003	-0.231	0.178	0.083	0.390	0.518	0.450	-0.125	-0.181	0.159	0.075	0.380	0.536	0.459	0.337	0.222	0.438	0.028	0.269	0.094	0.320	-0.098	0.514	0.126	-0.194	0.269	0.144	0.310	-0.073	ht24
ht25	0.479	0.038	-0.239	0.189	0.048	0.279	0.352	0.464	-0.107	-0.178	0.175	0.049	0.270	0.378	0.476	0.394	0.292	0.457	0.111	0.231	0.025	0.358	-0.039	0.510	0.305	-0.115	0.211	0.087	0.357	-0.018	ht25
ti1	0.471	0.229	-0.067	0.268	0.326	0.429	0.487	0.472	0.093	-0.136	0.264	0.303	0.431	0.498	0.469	-0.875	-0.490	-0.393	-0.553	-0.888	-0.925	-0.891	-0.147	-0.539	-0.136	-0.557	-0.643	-0.948	-0.876	-0.164	ti1
ti2	0.407	0.029	-0.118	0.051	0.056	0.205	0.449	0.412	-0.014	-0.125	0.038	0.037	0.209	0.455	0.404	-0.764	-0.662	-0.335	-0.615	-0.541	-0.588	-0.729	-0.209	-0.389	-0.036	-0.502	-0.459	-0.597	-0.720	-0.220	ti2
ti3	0.439	-0.075	-0.207	0.034	0.293	0.445	0.456	0.451	-0.122	-0.233	0.006	0.247	0.451	0.438	0.441	-0.786	-0.623	-0.369	-0.674	-0.603	-0.645	-0.763	-0.320	-0.520	-0.194	-0.477	-0.545	-0.649	-0.747	-0.315	ti3
ti4	0.531	-0.090	-0.196	-0.014	0.303	0.418	0.562	0.539	-0.140	-0.240	-0.037	0.263	0.424	0.534	0.533	-0.808	-0.663	-0.508	-0.736	-0.607	-0.653	-0.773	-0.273	-0.600	-0.298	-0.593	-0.526	-0.660	-0.760	-0.274	ti4
ti5	-0.291	0.904	0.598	0.202	0.061	0.005	-0.273	-0.324	0.961	0.529	0.202	0.077	-0.008	-0.269	-0.291	0.109	0.248	0.002	0.087	-0.142	0.201	0.105	0.123	-0.044	0.302	0.203	0.306	0.130	0.099	0.117	ti5
ti6	-0.397	0.532	0.892	0.271	0.017	-0.137	-0.340	-0.412	0.504	0.981	0.246	0.027	-0.136	-0.343	-0.394	0.143	0.182	0.065	0.101	0.254	0.226	0.126	0.169	-0.015	0.384	0.339	0.448	0.215	0.129	0.160	ti6
ti7	0.160	0.268	0.242	0.964	0.062	0.128	0.147	0.146	0.128	0.237	0.985	0.056	0.130	0.163	0.155	-0.021	0.105	0.092	0.140	-0.194	-0.258	-0.116	-0.019	0.056	0.092	-0.014	-0.081	-0.239	-0.042	-0.015	ti7
ti8	0.436	0.106	0.028	0.077	0.996	0.786	0.438	0.437	0.038	-0.004	0.070	0.993	0.785	0.458	0.438	-0.290	0.033	-0.329	-0.193	-0.290	-0.322	-0.299	-0.148	-0.393	-0.112	-0.407	-0.095	-0.316	-0.282	-0.163	ti8
ti9	0.767	0.041	-0.120	0.135	0.797	0.993	0.823	0.766	-0.006	-0.146	0.128	0.769	0.999	0.822	0.767	-0.395	-0.086	-0.231	-0.251	-0.348	-0.364	-0.401	-0.251	-0.330	-0.151	-0.582	-0.194	-0.364	-0.386	-0.266	ti9
ti10	0.897	-0.183	-0.367	0.180	0.474	0.822	0.997	0.895	-0.296	-0.317	0.158	0.432	0.823	0.993	0.896	-0.458	-0.334	-0.012	-0.573	0.001	-0.242	-0.453	-0.434	-0.028	-0.121	-0.637	0.005	-0.167	-0.446	-0.446	ti10
ti11	1.000	-0.192	-0.402	0.185	0.462	0.768	0.901	0.997	-0.299	-0.362	0.170	0.427	0.769	0.895	1.000	-0.441	-0.336	-0.033	-0.570	-0.077	-0.324	-0.451	-0.392	-0.027	-0.051	-0.654	-0.103	-0.245	-0.433	-0.410	ti11
ti12		1.000	0.568	0.291	0.105	0.047	-0.188	-0.230	0.889	0.488	0.291	0.123	0.036	-0.181	-0.192	-0.055	0.198	-0.014	0.032	-0.227	0.021	-0.052	0.131	-0.071	0.457	0.172	0.334	-0.044	-0.055	0.119	ti12
ti13			1.000	0.247	0.030	-0.118	-0.368	-0.414	0.548	0.881	0.227	0.045	-0.124	-0.378	-0.395	0.118	0.219	-0.001	0.100	0.139	0.228	0.102	0.177	-0.084	0.314	0.205	0.393	0.172	0.107	0.167	ti13
ti14				1.000	0.075	0.140	0.183	0.168	0.150	0.255	0.973	0.065	0.137	0.201	0.180	-0.029	0.089	0.100	0.121	-0.203	-0.272	-0.124	-0.035	0.048	0.111	-0.047	-0.083	-0.254	-0.042	-0.030	ti14
ti15					1.000	0.798	0.472	0.464	0.038	-0.001	0.067	0.990	0.798	0.493	0.464	-0.304	0.020	-0.334	-0.203	-0.287	-0.322	-0.311	-0.167	-0.396	-0.110	-0.422	-0.090	-0.314	-0.294	-0.184	ti15
ti16						1.000	0.822	0.767	-0.001	-0.147	0.129	0.770	0.994	0.823	0.767	-0.382	-0.075	-0.223	-0.246	-0.345	-0.355	-0.391	-0.240	-0.326	-0.150	-0.572	-0.196	-0.358	-0.375	-0.254	ti16
	ti11	ti12	ti13	ti14	ti15	ti16	ti17	ti18	ti19	ti20	ti21	ti22	ti23	ti24	ti25	frc1	frc2	frc3	frc4	frc5	frc6	frc7	frc8	frc9	frc10	frc11	frc12	frc13	frc14	frc15	

	ti11	**ti12**	**ti13**	**ti14**	**ti15**	**ti16**	**ti17**	**ti18**	**ti19**	**ti20**	**ti21**	**ti22**	**ti23**	**ti24**	**ti25**	**frc1**	**frc2**	**frc3**	**frc4**	**frc5**	**frc6**	**frc7**	**frc8**	**frc9**	**frc10**	**frc11**	**frc12**	**frc13**	**frc14**	**frc15**	
ti17							1.000	0.899	-0.306	-0.314	0.158	0.429	0.823	0.993	0.900	-0.465	-0.339	-0.020	-0.577	0.011	-0.231	-0.456	-0.440	-0.042	-0.128	-0.637	0.017	-0.155	-0.447	-0.454	ti17
ti18								1.000	-0.329	-0.376	0.155	0.428	0.768	0.892	0.998	-0.448	-0.346	-0.038	-0.588	-0.075	-0.327	-0.454	-0.385	-0.030	-0.064	-0.657	-0.112	-0.246	-0.438	-0.403	ti18
ti19									1.000	0.481	0.149	0.052	-0.012	-0.299	-0.299	0.086	0.176	0.016	0.089	-0.194	0.181	0.078	0.135	-0.039	0.342	0.205	0.246	0.093	0.069	0.129	ti19
ti20										1.000	0.226	0.009	-0.149	-0.324	-0.357	0.153	0.175	0.078	0.094	0.266	0.245	0.131	0.166	0.006	0.354	0.301	0.442	0.229	0.135	0.152	ti20
ti21											1.000	0.059	0.131	0.174	0.165	-0.017	0.109	0.098	0.151	-0.206	-0.259	-0.110	-0.033	0.065	0.095	-0.019	-0.082	-0.244	-0.038	-0.030	ti21
ti22												1.000	0.770	0.451	0.429	-0.284	0.050	-0.344	-0.183	-0.286	-0.316	-0.290	-0.103	-0.401	-0.109	-0.399	-0.079	-0.311	-0.278	-0.119	ti22
ti23													1.000	0.823	0.769	-0.391	-0.084	-0.226	-0.247	-0.341	-0.358	-0.397	-0.249	-0.326	-0.150	-0.579	-0.195	-0.358	-0.382	-0.264	ti23
ti24														1.000	0.894	-0.460	-0.321	0.006	-0.574	0.001	-0.248	-0.462	-0.434	-0.037	-0.076	-0.648	0.006	-0.173	-0.455	-0.448	ti24
ti25															1.000	-0.442	-0.337	-0.037	-0.571	-0.080	-0.324	-0.451	-0.393	-0.030	-0.052	-0.655	-0.104	-0.246	-0.433	-0.412	ti25
frc1																1.000	0.572	0.419	0.662	0.753	0.884	0.967	0.168	0.559	0.226	0.575	0.569	0.882	0.968	0.183	frc1
frc2																	1.000	0.277	0.644	0.384	0.429	0.552	0.151	0.280	0.133	0.398	0.411	0.438	0.553	0.147	frc2
frc3																		1.000	0.393	0.301	0.290	0.416	-0.159	0.763	0.250	0.212	0.129	0.288	0.415	-0.137	frc3
frc4																			1.000	0.414	0.438	0.626	0.081	0.523	0.073	0.655	0.301	0.449	0.627	0.079	frc4
frc5																				1.000	0.790	0.770	0.045	0.447	-0.042	0.365	0.678	0.859	0.770	0.058	frc5
frc6																					1.000	0.878	0.083	0.397	-0.016	0.475	0.704	0.985	0.881	0.101	frc6
frc7																						1.000	0.150	0.572	0.186	0.586	0.584	0.883	0.986	0.166	frc7
frc8																							1.000	-0.180	0.026	0.258	0.118	0.056	0.139	0.979	frc8
frc9																								1.000	0.163	0.165	0.263	0.424	0.570	-0.165	frc9
frc10																									1.000	-0.003	0.235	-0.033	0.192	0.033	frc10
frc11																										1.000	0.324	0.473	0.575	0.275	frc11
frc12																											1.000	0.718	0.586	0.116	frc12
frc13																												1.000	0.884	0.074	frc13
frc14																													1.000	0.155	frc14
frc15																														1.000	frc15
	ti11	**ti12**	**ti13**	**ti14**	**ti15**	**ti16**	**ti17**	**ti18**	**ti19**	**ti20**	**ti21**	**ti22**	**ti23**	**ti24**	**ti25**	**frc1**	**frc2**	**frc3**	**frc4**	**frc5**	**frc6**	**frc7**	**frc8**	**frc9**	**frc10**	**frc11**	**frc12**	**frc13**	**frc14**	**frc15**	

	frc16	**frc17**	**frc18**	**frc19**	**frc20**	**frc21**	**frc22**	**frc23**	**frc24**	**frc25**	**vel1**	**vel2**	**vel3**	**vel4**	**vel5**	**vel6**	**vel7**	**vel8**	**vel9**	**vel10**	**vel11**	**vel12**	**vel13**	**vel14**	**vel15**	**vel16**	**vel17**	**vel18**	**vel19**	**vel20**	
ht5	0.160	0.302	0.298	0.395	0.612	0.493	0.077	0.164	0.299	0.323	0.488	0.376	0.125	0.309	0.407	0.589	0.500	0.080	0.199	0.201	0.367	0.207	0.604	0.507	0.064	0.196	0.175	0.363	0.327	0.607	ht5
ht6	0.183	0.330	0.434	0.662	0.583	0.472	0.114	0.182	0.322	0.442	0.481	0.246	0.165	0.288	0.651	0.511	0.460	0.105	0.175	0.203	0.461	0.553	0.518	0.454	0.107	0.170	0.184	0.452	0.615	0.534	ht6
ht7	0.364	0.184	0.345	0.316	0.268	0.381	0.073	0.361	0.200	0.348	0.486	0.307	0.291	0.449	0.268	0.210	0.349	0.039	0.366	0.188	0.332	0.291	0.221	0.317	0.066	0.362	0.176	0.335	0.291	0.214	ht7
ht8	-0.170	-0.011	0.031	0.039	0.028	0.195	0.083	-0.160	-0.048	0.026	0.209	0.514	-0.140	0.245	0.058	0.005	0.197	0.064	-0.140	-0.007	0.060	0.010	0.041	0.186	0.071	-0.129	-0.014	0.040	0.058	0.018	ht8
ht9	0.151	0.020	-0.036	0.143	0.154	0.338	0.093	0.159	-0.002	-0.050	0.359	0.527	0.131	0.422	0.174	0.139	0.334	0.112	0.192	0.020	-0.020	0.104	0.171	0.323	0.118	0.195	-0.004	-0.048	0.143	0.159	ht9
ht10	0.511	0.155	-0.192	0.230	0.093	0.313	-0.106	0.513	0.157	-0.194	0.346	0.191	0.394	0.027	0.209	0.028	0.306	-0.069	0.514	0.174	-0.194	0.233	0.072	0.294	-0.101	0.511	0.164	-0.211	0.237	0.075	ht10
ht11	0.512	0.317	-0.102	0.214	0.030	0.363	-0.035	0.511	0.329	-0.104	0.413	0.259	0.424	0.132	0.171	-0.030	0.351	-0.010	0.510	0.341	-0.110	0.237	0.017	0.331	-0.028	0.505	0.336	-0.129	0.223	0.030	ht11
ht12	0.019	0.527	0.180	0.027	0.215	0.128	0.092	0.021	0.522	0.203	0.145	0.263	0.055	0.145	0.053	0.207	0.135	0.086	0.056	0.376	0.223	-0.137	0.225	0.146	0.074	0.052	0.334	0.219	-0.015	0.230	ht12
ht13	0.102	0.297	0.295	0.548	0.547	0.418	0.112	0.100	0.310	0.301	0.431	0.294	0.097	0.271	0.545	0.485	0.398	0.129	0.107	0.140	0.324	0.434	0.487	0.407	0.134	0.100	0.129	0.322	0.501	0.503	ht13
ht14	0.318	0.192	0.273	0.233	0.178	0.305	0.048	0.314	0.203	0.273	0.417	0.263	0.283	0.392	0.194	0.110	0.276	0.007	0.321	0.191	0.256	0.219	0.133	0.243	0.029	0.315	0.178	0.256	0.216	0.125	ht14
ht15	-0.170	-0.013	0.025	0.038	0.027	0.191	0.072	-0.161	-0.048	0.019	0.205	0.512	-0.141	0.243	0.057	0.004	0.193	0.057	-0.140	-0.006	0.053	0.009	0.040	0.182	0.066	-0.130	-0.013	0.033	0.056	0.017	ht15
ht16	0.141	0.017	-0.034	0.140	0.160	0.338	0.109	0.151	-0.003	-0.045	0.358	0.536	0.135	0.413	0.170	0.145	0.337	0.121	0.181	0.016	-0.023	0.106	0.182	0.324	0.126	0.185	-0.012	-0.047	0.140	0.166	ht16
ht17	0.509	0.152	-0.192	0.235	0.095	0.316	-0.108	0.511	0.155	-0.194	0.350	0.186	0.394	0.025	0.213	0.031	0.308	-0.072	0.512	0.171	-0.194	0.238	0.074	0.296	-0.104	0.509	0.161	-0.211	0.241	0.077	ht17
ht18	0.507	0.289	-0.136	0.204	0.003	0.337	-0.042	0.505	0.305	-0.143	0.380	0.231	0.409	0.074	0.157	-0.062	0.323	-0.024	0.502	0.314	-0.150	0.232	-0.015	0.301	-0.043	0.496	0.311	-0.171	0.213	-0.005	ht18
ht19	0.154	0.366	0.300	0.293	0.565	0.446	0.104	0.157	0.364	0.321	0.448	0.301	0.134	0.308	0.321	0.561	0.459	0.117	0.192	0.271	0.369	0.095	0.576	0.464	0.095	0.192	0.246	0.360	0.211	0.575	ht19
ht20	0.190	0.295	0.389	0.658	0.576	0.455	0.108	0.189	0.308	0.397	0.465	0.238	0.165	0.270	0.643	0.502	0.446	0.110	0.182	0.143	0.408	0.553	0.515	0.438	0.109	0.175	0.125	0.406	0.611	0.525	ht20
ht21	0.359	0.189	0.327	0.289	0.253	0.363	0.057	0.356	0.204	0.331	0.469	0.300	0.289	0.446	0.245	0.193	0.332	0.018	0.362	0.186	0.316	0.265	0.205	0.299	0.042	0.358	0.174	0.318	0.270	0.197	ht21
ht22	-0.168	-0.011	0.030	0.042	0.030	0.195	0.078	-0.158	-0.047	0.024	0.208	0.513	-0.140	0.246	0.060	0.007	0.197	0.056	-0.138	-0.007	0.059	0.013	0.043	0.187	0.064	-0.128	-0.013	0.039	0.060	0.019	ht22
ht23	0.153	0.020	-0.034	0.159	0.169	0.341	0.096	0.161	-0.001	-0.047	0.361	0.528	0.137	0.425	0.189	0.155	0.338	0.114	0.194	0.022	-0.019	0.122	0.185	0.326	0.120	0.196	-0.004	-0.046	0.158	0.174	ht23
ht24	0.510	0.154	-0.192	0.233	0.097	0.320	-0.103	0.511	0.157	-0.194	0.353	0.188	0.393	0.027	0.213	0.033	0.312	-0.067	0.512	0.169	-0.194	0.234	0.077	0.300	-0.099	0.510	0.159	-0.210	0.239	0.079	ht24
ht25	0.509	0.316	-0.112	0.209	0.026	0.359	-0.040	0.507	0.330	-0.114	0.408	0.256	0.418	0.124	0.166	-0.033	0.347	-0.014	0.506	0.338	-0.118	0.232	0.015	0.327	-0.032	0.501	0.334	-0.139	0.218	0.027	ht25
ti1	-0.537	-0.173	-0.551	-0.901	-0.930	-0.892	-0.168	-0.538	-0.178	-0.561	-0.858	-0.449	-0.355	-0.596	-0.922	-0.925	-0.891	-0.177	-0.548	-0.199	-0.579	-0.813	-0.907	-0.893	-0.178	-0.554	-0.181	-0.580	-0.873	-0.913	ti1
ti2	-0.385	-0.081	-0.496	-0.551	-0.592	-0.730	-0.215	-0.388	-0.077	-0.504	-0.755	-0.594	-0.330	-0.648	-0.574	-0.572	-0.721	-0.247	-0.405	-0.100	-0.536	-0.482	-0.581	-0.720	-0.251	-0.410	-0.077	-0.529	-0.535	-0.581	ti2
ti3	-0.517	-0.284	-0.465	-0.611	-0.651	-0.763	-0.305	-0.519	-0.264	-0.479	-0.779	-0.573	-0.330	-0.723	-0.632	-0.628	-0.748	-0.355	-0.540	-0.337	-0.499	-0.538	-0.621	-0.748	-0.374	-0.546	-0.325	-0.501	-0.589	-0.632	ti3
ti4	-0.595	-0.360	-0.586	-0.621	-0.656	-0.773	-0.258	-0.599	-0.342	-0.597	-0.805	-0.611	-0.488	-0.789	-0.634	-0.638	-0.757	-0.320	-0.623	-0.413	-0.619	-0.553	-0.636	-0.758	-0.345	-0.629	-0.396	-0.619	-0.594	-0.652	ti4
ti5	-0.047	0.368	0.181	-0.114	0.192	0.105	0.087	-0.045	0.360	0.206	0.129	0.243	0.021	0.126	-0.096	0.191	0.120	0.095	-0.004	0.264	0.253	-0.286	0.217	0.134	0.080	-0.008	0.230	0.249	-0.178	0.214	ti5
ti6	-0.012	0.449	0.333	0.265	0.226	0.128	0.137	-0.015	0.428	0.340	0.164	0.147	0.071	0.139	0.253	0.158	0.120	0.122	-0.020	0.299	0.372	0.161	0.176	0.119	0.126	-0.028	0.270	0.360	0.219	0.188	ti6
ti7	0.060	0.107	-0.008	-0.188	-0.246	-0.113	-0.017	0.057	0.120	-0.012	0.023	0.065	0.105	0.120	-0.246	-0.299	-0.145	-0.047	0.060	0.096	-0.037	-0.167	-0.277	-0.176	-0.019	0.054	0.097	-0.035	-0.196	-0.288	ti7
ti8	-0.402	-0.114	-0.398	-0.299	-0.323	-0.301	-0.164	-0.395	-0.139	-0.412	-0.295	0.097	-0.289	-0.220	-0.284	-0.324	-0.291	-0.209	-0.390	-0.116	-0.402	-0.292	-0.293	-0.300	-0.206	-0.384	-0.109	-0.419	-0.273	-0.318	ti8
ti9	-0.337	-0.169	-0.567	-0.361	-0.373	-0.402	-0.262	-0.331	-0.174	-0.588	-0.391	-0.049	-0.196	-0.298	-0.341	-0.366	-0.389	-0.295	-0.314	-0.184	-0.589	-0.347	-0.334	-0.401	-0.307	-0.315	-0.195	-0.611	-0.340	-0.357	ti9
ti10	-0.033	-0.159	-0.629	-0.030	-0.241	-0.453	-0.465	-0.029	-0.146	-0.641	-0.434	-0.338	-0.002	-0.616	-0.098	-0.296	-0.450	-0.457	-0.033	-0.199	-0.670	0.041	-0.255	-0.455	-0.487	-0.039	-0.192	-0.682	-0.005	-0.254	ti10
ti11	-0.028	-0.111	-0.645	-0.094	-0.325	-0.450	-0.422	-0.027	-0.075	-0.657	-0.421	-0.337	-0.018	-0.604	-0.183	-0.372	-0.445	-0.414	-0.032	-0.142	-0.691	0.003	-0.333	-0.464	-0.435	-0.043	-0.131	-0.704	-0.066	-0.327	ti11
ti12	-0.073	0.521	0.152	-0.221	0.002	-0.053	0.095	-0.072	0.512	0.176	-0.024	0.180	0.016	0.060	-0.195	0.006	-0.043	0.098	-0.037	0.384	0.200	-0.359	0.028	-0.028	0.088	-0.041	0.338	0.198	-0.259	0.030	ti12
ti13	-0.080	0.381	0.198	0.158	0.223	0.106	0.128	-0.084	0.383	0.205	0.141	0.200	0.005	0.131	0.159	0.172	0.091	0.147	-0.072	0.212	0.237	0.047	0.184	0.105	0.154	-0.080	0.193	0.233	0.111	0.196	ti13
ti14	0.053	0.124	-0.040	-0.199	-0.259	-0.121	-0.029	0.049	0.133	-0.046	0.015	0.053	0.118	0.105	-0.248	-0.322	-0.149	-0.067	0.054	0.110	-0.070	-0.174	-0.290	-0.181	-0.044	0.046	0.109	-0.071	-0.202	-0.301	ti14
ti15	-0.406	-0.125	-0.413	-0.296	-0.323	-0.314	-0.182	-0.398	-0.142	-0.427	-0.308	0.086	-0.295	-0.232	-0.282	-0.325	-0.303	-0.228	-0.393	-0.120	-0.417	-0.289	-0.294	-0.312	-0.229	-0.387	-0.118	-0.434	-0.270	-0.319	ti15
ti16	-0.334	-0.167	-0.559	-0.357	-0.364	-0.392	-0.248	-0.327	-0.171	-0.578	-0.381	-0.034	-0.187	-0.294	-0.338	-0.356	-0.378	-0.286	-0.310	-0.182	-0.584	-0.341	-0.322	-0.390	-0.298	-0.312	-0.195	-0.603	-0.336	-0.347	ti16
	frc16	**frc17**	**frc18**	**frc19**	**frc20**	**frc21**	**frc22**	**frc23**	**frc24**	**frc25**	**vel1**	**vel2**	**vel3**	**vel4**	**vel5**	**vel6**	**vel7**	**vel8**	**vel9**	**vel10**	**vel11**	**vel12**	**vel13**	**vel14**	**vel15**	**vel16**	**vel17**	**vel18**	**vel19**	**vel20**	

	frc16	**frc17**	**frc18**	**frc19**	**frc20**	**frc21**	**frc22**	**frc23**	**frc24**	**frc25**	**vel1**	**vel2**	**vel3**	**vel4**	**vel5**	**vel6**	**vel7**	**vel8**	**vel9**	**vel10**	**vel11**	**vel12**	**vel13**	**vel14**	**vel15**	**vel16**	**vel17**	**vel18**	**vel19**	**vel20**	
ti17	-0.048	-0.172	-0.629	-0.019	-0.230	-0.456	-0.473	-0.043	-0.155	-0.641	-0.441	-0.344	-0.005	-0.621	-0.086	-0.284	-0.452	-0.465	-0.050	-0.213	-0.670	0.051	-0.245	-0.458	-0.495	-0.056	-0.211	-0.683	0.005	-0.242	ti17
ti18	-0.031	-0.126	-0.645	-0.091	-0.328	-0.453	-0.415	-0.030	-0.088	-0.660	-0.429	-0.344	-0.027	-0.623	-0.181	-0.377	-0.449	-0.411	-0.035	-0.156	-0.694	0.004	-0.339	-0.469	-0.432	-0.047	-0.145	-0.708	-0.065	-0.335	ti18
ti19	-0.042	0.410	0.187	-0.168	0.161	0.078	0.105	-0.041	0.401	0.208	0.104	0.170	0.034	0.124	-0.133	0.177	0.096	0.124	-0.001	0.314	0.255	-0.337	0.199	0.107	0.105	-0.003	0.280	0.248	-0.237	0.194	ti19
ti20	0.008	0.408	0.294	0.284	0.244	0.133	0.127	0.005	0.409	0.301	0.169	0.143	0.079	0.130	0.267	0.172	0.128	0.129	0.000	0.233	0.324	0.183	0.198	0.125	0.130	-0.008	0.205	0.319	0.238	0.205	ti20
ti21	0.068	0.116	-0.014	-0.201	-0.248	-0.107	-0.027	0.065	0.128	-0.017	0.027	0.068	0.111	0.130	-0.256	-0.303	-0.137	-0.063	0.069	0.098	-0.040	-0.182	-0.280	-0.170	-0.038	0.062	0.100	-0.038	-0.205	-0.291	ti21
ti22	-0.411	-0.111	-0.390	-0.295	-0.317	-0.293	-0.137	-0.402	-0.133	-0.404	-0.288	0.115	-0.305	-0.211	-0.278	-0.317	-0.282	-0.150	-0.397	-0.116	-0.390	-0.290	-0.286	-0.290	-0.144	-0.390	-0.111	-0.408	-0.267	-0.311	ti22
ti23	-0.333	-0.169	-0.564	-0.354	-0.367	-0.398	-0.259	-0.327	-0.173	-0.585	-0.387	-0.046	-0.191	-0.294	-0.335	-0.359	-0.385	-0.294	-0.310	-0.183	-0.587	-0.339	-0.328	-0.397	-0.305	-0.312	-0.194	-0.608	-0.333	-0.350	ti23
ti24	-0.042	-0.122	-0.640	-0.031	-0.246	-0.462	-0.472	-0.038	-0.112	-0.652	-0.436	-0.322	0.023	-0.614	-0.098	-0.304	-0.462	-0.461	-0.046	-0.147	-0.679	0.041	-0.263	-0.465	-0.488	-0.051	-0.143	-0.693	-0.006	-0.259	ti24
ti25	-0.031	-0.113	-0.647	-0.096	-0.325	-0.449	-0.424	-0.030	-0.075	-0.658	-0.421	-0.338	-0.023	-0.606	-0.185	-0.371	-0.445	-0.415	-0.034	-0.144	-0.692	-0.001	-0.331	-0.464	-0.436	-0.046	-0.134	-0.705	-0.069	-0.326	ti25
frc1	0.557	0.259	0.573	0.766	0.880	0.968	0.186	0.559	0.277	0.579	0.990	0.503	0.387	0.698	0.785	0.864	0.958	0.195	0.570	0.291	0.590	0.662	0.850	0.947	0.194	0.575	0.277	0.592	0.725	0.850	frc1
frc2	0.276	0.170	0.386	0.394	0.435	0.554	0.134	0.280	0.144	0.402	0.561	0.971	0.277	0.649	0.394	0.385	0.535	0.166	0.299	0.201	0.419	0.329	0.412	0.529	0.186	0.303	0.188	0.410	0.389	0.408	frc2
frc3	0.765	0.275	0.208	0.298	0.289	0.417	-0.139	0.762	0.251	0.216	0.422	0.235	0.972	0.402	0.293	0.291	0.400	-0.098	0.718	0.281	0.161	0.301	0.278	0.403	-0.081	0.716	0.274	0.167	0.282	0.315	frc3
frc4	0.519	0.156	0.652	0.422	0.441	0.628	0.074	0.523	0.105	0.658	0.658	0.553	0.370	0.982	0.437	0.418	0.611	0.113	0.539	0.210	0.706	0.393	0.430	0.606	0.135	0.544	0.194	0.692	0.415	0.438	frc4
frc5	0.444	-0.069	0.362	0.997	0.797	0.771	0.066	0.448	-0.059	0.369	0.722	0.318	0.260	0.417	0.982	0.748	0.749	0.050	0.436	-0.084	0.349	0.967	0.732	0.743	0.044	0.437	-0.078	0.352	0.988	0.748	frc5
frc6	0.388	-0.039	0.459	0.819	0.999	0.882	0.093	0.396	0.010	0.477	0.857	0.366	0.252	0.463	0.833	0.981	0.878	0.110	0.418	-0.035	0.470	0.670	0.986	0.877	0.097	0.421	-0.043	0.485	0.753	0.986	frc6
frc7	0.570	0.226	0.586	0.783	0.879	1.000	0.171	0.572	0.235	0.589	0.951	0.487	0.369	0.661	0.794	0.863	0.992	0.172	0.572	0.242	0.597	0.685	0.849	0.988	0.170	0.576	0.227	0.597	0.736	0.849	frc7
frc8	-0.179	0.064	0.261	0.043	0.082	0.150	0.950	-0.179	0.069	0.257	0.148	0.141	-0.139	0.098	0.074	0.057	0.146	0.912	-0.168	0.003	0.284	0.004	0.068	0.143	0.900	-0.171	-0.011	0.274	0.046	0.067	frc8
frc9	0.998	0.159	0.165	0.452	0.396	0.574	-0.182	1.000	0.202	0.168	0.564	0.229	0.685	0.537	0.436	0.396	0.554	-0.132	0.982	0.195	0.151	0.449	0.390	0.558	-0.118	0.984	0.190	0.157	0.427	0.411	frc9
frc10	0.165	0.973	0.009	-0.025	-0.019	0.185	0.003	0.161	0.973	0.003	0.239	0.132	0.269	0.139	0.008	-0.042	0.178	0.009	0.161	0.917	0.025	-0.063	-0.017	0.170	0.006	0.166	0.911	0.006	-0.031	-0.006	frc10
frc11	0.161	0.028	0.996	0.381	0.469	0.589	0.284	0.166	0.033	1.000	0.575	0.345	0.189	0.649	0.410	0.515	0.589	0.273	0.146	0.038	0.984	0.288	0.474	0.607	0.303	0.154	0.009	0.988	0.343	0.491	frc11
frc12	0.257	0.244	0.320	0.686	0.705	0.588	0.096	0.263	0.274	0.326	0.565	0.367	0.115	0.316	0.699	0.663	0.574	0.089	0.290	0.097	0.306	0.515	0.671	0.571	0.070	0.284	0.076	0.311	0.650	0.683	frc12
frc13	0.415	-0.066	0.459	0.881	0.986	0.886	0.070	0.424	-0.018	0.476	0.853	0.375	0.251	0.469	0.888	0.966	0.879	0.083	0.443	-0.053	0.467	0.751	0.963	0.879	0.069	0.446	-0.058	0.480	0.829	0.966	frc13
frc14	0.568	0.226	0.578	0.782	0.880	0.987	0.162	0.570	0.240	0.579	0.953	0.490	0.371	0.659	0.796	0.862	0.975	0.155	0.572	0.240	0.582	0.684	0.850	0.960	0.155	0.576	0.221	0.584	0.736	0.850	frc14
frc15	-0.162	0.081	0.278	0.057	0.102	0.166	0.942	-0.164	0.079	0.273	0.167	0.135	-0.121	0.098	0.090	0.081	0.163	0.904	-0.154	0.023	0.303	0.016	0.089	0.160	0.897	-0.158	0.010	0.292	0.061	0.089	frc15
frc16	1.000	0.162	0.161	0.448	0.388	0.571	-0.178	0.998	0.204	0.164	0.562	0.224	0.685	0.533	0.430	0.386	0.552	-0.133	0.981	0.201	0.147	0.446	0.379	0.555	-0.119	0.979	0.195	0.153	0.424	0.401	frc16
frc17		1.000	0.039	-0.057	-0.041	0.225	0.053	0.157	0.973	0.033	0.268	0.161	0.284	0.221	-0.008	-0.067	0.218	0.056	0.155	0.913	0.059	-0.103	-0.040	0.208	0.062	0.162	0.918	0.041	-0.056	-0.032	frc17
frc18			1.000	0.380	0.453	0.590	0.286	0.166	0.045	0.996	0.574	0.330	0.183	0.644	0.404	0.489	0.588	0.268	0.140	0.041	0.984	0.284	0.451	0.604	0.299	0.149	0.013	0.984	0.338	0.467	frc18
frc19				1.000	0.824	0.784	0.067	0.452	-0.036	0.386	0.736	0.331	0.253	0.429	0.983	0.777	0.762	0.050	0.441	-0.079	0.368	0.956	0.762	0.758	0.044	0.441	-0.071	0.372	0.980	0.775	frc19
frc20					1.000	0.882	0.096	0.395	0.006	0.471	0.853	0.376	0.249	0.465	0.838	0.980	0.878	0.108	0.416	-0.031	0.465	0.678	0.984	0.878	0.095	0.419	-0.037	0.480	0.760	0.983	frc20
frc21						1.000	0.171	0.573	0.234	0.593	0.953	0.489	0.370	0.663	0.795	0.866	0.992	0.172	0.573	0.241	0.600	0.685	0.852	0.987	0.170	0.578	0.225	0.601	0.736	0.852	frc21
frc22							1.000	-0.181	0.051	0.284	0.169	0.125	-0.127	0.095	0.084	0.068	0.166	0.806	-0.175	-0.008	0.306	0.032	0.071	0.160	0.791	-0.180	-0.016	0.302	0.062	0.071	frc22
frc23								1.000	0.199	0.169	0.563	0.228	0.684	0.537	0.437	0.395	0.554	-0.132	0.982	0.192	0.151	0.450	0.389	0.557	-0.118	0.983	0.186	0.157	0.428	0.410	frc23
frc24									1.000	0.038	0.293	0.140	0.253	0.173	0.007	-0.015	0.230	0.056	0.204	0.877	0.061	-0.092	0.010	0.220	0.054	0.209	0.874	0.044	-0.043	0.016	frc24
frc25										1.000	0.579	0.348	0.194	0.653	0.413	0.517	0.592	0.271	0.148	0.043	0.985	0.292	0.475	0.610	0.302	0.157	0.013	0.989	0.348	0.493	frc25
vel1											1.000	0.491	0.393	0.696	0.756	0.842	0.948	0.182	0.577	0.299	0.589	0.634	0.827	0.938	0.180	0.582	0.286	0.590	0.699	0.829	vel1
vel2												1.000	0.236	0.565	0.334	0.334	0.475	0.148	0.248	0.209	0.360	0.266	0.357	0.469	0.166	0.252	0.193	0.357	0.332	0.352	vel2
vel3													1.000	0.381	0.258	0.257	0.358	-0.080	0.656	0.289	0.145	0.262	0.245	0.360	-0.063	0.656	0.275	0.148	0.246	0.279	vel3
	frc16	**frc17**	**frc18**	**frc19**	**frc20**	**frc21**	**frc22**	**frc23**	**frc24**	**frc25**	**vel1**	**vel2**	**vel3**	**vel4**	**vel5**	**vel6**	**vel7**	**vel8**	**vel9**	**vel10**	**vel11**	**vel12**	**vel13**	**vel14**	**vel15**	**vel16**	**vel17**	**vel18**	**vel19**	**vel20**	

	frc16	**frc17**	**frc18**	**frc19**	**frc20**	**frc21**	**frc22**	**frc23**	**frc24**	**frc25**	**vel1**	**vel2**	**vel3**	**vel4**	**vel5**	**vel6**	**vel7**	**vel8**	**vel9**	**vel10**	**vel11**	**vel12**	**vel13**	**vel14**	**vel15**	**vel16**	**vel17**	**vel18**	**vel19**	**vel20**	
vel4														1.000	0.447	0.449	0.647	0.134	0.558	0.282	0.704	0.391	0.458	0.645	0.155	0.563	0.263	0.692	0.420	0.469	vel4
vel5															1.000	0.805	0.781	0.094	0.434	-0.024	0.396	0.938	0.790	0.775	0.086	0.437	-0.026	0.401	0.980	0.804	vel5
vel6																1.000	0.871	0.102	0.426	-0.036	0.505	0.638	0.989	0.874	0.090	0.430	-0.047	0.530	0.722	0.990	vel6
vel7																	1.000	0.172	0.557	0.229	0.602	0.665	0.857	0.993	0.166	0.561	0.213	0.604	0.721	0.857	vel7
vel8																		1.000	-0.123	0.011	0.302	0.023	0.109	0.177	0.985	-0.123	-0.006	0.293	0.061	0.110	vel8
vel9																			1.000	0.198	0.134	0.428	0.421	0.560	-0.109	0.997	0.189	0.145	0.421	0.439	vel9
vel10																				1.000	0.067	-0.099	-0.027	0.230	0.015	0.207	0.985	0.054	-0.078	-0.013	vel10
vel11																					1.000	0.268	0.466	0.622	0.331	0.145	0.038	0.996	0.326	0.481	vel11
vel12																						1.000	0.606	0.663	0.022	0.430	-0.084	0.275	0.970	0.629	vel12
vel13																							1.000	0.860	0.098	0.425	-0.037	0.484	0.701	0.995	vel13
vel14																								1.000	0.171	0.565	0.213	0.623	0.716	0.860	vel14
vel15																									1.000	-0.107	0.003	0.322	0.054	0.097	vel15
vel16																										1.000	0.200	0.155	0.420	0.442	vel16
vel17																											1.000	0.025	-0.066	-0.027	vel17
vel18																												1.000	0.335	0.498	vel18
vel19																													1.000	0.717	vel19
vel20																														1.000	vel20
	frc16	**frc17**	**frc18**	**frc19**	**frc20**	**frc21**	**frc22**	**frc23**	**frc24**	**frc25**	**vel1**	**vel2**	**vel3**	**vel4**	**vel5**	**vel6**	**vel7**	**vel8**	**vel9**	**vel10**	**vel11**	**vel12**	**vel13**	**vel14**	**vel15**	**vel16**	**vel17**	**vel18**	**vel19**	**vel10**	

	vel21	vel22	vel23	vel24	vel25	pow1	pow2	pow3	pow4	pow5	pow6	pow7	pow8	pow9	pow10	pow11	pow12	pow13	pow14	pow15	pow16	pow17	pow18	pow19	pow20	pow21	pow22	pow23	pow24	pow25	
ht5	0.495	0.088	0.190	0.204	0.354	0.474	0.428	0.124	0.258	0.366	0.599	0.477	0.179	0.157	0.387	0.312	0.485	0.585	0.479	0.175	0.152	0.413	0.298	0.350	0.605	0.477	0.159	0.153	0.377	0.309	ht5
ht6	0.444	0.116	0.168	0.238	0.445	0.468	0.312	0.192	0.238	0.645	0.547	0.452	0.191	0.200	0.354	0.404	0.688	0.561	0.453	0.193	0.199	0.377	0.396	0.636	0.559	0.447	0.192	0.198	0.354	0.396	ht6
ht7	0.346	0.072	0.364	0.202	0.327	0.450	0.386	0.311	0.437	0.290	0.233	0.362	0.085	0.356	0.163	0.321	0.310	0.259	0.400	0.094	0.355	0.169	0.322	0.304	0.243	0.363	0.093	0.354	0.177	0.320	ht7
ht8	0.196	0.090	-0.135	-0.028	0.049	0.195	0.488	-0.159	0.239	0.059	0.017	0.179	0.119	-0.148	-0.028	0.006	0.152	0.045	0.181	0.104	-0.152	-0.007	-0.001	0.060	0.026	0.176	0.123	-0.148	-0.033	-0.002	ht8
ht9	0.329	0.123	0.192	0.014	-0.031	0.336	0.556	0.134	0.415	0.163	0.147	0.318	0.117	0.161	0.033	-0.073	0.209	0.166	0.318	0.106	0.156	0.054	-0.076	0.150	0.152	0.315	0.121	0.160	0.030	-0.078	ht9
ht10	0.295	-0.067	0.514	0.187	-0.203	0.305	0.232	0.428	0.010	0.258	0.051	0.287	-0.112	0.484	0.145	-0.219	0.293	0.102	0.279	-0.103	0.479	0.150	-0.224	0.248	0.071	0.283	-0.127	0.479	0.147	-0.223	ht10
ht11	0.341	-0.002	0.508	0.349	-0.122	0.375	0.306	0.445	0.096	0.239	-0.001	0.335	-0.038	0.490	0.301	-0.136	0.272	0.058	0.332	-0.033	0.486	0.300	-0.142	0.250	0.023	0.332	-0.048	0.485	0.311	-0.140	ht11
ht12	0.137	0.095	0.051	0.393	0.211	0.118	0.318	0.013	0.111	0.027	0.215	0.117	0.178	0.008	0.596	0.181	0.301	0.192	0.121	0.172	0.004	0.620	0.168	0.002	0.215	0.117	0.156	0.004	0.585	0.180	ht12
ht13	0.394	0.132	0.101	0.207	0.315	0.420	0.343	0.120	0.232	0.532	0.522	0.398	0.179	0.116	0.345	0.270	0.598	0.509	0.406	0.180	0.115	0.373	0.264	0.524	0.529	0.399	0.185	0.115	0.341	0.265	ht13
ht14	0.274	0.036	0.318	0.203	0.251	0.381	0.339	0.288	0.381	0.219	0.144	0.288	0.064	0.310	0.169	0.250	0.250	0.173	0.333	0.072	0.310	0.174	0.252	0.230	0.158	0.289	0.070	0.308	0.179	0.249	ht14
ht15	0.192	0.081	-0.135	-0.028	0.042	0.191	0.486	-0.160	0.237	0.058	0.016	0.174	0.107	-0.149	-0.029	-0.001	0.150	0.044	0.177	0.092	-0.152	-0.008	-0.007	0.058	0.025	0.172	0.111	-0.148	-0.034	-0.008	ht15
ht16	0.331	0.133	0.183	0.003	-0.032	0.339	0.560	0.136	0.407	0.159	0.154	0.320	0.132	0.153	0.027	-0.068	0.202	0.172	0.320	0.121	0.147	0.051	-0.071	0.147	0.160	0.317	0.137	0.152	0.026	-0.072	ht16
ht17	0.297	-0.070	0.512	0.184	-0.203	0.308	0.227	0.426	0.008	0.262	0.053	0.290	-0.115	0.481	0.143	-0.219	0.296	0.105	0.281	-0.107	0.476	0.147	-0.224	0.252	0.074	0.285	-0.130	0.477	0.144	-0.223	ht17
ht18	0.311	-0.019	0.499	0.325	-0.162	0.344	0.269	0.438	0.035	0.229	-0.029	0.309	-0.041	0.485	0.271	-0.172	0.256	0.034	0.304	-0.037	0.482	0.268	-0.175	0.242	-0.006	0.306	-0.053	0.480	0.281	-0.176	ht18
ht19	0.456	0.122	0.189	0.277	0.355	0.437	0.352	0.138	0.254	0.261	0.565	0.436	0.173	0.155	0.443	0.317	0.374	0.536	0.434	0.169	0.151	0.466	0.304	0.237	0.562	0.435	0.156	0.151	0.436	0.314	ht19
ht20	0.427	0.114	0.174	0.197	0.398	0.455	0.301	0.200	0.221	0.637	0.542	0.438	0.181	0.208	0.344	0.365	0.676	0.555	0.438	0.179	0.205	0.366	0.359	0.633	0.553	0.432	0.182	0.205	0.341	0.359	ht20
ht21	0.329	0.048	0.359	0.204	0.312	0.433	0.383	0.305	0.439	0.266	0.219	0.345	0.069	0.350	0.170	0.305	0.293	0.243	0.382	0.077	0.349	0.176	0.306	0.281	0.229	0.346	0.075	0.348	0.184	0.305	ht21
ht22	0.197	0.084	-0.133	-0.027	0.047	0.194	0.488	-0.159	0.240	0.061	0.018	0.178	0.114	-0.147	-0.028	0.004	0.154	0.047	0.180	0.099	-0.150	-0.006	-0.003	0.062	0.027	0.176	0.117	-0.146	-0.033	-0.003	ht22
ht23	0.333	0.124	0.194	0.014	-0.029	0.340	0.556	0.142	0.419	0.178	0.163	0.323	0.119	0.165	0.034	-0.070	0.218	0.182	0.322	0.108	0.160	0.055	-0.073	0.166	0.169	0.320	0.124	0.163	0.031	-0.075	ht23
ht24	0.302	-0.064	0.513	0.184	-0.203	0.311	0.229	0.425	0.010	0.261	0.055	0.294	-0.110	0.482	0.146	-0.219	0.297	0.106	0.285	-0.102	0.477	0.151	-0.224	0.250	0.076	0.289	-0.125	0.477	0.147	-0.223	ht24
ht25	0.336	-0.008	0.504	0.348	-0.131	0.370	0.302	0.441	0.088	0.234	-0.005	0.330	-0.043	0.486	0.302	-0.146	0.268	0.054	0.327	-0.038	0.483	0.301	-0.152	0.245	0.019	0.327	-0.053	0.481	0.312	-0.150	ht25
ti1	**-0.892**	-0.208	-0.554	-0.236	-0.575	**-0.850**	-0.476	-0.405	-0.512	**-0.877**	**-0.913**	**-0.865**	-0.197	-0.521	-0.182	-0.518	**-0.787**	**-0.926**	**-0.863**	-0.212	-0.521	-0.199	-0.514	**-0.866**	**-0.911**	**-0.867**	-0.197	-0.522	-0.191	-0.517	ti1
ti2	**-0.720**	-0.275	-0.406	-0.109	-0.526	**-0.733**	-0.638	-0.332	-0.573	-0.526	-0.573	**-0.696**	-0.210	-0.367	-0.079	-0.460	-0.505	-0.585	**-0.695**	-0.224	-0.366	-0.099	-0.452	-0.516	-0.579	**-0.696**	-0.219	-0.366	-0.083	-0.455	ti2
ti3	**-0.749**	-0.381	-0.544	-0.344	-0.496	**-0.749**	-0.617	-0.373	-0.624	-0.593	-0.619	**-0.729**	-0.319	-0.498	-0.241	-0.431	-0.591	-0.623	**-0.723**	-0.331	-0.496	-0.277	-0.424	-0.581	-0.624	**-0.729**	-0.324	-0.497	-0.256	-0.430	ti3
ti4	**-0.759**	-0.340	-0.627	-0.399	-0.612	**-0.771**	-0.653	-0.503	-0.679	-0.593	-0.630	**-0.736**	-0.269	-0.574	-0.314	-0.535	-0.577	-0.638	**-0.735**	-0.281	-0.571	-0.339	-0.529	-0.586	-0.637	**-0.738**	-0.274	-0.573	-0.328	-0.532	ti4
ti5	0.126	0.094	-0.011	0.266	0.241	0.107	0.282	-0.017	0.092	-0.137	0.195	0.099	0.167	-0.056	0.435	0.207	0.047	0.162	0.102	0.161	-0.060	0.463	0.194	-0.153	0.198	0.102	0.149	-0.060	0.425	0.205	ti5
ti6	0.112	0.128	-0.027	0.332	0.354	0.139	0.208	0.066	0.092	0.248	0.193	0.114	0.205	0.001	0.459	0.309	0.359	0.194	0.115	0.203	0.001	0.491	0.301	0.240	0.204	0.111	0.207	-0.002	0.458	0.302	ti6
ti7	-0.146	-0.032	0.056	0.086	-0.040	-0.018	0.123	0.085	0.141	-0.204	-0.274	-0.123	-0.023	0.057	0.078	-0.018	-0.132	-0.254	-0.085	-0.022	0.056	0.073	-0.014	-0.183	-0.262	-0.122	-0.014	0.055	0.086	-0.018	ti7
ti8	-0.291	-0.203	-0.388	-0.141	-0.406	-0.298	0.031	-0.319	-0.173	-0.262	-0.313	-0.297	-0.131	-0.368	-0.120	-0.389	-0.174	-0.298	-0.292	-0.152	-0.371	-0.119	-0.390	-0.263	-0.311	-0.300	-0.133	-0.368	-0.134	-0.394	ti8
ti9	-0.395	-0.307	-0.317	-0.200	-0.593	-0.392	-0.078	-0.235	-0.225	-0.324	-0.356	-0.391	-0.242	-0.316	-0.138	-0.551	-0.271	-0.345	-0.388	-0.264	-0.320	-0.149	-0.547	-0.330	-0.357	-0.395	-0.246	-0.317	-0.152	-0.553	ti9
ti10	-0.461	-0.485	-0.038	-0.180	-0.673	-0.447	-0.323	-0.009	-0.539	-0.015	-0.265	-0.442	-0.437	-0.033	-0.133	-0.601	0.044	-0.201	-0.446	-0.443	-0.038	-0.155	-0.599	0.004	-0.247	-0.447	-0.454	-0.035	-0.145	-0.603	ti10
ti11	-0.463	-0.448	-0.039	-0.125	-0.695	-0.426	-0.322	-0.030	-0.541	-0.078	-0.334	-0.436	-0.400	-0.029	-0.080	-0.624	-0.030	-0.269	-0.437	-0.410	-0.033	-0.109	-0.622	-0.037	-0.316	-0.443	-0.413	-0.031	-0.083	-0.625	ti11
ti12	-0.035	0.099	-0.040	0.395	0.188	-0.051	0.233	-0.039	0.041	-0.219	0.012	-0.057	0.160	-0.087	0.573	0.162	0.038	-0.019	-0.053	0.154	-0.089	0.601	0.148	-0.241	0.009	-0.055	0.143	-0.090	0.563	0.160	ti12
ti13	0.095	0.143	-0.078	0.278	0.228	0.121	0.241	-0.000	0.097	0.142	0.204	0.091	0.183	-0.071	0.417	0.183	0.270	0.175	0.101	0.182	-0.071	0.451	0.177	0.133	0.210	0.095	0.191	-0.072	0.411	0.178	ti13
ti14	-0.150	-0.054	0.049	0.100	-0.074	-0.025	0.110	0.089	0.123	-0.206	-0.287	-0.129	-0.029	0.049	0.093	-0.050	-0.133	-0.264	-0.086	-0.029	0.049	0.088	-0.046	-0.187	-0.271	-0.128	-0.023	0.047	0.098	-0.050	ti14
ti15	-0.303	-0.221	-0.391	-0.153	-0.421	-0.310	0.017	-0.324	-0.182	-0.260	-0.313	-0.309	-0.150	-0.372	-0.125	-0.403	-0.170	-0.297	-0.303	-0.171	-0.375	-0.127	-0.403	-0.260	-0.312	-0.311	-0.152	-0.371	-0.140	-0.407	ti15
ti16	-0.384	-0.297	-0.313	-0.202	-0.587	-0.380	-0.066	-0.227	-0.221	-0.321	-0.346	-0.380	-0.228	-0.312	-0.139	-0.541	-0.269	-0.336	-0.377	-0.250	-0.316	-0.147	-0.538	-0.326	-0.347	-0.383	-0.232	-0.313	-0.152	-0.543	ti16
	vel21	**vel22**	**vel23**	**vel24**	**vel25**	**pow1**	**pow2**	**pow3**	**pow4**	**pow5**	**pow6**	**pow7**	**pow8**	**pow9**	**pow10**	**pow11**	**pow12**	**pow13**	**pow14**	**pow15**	**pow16**	**pow17**	**pow18**	**pow19**	**pow20**	**pow21**	**pow22**	**pow23**	**pow24**	**pow25**	

	vel21	vel22	vel23	vel24	vel25	pow1	pow2	pow3	pow4	pow5	pow6	pow7	pow8	pow9	pow10	pow11	pow12	pow13	pow14	pow15	pow16	pow17	pow18	pow19	pow20	pow21	pow22	pow23	pow24	pow25	
ti17	-0.464	-0.494	-0.055	-0.198	-0.673	-0.451	-0.329	-0.018	-0.542	-0.004	-0.253	-0.444	-0.445	-0.046	-0.141	-0.603	0.058	-0.190	-0.447	-0.452	-0.051	-0.165	-0.601	0.015	-0.235	-0.450	-0.462	-0.048	-0.153	-0.604	ti17
ti18	-0.468	-0.446	-0.043	-0.137	-0.699	-0.432	-0.334	-0.032	-0.564	-0.077	-0.338	-0.439	-0.391	-0.031	-0.097	-0.626	-0.034	-0.271	-0.441	-0.402	-0.035	-0.126	-0.623	-0.036	-0.320	-0.446	-0.404	-0.033	-0.100	-0.627	ti18
ti19	0.102	0.120	-0.004	0.316	0.242	0.086	0.211	0.001	0.091	-0.187	0.176	0.075	0.157	-0.049	0.467	0.213	-0.021	0.129	0.076	0.151	-0.052	0.494	0.200	-0.212	0.168	0.078	0.142	-0.052	0.459	0.210	ti19
ti20	0.116	0.125	-0.008	0.287	0.312	0.148	0.202	0.083	0.083	0.259	0.211	0.121	0.191	0.021	0.446	0.277	0.365	0.213	0.122	0.185	0.020	0.476	0.270	0.258	0.224	0.117	0.194	0.018	0.440	0.271	ti20
ti21	-0.139	-0.051	0.064	0.093	-0.042	-0.013	0.130	0.089	0.153	-0.215	-0.275	-0.116	-0.032	0.063	0.087	-0.022	-0.139	-0.257	-0.080	-0.033	0.062	0.083	-0.018	-0.193	-0.263	-0.116	-0.026	0.061	0.095	-0.022	ti21
ti22	-0.282	-0.156	-0.394	-0.142	-0.395	-0.292	0.048	-0.334	-0.164	-0.256	-0.308	-0.290	-0.107	-0.376	-0.111	-0.383	-0.162	-0.293	-0.287	-0.127	-0.380	-0.109	-0.384	-0.258	-0.306	-0.292	-0.106	-0.376	-0.126	-0.388	ti22
ti23	-0.391	-0.306	-0.314	-0.199	-0.590	-0.388	-0.076	-0.229	-0.220	-0.317	-0.349	-0.387	-0.239	-0.312	-0.138	-0.548	-0.267	-0.338	-0.384	-0.261	-0.315	-0.148	-0.545	-0.322	-0.350	-0.390	-0.243	-0.313	-0.151	-0.550	ti23
ti24	-0.471	-0.490	-0.049	-0.148	-0.684	-0.450	-0.313	0.006	-0.543	-0.015	-0.273	-0.452	-0.441	-0.039	-0.104	-0.618	0.045	-0.209	-0.456	-0.449	-0.044	-0.128	-0.617	0.003	-0.254	-0.457	-0.459	-0.041	-0.116	-0.620	ti24
ti25	-0.463	-0.451	-0.042	-0.126	-0.697	-0.426	-0.323	-0.033	-0.543	-0.081	-0.334	-0.436	-0.401	-0.031	-0.080	-0.626	-0.032	-0.269	-0.437	-0.412	-0.035	-0.109	-0.624	-0.040	-0.316	-0.443	-0.414	-0.034	-0.083	-0.627	ti25
frc1	0.956	0.219	0.576	0.315	0.586	0.993	0.571	0.424	0.625	0.752	0.880	0.956	0.218	0.541	0.270	0.539	0.673	0.877	0.960	0.228	0.541	0.281	0.537	0.735	0.871	0.957	0.216	0.541	0.281	0.538	frc1
frc2	0.533	0.187	0.298	0.165	0.406	0.552	0.989	0.271	0.620	0.380	0.413	0.528	0.157	0.271	0.134	0.352	0.411	0.432	0.531	0.164	0.268	0.155	0.339	0.383	0.426	0.527	0.161	0.269	0.142	0.346	frc2
frc3	0.403	-0.107	0.720	0.259	0.161	0.408	0.282	0.982	0.381	0.294	0.289	0.402	-0.127	0.764	0.236	0.160	0.210	0.283	0.406	-0.122	0.764	0.240	0.161	0.289	0.298	0.405	-0.132	0.763	0.241	0.164	frc3
frc4	0.609	0.136	0.539	0.186	0.694	0.654	0.657	0.406	0.990	0.415	0.425	0.609	0.083	0.515	0.118	0.622	0.368	0.438	0.613	0.096	0.514	0.148	0.613	0.411	0.434	0.610	0.088	0.514	0.131	0.617	frc4
frc5	0.731	0.065	0.435	-0.087	0.344	0.731	0.386	0.323	0.401	0.992	0.766	0.749	0.105	0.452	-0.057	0.326	0.902	0.808	0.747	0.114	0.449	-0.059	0.324	0.993	0.771	0.743	0.104	0.451	-0.050	0.324	frc5
frc6	0.866	0.119	0.417	-0.025	0.471	0.869	0.434	0.297	0.426	0.783	0.995	0.865	0.142	0.390	0.029	0.466	0.760	0.992	0.868	0.146	0.385	0.030	0.461	0.769	0.995	0.864	0.137	0.389	0.034	0.465	frc6
frc7	0.991	0.198	0.577	0.272	0.595	0.966	0.551	0.432	0.593	0.769	0.877	0.994	0.206	0.561	0.236	0.554	0.694	0.879	0.991	0.218	0.560	0.252	0.554	0.753	0.870	0.994	0.202	0.562	0.247	0.553	frc7
frc8	0.143	0.954	-0.168	-0.016	0.277	0.153	0.152	-0.171	0.055	0.050	0.066	0.142	0.908	-0.192	0.072	0.227	0.079	0.054	0.133	0.908	-0.193	0.094	0.226	0.036	0.069	0.140	0.927	-0.193	0.071	0.223	frc8
frc9	0.551	-0.140	0.984	0.230	0.154	0.552	0.284	0.785	0.507	0.439	0.390	0.557	-0.134	0.989	0.187	0.145	0.371	0.407	0.562	-0.124	0.988	0.188	0.147	0.440	0.394	0.557	-0.149	0.988	0.191	0.147	frc9
frc10	0.199	0.021	0.163	0.927	0.008	0.230	0.155	0.225	0.061	-0.024	-0.046	0.179	0.081	0.190	0.940	-0.022	0.117	-0.049	0.184	0.084	0.193	0.931	-0.023	-0.027	-0.034	0.188	0.078	0.188	0.947	-0.026	frc10
frc11	0.599	0.294	0.144	0.024	0.987	0.574	0.382	0.197	0.631	0.363	0.497	0.579	0.274	0.151	0.041	0.989	0.332	0.480	0.589	0.281	0.152	0.046	0.987	0.342	0.482	0.587	0.286	0.151	0.046	0.989	frc11
frc12	0.554	0.102	0.282	0.129	0.303	0.549	0.409	0.133	0.286	0.676	0.680	0.557	0.194	0.258	0.304	0.292	0.906	0.697	0.557	0.190	0.252	0.313	0.290	0.660	0.689	0.550	0.174	0.253	0.305	0.290	frc12
frc13	0.866	0.093	0.442	-0.050	0.466	0.865	0.442	0.298	0.435	0.848	0.977	0.868	0.122	0.419	-0.004	0.463	0.809	0.991	0.870	0.126	0.414	-0.008	0.458	0.838	0.977	0.865	0.115	0.417	0.002	0.462	frc13
frc14	0.974	0.186	0.577	0.273	0.580	0.968	0.553	0.430	0.596	0.770	0.879	0.979	0.199	0.560	0.240	0.546	0.696	0.881	0.991	0.210	0.559	0.253	0.547	0.753	0.872	0.980	0.196	0.560	0.250	0.546	frc14
frc15	0.161	0.950	-0.154	0.005	0.295	0.170	0.147	-0.149	0.053	0.062	0.086	0.158	0.896	-0.175	0.082	0.245	0.082	0.072	0.150	0.912	-0.176	0.107	0.243	0.048	0.089	0.157	0.923	-0.176	0.082	0.240	frc15
frc16	0.549	-0.139	0.982	0.235	0.150	0.550	0.279	0.789	0.502	0.434	0.380	0.555	-0.130	0.989	0.189	0.140	0.366	0.397	0.560	-0.119	0.989	0.190	0.143	0.436	0.386	0.555	-0.144	0.988	0.192	0.143	frc16
frc17	0.238	0.079	0.160	0.941	0.044	0.257	0.197	0.249	0.148	-0.049	-0.073	0.216	0.120	0.188	0.951	0.003	0.099	-0.082	0.215	0.127	0.191	0.957	0.002	-0.059	-0.060	0.224	0.119	0.187	0.960	-0.000	frc17
frc18	0.598	0.292	0.139	0.030	0.986	0.573	0.368	0.194	0.627	0.360	0.477	0.580	0.279	0.155	0.056	0.986	0.330	0.463	0.591	0.285	0.155	0.059	0.987	0.341	0.463	0.588	0.291	0.155	0.060	0.985	frc18
frc19	0.746	0.066	0.440	-0.078	0.363	0.744	0.397	0.323	0.408	0.988	0.796	0.762	0.107	0.458	-0.035	0.347	0.900	0.834	0.760	0.114	0.454	-0.041	0.346	0.988	0.798	0.756	0.106	0.457	-0.028	0.345	frc19
frc20	0.866	0.119	0.416	-0.022	0.466	0.866	0.440	0.297	0.429	0.789	0.994	0.866	0.144	0.391	0.022	0.459	0.765	0.992	0.868	0.149	0.386	0.023	0.454	0.774	0.995	0.864	0.139	0.389	0.028	0.458	frc20
frc21	0.991	0.198	0.579	0.270	0.598	0.967	0.553	0.433	0.595	0.770	0.880	0.994	0.207	0.562	0.236	0.558	0.697	0.882	0.991	0.218	0.561	0.251	0.557	0.754	0.874	0.994	0.202	0.563	0.247	0.557	frc21
frc22	0.161	0.906	-0.175	-0.023	0.301	0.173	0.138	-0.146	0.046	0.062	0.076	0.164	0.945	-0.190	0.041	0.251	0.073	0.064	0.156	0.949	-0.190	0.066	0.250	0.052	0.080	0.161	0.957	-0.190	0.047	0.248	frc22
frc23	0.551	-0.139	0.984	0.226	0.155	0.551	0.283	0.785	0.507	0.440	0.389	0.557	-0.133	0.989	0.186	0.145	0.371	0.406	0.562	-0.122	0.988	0.186	0.148	0.441	0.393	0.557	-0.148	0.989	0.189	0.148	frc23
frc24	0.249	0.070	0.207	0.920	0.048	0.280	0.170	0.225	0.092	-0.038	-0.022	0.228	0.125	0.222	0.969	0.012	0.126	-0.031	0.231	0.130	0.225	0.963	0.012	-0.041	-0.012	0.236	0.122	0.220	0.975	0.008	frc24
frc25	0.602	0.293	0.146	0.028	0.987	0.578	0.387	0.201	0.635	0.366	0.498	0.582	0.273	0.155	0.047	0.988	0.336	0.482	0.592	0.280	0.155	0.052	0.985	0.346	0.483	0.590	0.286	0.155	0.052	0.987	frc25
vel1	0.947	0.203	0.582	0.330	0.585	0.989	0.560	0.428	0.622	0.719	0.852	0.942	0.199	0.545	0.283	0.544	0.655	0.848	0.947	0.210	0.545	0.292	0.542	0.704	0.843	0.943	0.198	0.545	0.295	0.542	vel1
vel2	0.473	0.174	0.248	0.165	0.352	0.478	0.945	0.232	0.525	0.317	0.353	0.461	0.153	0.224	0.125	0.301	0.354	0.370	0.465	0.157	0.221	0.145	0.290	0.323	0.366	0.461	0.157	0.223	0.132	0.297	vel2
vel3	0.361	-0.085	0.657	0.243	0.140	0.374	0.282	0.932	0.359	0.255	0.253	0.353	-0.112	0.677	0.239	0.135	0.182	0.248	0.358	-0.110	0.675	0.238	0.133	0.248	0.260	0.356	-0.117	0.675	0.244	0.138	vel3
	vel21	**vel22**	**vel23**	**vel24**	**vel25**	**pow1**	**pow2**	**pow3**	**pow4**	**pow5**	**pow6**	**pow7**	**pow8**	**pow9**	**pow10**	**pow11**	**pow12**	**pow13**	**pow14**	**pow15**	**pow16**	**pow17**	**pow18**	**pow19**	**pow20**	**pow21**	**pow22**	**pow23**	**pow24**	**pow25**	

	vel21	vel22	vel23	vel24	vel25	pow1	pow2	pow3	pow4	pow5	pow6	pow7	pow8	pow9	pow10	pow11	pow12	pow13	pow14	pow15	pow16	pow17	pow18	pow19	pow20	pow21	pow22	pow23	pow24	pow25	
vel4	0.648	0.160	0.558	0.256	0.693	0.685	0.653	0.413	0.959	0.415	0.449	0.641	0.107	0.526	0.183	0.617	0.369	0.458	0.644	0.121	0.525	0.214	0.607	0.411	0.456	0.642	0.111	0.525	0.195	0.613	vel4
vel5	0.766	0.107	0.432	-0.018	0.393	0.763	0.396	0.312	0.426	0.983	0.811	0.773	0.128	0.440	0.009	0.375	0.898	0.844	0.772	0.137	0.436	0.008	0.372	0.976	0.813	0.768	0.128	0.439	0.015	0.373	vel5
vel6	0.864	0.108	0.424	-0.023	0.513	0.849	0.389	0.300	0.409	0.739	0.984	0.850	0.117	0.391	0.003	0.511	0.711	0.976	0.852	0.124	0.386	0.001	0.503	0.724	0.979	0.850	0.113	0.390	0.005	0.513	vel6
vel7	0.996	0.195	0.562	0.262	0.600	0.960	0.537	0.417	0.580	0.749	0.879	0.992	0.203	0.544	0.234	0.559	0.678	0.879	0.985	0.214	0.543	0.251	0.558	0.733	0.872	0.990	0.199	0.545	0.246	0.558	vel7
vel8	0.174	0.935	-0.120	-0.007	0.294	0.183	0.165	-0.108	0.089	0.057	0.099	0.164	0.706	-0.143	0.081	0.243	0.062	0.085	0.155	0.714	-0.144	0.105	0.237	0.042	0.101	0.165	0.748	-0.143	0.079	0.238	vel8
vel9	0.553	-0.129	0.997	0.234	0.140	0.561	0.303	0.731	0.520	0.429	0.415	0.554	-0.118	0.960	0.190	0.128	0.379	0.430	0.561	-0.106	0.957	0.190	0.129	0.428	0.418	0.554	-0.132	0.957	0.191	0.132	vel9
vel10	0.256	0.024	0.206	0.959	0.055	0.283	0.214	0.258	0.189	-0.070	-0.061	0.229	0.051	0.220	0.797	0.023	-0.004	-0.072	0.231	0.057	0.226	0.803	0.020	-0.085	-0.051	0.239	0.047	0.219	0.817	0.021	vel10
vel11	0.614	0.323	0.134	0.051	0.998	0.586	0.403	0.145	0.680	0.343	0.486	0.585	0.296	0.137	0.075	0.965	0.306	0.469	0.594	0.305	0.138	0.082	0.962	0.322	0.472	0.594	0.309	0.137	0.079	0.963	vel11
vel12	0.650	0.037	0.428	-0.104	0.263	0.644	0.334	0.327	0.385	0.961	0.648	0.669	0.051	0.458	-0.105	0.254	0.814	0.692	0.668	0.061	0.455	-0.112	0.252	0.969	0.651	0.664	0.054	0.459	-0.098	0.252	vel12
vel13	0.849	0.115	0.419	-0.008	0.470	0.835	0.419	0.287	0.421	0.724	0.985	0.837	0.121	0.384	0.039	0.471	0.702	0.980	0.840	0.125	0.378	0.038	0.463	0.707	0.984	0.836	0.118	0.383	0.039	0.470	vel13
vel14	0.995	0.195	0.565	0.258	0.620	0.948	0.529	0.420	0.573	0.741	0.879	0.984	0.195	0.547	0.227	0.576	0.672	0.879	0.976	0.207	0.546	0.243	0.574	0.727	0.872	0.986	0.191	0.548	0.238	0.575	vel14
vel15	0.169	0.930	-0.106	0.001	0.323	0.178	0.185	-0.092	0.109	0.051	0.085	0.159	0.683	-0.129	0.080	0.269	0.048	0.071	0.152	0.698	-0.130	0.107	0.264	0.036	0.087	0.160	0.732	-0.129	0.081	0.265	vel15
vel16	0.558	-0.130	0.998	0.244	0.150	0.566	0.305	0.728	0.526	0.430	0.418	0.558	-0.126	0.960	0.193	0.138	0.375	0.434	0.565	-0.114	0.958	0.193	0.138	0.428	0.420	0.559	-0.140	0.958	0.194	0.141	vel16
vel17	0.238	0.014	0.199	0.969	0.025	0.270	0.204	0.253	0.176	-0.066	-0.069	0.213	0.038	0.216	0.798	-0.009	-0.011	-0.078	0.213	0.046	0.222	0.805	-0.012	-0.074	-0.059	0.223	0.036	0.215	0.819	-0.012	vel17
vel18	0.614	0.313	0.145	0.039	0.998	0.588	0.394	0.151	0.665	0.345	0.506	0.587	0.292	0.141	0.054	0.971	0.312	0.486	0.596	0.300	0.142	0.063	0.967	0.327	0.489	0.595	0.304	0.142	0.060	0.970	vel18
vel19	0.705	0.074	0.417	-0.076	0.323	0.704	0.389	0.303	0.404	0.984	0.730	0.716	0.100	0.433	-0.045	0.305	0.885	0.775	0.714	0.110	0.430	-0.048	0.303	0.988	0.733	0.710	0.100	0.432	-0.036	0.303	vel19
vel20	0.847	0.116	0.437	-0.002	0.484	0.837	0.415	0.324	0.430	0.741	0.985	0.836	0.123	0.407	0.042	0.483	0.723	0.979	0.839	0.128	0.402	0.041	0.475	0.723	0.986	0.835	0.119	0.405	0.042	0.483	vel20
vel21	1.000	0.199	0.559	0.287	0.612	0.957	0.534	0.419	0.578	0.731	0.868	0.989	0.195	0.541	0.255	0.571	0.655	0.866	0.984	0.208	0.540	0.271	0.569	0.716	0.860	0.991	0.192	0.542	0.265	0.570	vel21
vel22		1.000	-0.127	0.009	0.314	0.202	0.187	-0.117	0.107	0.068	0.105	0.187	0.824	-0.152	0.086	0.259	0.075	0.092	0.180	0.836	-0.152	0.113	0.254	0.054	0.108	0.188	0.851	-0.152	0.087	0.254	vel22
vel23			1.000	0.243	0.140	0.566	0.302	0.733	0.519	0.428	0.414	0.560	-0.121	0.962	0.190	0.127	0.373	0.429	0.567	-0.109	0.960	0.191	0.127	0.427	0.417	0.561	-0.136	0.961	0.191	0.130	vel23
vel24				1.000	0.041	0.314	0.183	0.245	0.170	-0.070	-0.051	0.262	0.037	0.252	0.856	0.011	0.014	-0.065	0.266	0.049	0.258	0.863	0.009	-0.084	-0.043	0.272	0.035	0.251	0.872	0.008	vel24
vel25					1.000	0.583	0.388	0.147	0.668	0.337	0.490	0.585	0.293	0.140	0.060	0.971	0.302	0.471	0.593	0.301	0.141	0.068	0.968	0.316	0.474	0.593	0.304	0.140	0.065	0.969	vel25
pow1						1.000	0.553	0.417	0.624	0.734	0.871	0.966	0.207	0.537	0.274	0.546	0.655	0.866	0.970	0.217	0.538	0.284	0.544	0.717	0.861	0.966	0.205	0.538	0.287	0.544	pow1
pow2							1.000	0.277	0.640	0.384	0.418	0.531	0.163	0.277	0.165	0.332	0.414	0.437	0.533	0.169	0.274	0.187	0.319	0.387	0.432	0.530	0.168	0.275	0.172	0.326	pow2
pow3								1.000	0.397	0.316	0.296	0.421	-0.133	0.803	0.204	0.146	0.224	0.292	0.425	-0.129	0.803	0.209	0.148	0.314	0.306	0.424	-0.139	0.803	0.209	0.151	pow3
pow4									1.000	0.409	0.418	0.583	0.059	0.504	0.115	0.604	0.359	0.429	0.586	0.071	0.503	0.145	0.593	0.403	0.426	0.583	0.063	0.503	0.125	0.599	pow4
pow5										1.000	0.764	0.752	0.107	0.445	-0.037	0.326	0.909	0.805	0.750	0.115	0.442	-0.038	0.324	0.998	0.769	0.745	0.106	0.445	-0.029	0.324	pow5
pow6											1.000	0.870	0.128	0.385	-0.001	0.492	0.738	0.994	0.872	0.132	0.380	-0.001	0.487	0.750	0.999	0.868	0.122	0.384	0.003	0.492	pow6
pow7												1.000	0.202	0.550	0.230	0.555	0.673	0.870	0.995	0.212	0.549	0.247	0.555	0.737	0.863	0.999	0.197	0.551	0.242	0.554	pow7
pow8													1.000	-0.140	0.112	0.250	0.153	0.118	0.195	0.993	-0.141	0.132	0.251	0.094	0.132	0.198	0.992	-0.141	0.114	0.248	pow8
pow9														1.000	0.209	0.130	0.375	0.402	0.555	-0.131	0.999	0.212	0.134	0.449	0.391	0.550	-0.153	1.000	0.215	0.133	pow9
pow10															1.000	0.019	0.141	-0.010	0.234	0.116	0.211	0.995	0.019	-0.043	0.011	0.240	0.114	0.207	0.997	0.016	pow10
pow11																1.000	0.297	0.475	0.566	0.257	0.131	0.024	0.999	0.307	0.475	0.564	0.261	0.130	0.024	1.000	pow11
pow12																	1.000	0.772	0.672	0.154	0.368	0.142	0.295	0.903	0.747	0.665	0.141	0.372	0.146	0.294	pow12
pow13																		1.000	0.872	0.121	0.396	-0.012	0.470	0.792	0.994	0.868	0.112	0.401	-0.005	0.475	pow13
pow14																			1.000	0.205	0.555	0.248	0.567	0.734	0.865	0.996	0.192	0.556	0.245	0.566	pow14
pow15																				1.000	-0.130	0.139	0.258	0.102	0.135	0.209	0.992	-0.131	0.119	0.254	pow15
	vel21	**vel22**	**vel23**	**vel24**	**vel25**	**pow1**	**pow2**	**pow3**	**pow4**	**pow5**	**pow6**	**pow7**	**pow8**	**pow9**	**pow10**	**pow11**	**pow12**	**pow13**	**pow14**	**pow15**	**pow16**	**pow17**	**pow18**	**pow19**	**pow20**	**pow21**	**pow22**	**pow23**	**pow24**	**pow25**	

	vel21	vel22	vel23	vel24	vel25	pow1	pow2	pow3	pow4	pow5	pow6	pow7	pow8	pow9	pow10	pow11	pow12	pow13	pow14	pow15	pow16	pow17	pow18	pow19	pow20	pow21	pow22	pow23	pow24	pow25	
pow16																					1.000	0.214	0.135	0.445	0.385	0.549	-0.153	1.000	0.217	0.134	pow16
pow17																						1.000	0.023	-0.047	0.011	0.255	0.135	0.210	0.995	0.020	pow17
pow18																							1.000	0.306	0.469	0.564	0.262	0.134	0.024	0.999	pow18
pow19																								1.000	0.753	0.730	0.093	0.448	-0.034	0.305	pow19
pow20																									1.000	0.861	0.127	0.389	0.015	0.474	pow20
pow21																										1.000	0.194	0.552	0.251	0.563	pow21
pow22																											1.000	-0.154	0.116	0.258	pow22
pow23																												1.000	0.212	0.133	pow23
pow24																													1.000	0.021	pow24
pow25																														1.000	pow25
	vel21	vel22	vel23	vel24	vel25	pow1	pow2	pow3	pow4	pow5	pow6	pow7	pow8	pow9	pow10	pow11	pow12	pow13	pow14	pow15	pow16	pow17	pow18	pow19	pow20	pow21	pow22	pow23	pow24	pow25	

APPENDIX 7

FACTOR SOLUTIONS AND LOADINGS

Table A7.1: Results of PCA of Event data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	121	14		10		60
Second	61	8	95.2%	7	93.4%	4
Third	57	7	95.0%	6	92.9%	2
Fourth	55	7	95.3%	6	93.4%	0

Table A7.2: Factor structure (loadings > 0.3) from PCA of Event data

Row	Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
1	ti1	-0.933746					
2	ti5					0.953439	
3	ti7				0.952990		
4	ti12					0.942342	
5	ti14				0.947917		
6	ti19					0.944472	
7	ti21				0.957379		
8	ht8						0.989093
9	ht12					0.940355	
10	ht14				0.925087		
11	ht15						0.990255
12	ht21	0.300051			0.927006		
13	ht22						0.989578
14	frc1	0.950116					
15	frc5	0.878869					
16	frc6	0.975110					
17	frc7	0.959994					
18	frc8			0.986539			
19	frc10		0.980510				
20	frc12	0.748476				0.309724	
21	frc13	0.979618					
22	frc14	0.958021					
23	frc15			0.983664			
24	frc17		0.982865				
25	frc19	0.889919					
26	frc20	0.976911					
27	frc21	0.960895					
28	frc22			0.971892			
29	frc24		0.964602				
30	vel1	0.935916					
31	vel5	0.900882					
32	vel6	0.965660					
33	vel7	0.957721					
34	vel8			0.907574			
35	vel10		0.931672				
36	vel13	0.957209					
37	vel14	0.953229					
38	vel15			0.898338			
39	vel17		0.913736				
40	vel19	0.860000					
41	vel20	0.962041					
42	vel21	0.951365					
43	vel22			0.957655			
44	vel24		0.954066				
45	pow1	0.944253					
46	pow6	0.969766					
47	pow7	0.951519					
48	pow8			0.928778			
49	pow10		0.924298				
50	pow13	0.973500					
51	pow14	0.952014					
52	pow15			0.936049			
53	pow17		0.924686				
54	pow20	0.968596					

55	pow21	0.949901					
56	pow22			0.949897			
57	pow24		0.932893				
R²	**93.2%**	**42.5%**	**16.3%**	**15.7%**	**7.3%**	**6.7%**	**4.8%**

Interpretation of factors

Factor 1:	Exertion before first grip change
Factor 2:	Exertion at second grip change
Factor 3:	Exertion at first grip change
Factor 4:	Time and height of main peak exertion
Factor 5:	Time of initial peak exertion & height of initial peak velocity
Factor 6:	Height of first grip change

Table A7.3: Results of PCA of Event data after deletion of correlated variables

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	29	8	89.1%	5	77.4%	17
Second	12	3	79.7%	3	79.7%	2
Third	10	3		2	74.5%	1
Fourth	9	2	89.1%	2	89.1%	0

Table A7.4: Factor structure (loadings > 0.3) from PCA of Event data after deletion of correlated variables

Row	Variable	Factor 1	Factor 2
1	ti1	0.92862	
2	ti2	0.86278	
3	ti3	0.90344	
4	ti4	0.91404	
5	ti5		0.86862
6	ti6		0.85999
7	frc1	-0.95185	
8	frc5	-0.84365	
9	frc7	-0.94037	
R²	**81.6%**	**64.4%**	**17.2%**

Interpretation of factors

Factor 1:	Slowness of whole exertion, i.e. duration of exertion
Factor 2:	Timing of initial peak force and subsequent dip

Table A7.5: Results of PCA of transformed Event data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	121	13	94.8%	10	91.8%	63
Second	58	7	94.9%	7	94.9%	5
Third	53	7	95.1%	7	95.1%	5
Fourth	48	7	95.9%	7	95.9%	1
Fifth	47	7	95.9%	7	95.9%	0

Table A7.6: Factor structure (loadings > 0.3) from PCA of transformed Event variables

Row	Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
1	ti1	0.939156						
2	ti5					0.961149		
3	ti6							0.922857
4	ti7						0.949343	
5	ti12					0.925769		
6	ti14						0.936929	
7	ti19					0.965850		
8	ti20							0.929754
9	ht8				0.982244			
10	ht15				0.995841			
11	ht22				0.995358			
12	frc1	0.967071						
13	frc6	0.965580						
14	frc7	0.974702						
15	frc8			0.980028				
16	frc10		0.959275					
17	frc13	0.963125						
18	frc14	0.973338						

19	frc15			0.977542				
20	frc17		0.971462					
21	frc20	0.966052						
22	frc21	0.975695						
23	frc22			0.938698				
24	frc24		0.947870					
25	vel1	0.954726						
26	vel6	0.958162						
27	vel7	0.973403						
28	vel8			-0.975251				
29	vel10		0.966020					
30	vel13	0.950390						
31	vel14	0.967772						
32	vel15			-0.974557				
33	vel17		0.958062					
34	vel20	0.952517						
35	vel21	0.969019						
36	vel22			0.969499				
37	vel24		0.987378					
38	pow1	0.963362						
39	pow6	0.962295						
40	pow7	0.976520						
41	pow10		0.932190					
42	pow13	0.962291						
43	pow14	0.977587						
44	pow17		0.914349					
45	pow20	0.960154						
46	pow21	0.975597						
47	pow24		0.977941					
R^2	**95.1%**	**40.1%**	**17.1%**	**15.2%**	**8.8%**	**6.0%**	**5.5%**	**2.4%**

Interpretation of factors

Factor 1:	Exertion before first grip change
Factor 2:	Exertion at second grip change
Factor 3:	Exertion at first grip change
Factor 4:	Height of first grip change
Factor 5:	Time of initial peak exertion
Factor 6:	Time of main peak exertion
Factor 7:	Time of dip after initial peak exertion

Table A7.7: Results of PCA of female Event data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	121	15	95.8%	9	87.7%	72
Second	49	8	93.8%	7	91.7%	8
Third	41	7	94.7%	6	92.1%	0

Table A7.8: Factor structure (loadings > 0.3) from PCA of female Event data

Row	Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
1	ti1	-0.915800					
2	ht7					0.975660	
3	ht8				0.947730		
4	ht9				0.928980		
5	ht14					0.965810	
6	ht15				0.947600		
7	ht16				0.929560		
8	ht21					0.979260	
9	ht22				0.947900		
10	ht23				0.928960		
11	frc3						0.948830
12	frc8		0.953570				
13	frc11			0.935000			
14	frc12	0.927900					
15	frc13	0.974490					
16	frc15		0.935080				
17	frc19	0.979360					
18	frc22		0.922190				
19	vel3						0.958680
20	vel6	0.973770					

21	vel8		0.853940				
22	vel11			0.985090			
23	vel13	0.953290					
24	vel15		0.847120				
25	vel18			0.956000			
26	vel19	0.993180					
27	vel20	0.964340					
28	vel22		0.923150				
29	vel25			0.964890			
30	pow3						0.925710
31	pow6	0.965300					
32	pow8		0.873480				
33	pow11			0.974770			
34	pow12	0.963530					
35	pow13	0.965640					
36	pow15		0.902750				
37	pow18			0.960540			
38	pow19	0.976110					
39	pow20	0.958830					
40	pow22		0.938000				
41	pow25			0.960220			
R^2	**92.1%**	**32.8%**	**21.3%**	**14.0%**	**12.0%**	**7.4%**	**4.6%**

Interpretation of factors

Factor 1:	Exertion at initial peak / subsequent dip (before first grip change)
Factor 2:	Exertion at first grip change
Factor 3:	Exertion at peak exertion after second grip change
Factor 4:	Heights of first grip change and subsequent peak exertion
Factor 5:	Height of main peak exertion
Factor 6:	Exertion at 1.45 m

Table A7.9: Results of confirmatory PCA of female Events factor structure using male data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	41	6	92.5%	6	92.5%	9
Second	32	6	92.6%	6	92.6%	4
Third	28	5	91.4%	5	91.4%	0

Table A7.10: Factor structure (loadings > 0.3) from PCA of male Event data carried out to confirm the female Events factor structure

Row	Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1	ti1		-0.90689			
2	ht7				0.97951	
3	ht8			0.9131		
4	ht9			0.95864		
5	ht14				0.97517	
6	ht15			0.91309		
7	ht16			0.95628		
8	ht21				0.98507	
9	ht22			0.91331		
10	ht23			0.95848		
11	frc3					0.93647
12	frc8	0.98332				
13	frc12		0.78296			
14	frc13		0.91364			
15	frc15	0.98738				
16	frc19		0.96312			
17	frc22	0.96904				
18	vel3					0.92666
19	vel8	0.91001				
20	vel15	0.9022				
21	vel19		0.94381			
22	vel22	0.95722				
23	pow3					0.92394
24	pow8	0.94195				
25	pow12		0.94536			
26	pow15	0.94791				
27	pow19		0.9478			
28	pow22	0.95714				

R^2	**91.4%**	**31.5%**	**22.4%**	**19.7%**	**10.4%**	**7.3%**

Interpretation of factors

Factor 1: Exertion at first grip change
Factor 2: Exertion below first grip change
Factor 3: Heights of first grip change and subsequent peak
Factor 4: Height of main peak
Factor 5: Exertion at 1.45 m

Table A7.11: Results of PCA of male Event data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	121	15	95.8%	7	81.5%	50
Second	71	9	94.5%	7	89.7%	15
Third	56	7	93.8%	7	93.8%	0
Fourth	56	6	92.5%	6	92.5%	0

Table A7.12: Factor structure (loadings > 0.3) from PCA of male Event data

Row	Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
1	ti1	-0.890820					
2	ti6						0.913960
3	ti10		0.892210				
4	ti11		0.847190				
5	ti17		0.891170				
6	ti20						0.929010
7	ti24		0.887260				
8	ti25		0.836960				
9	ht10		0.942450				
10	ht11		0.939970				
11	ht17		0.946700				
12	ht18		0.950130				
13	ht24		0.945790				
14	ht25		0.944370				
15	frc1	0.965830					
16	frc2					0.973050	
17	frc6	0.956980					
18	frc7	0.973300					
19	frc8				0.983220		
20	frc10			0.980440			
21	frc13	0.951810					
22	frc14	0.962560					
23	frc15				0.982730		
24	frc17			0.989160			
25	frc20	0.956450					
26	frc21	0.974190					
27	frc22				0.963760		
28	frc24			0.971420			
29	vel1	0.953530					
30	vel2					0.976100	
31	vel6	0.951160					
32	vel7	0.972180					
33	vel8				0.912280		
34	vel10			0.935680			
35	vel13	0.943580					
36	vel14	0.963810					
37	vel15				0.904830		
38	vel17			0.913520			
39	vel20	0.943420					
40	vel21	0.966770					
41	vel22				0.957010		
42	vel24			0.959500			
43	pow1	0.960040					
44	pow2					0.959700	
45	pow6	0.952020					
46	pow7	0.967420					
47	pow8				0.931030		
48	pow10			0.934280			
49	pow13	0.951110					
50	pow14	0.965770					

51	pow15				0.936230		
52	pow17			0.937580			
53	pow20	0.948270					
54	pow21	0.966350					
55	pow22				0.948140		
56	pow24			0.943560			
R²	**92.5%**	**37.5%**	**19.4%**	**15.6%**	**11.9%**	**5.0%**	**3.0%**

Interpretation of factors

Factor 1:	Exertion before first grip change
Factor 2:	Time and height of second grip change and subsequent peak
Factor 3:	Exertion at second grip change
Factor 4:	Exertion at first grip change
Factor 5:	Exertion at 1.0 m
Factor 6:	Time of dip after initial peak exertion

Table A7.13: Results of confirmatory PCA of male factor structure using female data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	56	9	96.2%	4	82.3%	24
Second	32	5	94.8%	4	91.6%	9
Third	23	4	96.3%	4	96.3%	6
Fourth	17	3	93.8%	3	93.8%	0

Table A7.14: Factor structure (loadings > 0.3) from PCA of male data carried out to confirm the female Events factor structure

Row	Variable	Factor 1	Factor 2	Factor 3
1	ti1	-0.94031		
2	frc7	0.99624		
3	frc14	0.99327		
4	frc21	0.99585		
5	vel7	0.9915		
6	vel8			0.94841
7	vel10		0.94972	
8	vel14	0.99209		
9	vel15			0.95253
10	vel17		0.9863	
11	vel21	0.9933		
12	vel24		0.97713	
13	pow7	0.99423		
14	pow8			0.73288
15	pow14	0.99391		
16	pow21	0.99437		
17	pow24		0.92089	
R²	**93.8%**	**57.8%**	**23.9%**	**12.1%**

Interpretation of factors

Factor 1:	Exertion before first grip change
Factor 2:	Exertion at second grip change
Factor 3:	Exertion at first grip change

Table A7.15: Results of PCA of initial pulls Event data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	121	13	94.9%	10	91.7%	51
Second	70	9	95.6%	8	94.2%	10
Third	60	7	94.4%	7	94.4%	0

Table A7.16: Factor structure (loadings > 0.3) from PCA of initial pulls Event data

Row	Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	Factor 7
1	ti1	-0.911590						
2	ti5						0.956990	
3	ti7					0.954820		
4	ti12						0.964810	
5	ti14					0.905140		
6	ti19						0.955520	
7	ti21					0.938190		
8	ht7					0.923240		

9	ht8							0.983750
10	ht10				0.938390			
11	ht11				0.958020			
12	ht12						0.955490	
13	ht14					0.889320		
14	ht15							0.984990
15	ht17				0.936700			
16	ht18				0.957030			
17	ht21					0.923540		
18	ht22							0.984270
19	ht24				0.935070			
20	ht25				0.956330			
21	frc1	0.957450						
22	frc6	0.974150						
23	frc7	0.965610						
24	frc8		0.985600					
25	frc10			0.978420				
26	frc12	0.796090						
27	frc13	0.972050						
28	frc14	0.961570						
29	frc15		0.987450					
30	frc17			0.983650				
31	frc20	0.982710						
32	frc21	0.965730						
33	frc22		0.973790					
34	frc24			0.966130				
35	vel1	0.948990						
36	vel6	0.976810						
37	vel7	0.966970						
38	vel8		0.919060					
39	vel10			0.923000				
40	vel13	0.966000						
41	vel14	0.962460						
42	vel15		0.915630					
43	vel17			0.879220				
44	vel20	0.971640						
45	vel21	0.963330						
46	vel22		0.961600					
47	vel24			0.961240				
48	pow1	0.955460						
49	pow6	0.977250						
50	pow7	0.960880						
51	pow8		0.939470					
52	pow10			0.919400				
53	pow13	0.971380						
54	pow14	0.959880						
55	pow15		0.946810					
56	pow17			0.921510				
57	pow20	0.976490						
58	pow21	0.959180						
59	pow22		0.961690					
60	pow24			0.929200				
R^2	**94.4%**	**36.7%**	**15.5%**	**14.7%**	**10.2%**	**8.4%**	**4.8%**	**4.2%**

Interpretation of factors

Factor 1:	Exertion before first grip change
Factor 2:	Exertion at first grip change
Factor 3:	Exertion at second grip change
Factor 4:	Height of second grip change and subsequent peak exertion
Factor 5:	Time and height of main peak exertion
Factor 6:	Time of initial peak exertion & height of peak velocity at initial peak exertion
Factor 7:	Height of first grip change

Table A7.17: Results of confirmatory PCA of initial pull Events factor structure using second pulls data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	60	7	94.6	7	94.6%	5
Second	55	7	95.4%	6	93.4%	2
Third	53	6	94.7%	6	94.7%	0

Table A7.18: Factor structure (loadings > 0.3) from PCA of second pull data carried out to confirm the initial pull Events factor structure

Row	Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
1	ti1	-0.9106					
2	ti7					0.96581	
3	ti14					0.96679	
4	ti21					0.96796	
5	ht8						0.9794
6	ht10				0.95272		
7	ht11				0.93211		
8	ht14					0.90497	
9	ht15						0.97942
10	ht17				0.95202		
11	ht18				0.94162		
12	ht22						0.97986
13	ht24				0.95087		
14	ht25				0.93231		
15	frc1	0.93059					
16	frc6	0.98032					
17	frc7	0.94223					
18	frc8			0.98861			
19	frc10		0.97577				
20	frc13	0.97471					
21	frc14	0.94212					
22	frc15			0.9837			
23	frc17		0.98387				
24	frc20	0.97989					
25	frc21	0.94461					
26	frc22			0.96582			
27	frc24		0.97023				
28	vel1	0.91313					
29	vel6	0.97428					
30	vel7	0.94216					
31	vel8			0.90172			
32	vel10		0.92408				
33	vel13	0.96224					
34	vel14	0.93961					
35	vel15			0.88941			
36	vel17		0.92714				
37	vel20	0.96168					
38	vel21	0.9365					
39	vel22			0.95583			
40	vel24		0.95228				
41	pow1	0.92829					
42	pow6	0.9841					
43	pow7	0.93736					
44	pow8			0.92069			
45	pow10		0.9457				
46	pow13	0.98084					
47	pow14	0.9411					
48	pow15			0.9269			
49	pow17		0.94685				
50	pow20	0.9775					
51	pow21	0.93722					
52	pow22			0.94057			
53	pow24		0.95477				
R^2	**94.7%**	**40.6%**	**18.0%**	**15.1%**	**10.2%**	**6.1%**	**4.8%**

Interpretation of factors

Factor 1:	Exertion before first grip change
Factor 2:	Exertion at second grip change
Factor 3:	Exertion at first grip change
Factor 4:	Height of second grip change and subsequent peak
Factor 5:	Time of main peak exertion and height of peak velocity at main peak exertion
Factor 6:	Height of first grip change

Table A7.19: Results of PCA of second pulls Event data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	121	14	95.9%	10	91.6%	68
Second	53	7	94.3%	7	94.3%	5
Third	48	6	93.8%	6	93.8%	3
Fourth	43	5	94.2%	5	94.2%	0

Table A7.20: Factor structure (loadings > 0.3) from PCA of second pulls Event data

Row	Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1	ti1	-0.923110				
2	ti7				0.968640	
3	ti14				0.974570	
4	ti21				0.973360	
5	ht8					0.988770
6	ht14				0.920260	
7	ht15					0.988670
8	ht22					0.988960
9	frc1	0.943970				
10	frc7	0.954610				
11	frc8			0.989150		
12	frc10		0.976380			
13	frc13	0.971380				
14	frc14	0.953870				
15	frc15			0.983400		
16	frc17		0.987980			
17	frc20	0.971150				
18	frc21	0.956570				
19	frc22			0.966850		
20	frc24		0.973830			
21	vel1	0.927750				
22	vel6	0.961640				
23	vel7	0.953440				
24	vel8			0.899930		
25	vel10		0.931160			
26	vel13	0.951600				
27	vel15			0.889350		
28	vel17		0.933050			
29	vel20	0.951970				
30	vel21	0.946670				
31	vel22			0.954850		
32	vel24		0.960710			
33	pow1	0.940360				
34	pow6	0.973460				
35	pow7	0.948200				
36	pow8			0.924240		
37	pow10		0.947700			
38	pow13	0.974500				
39	pow14	0.951250				
40	pow15			0.930410		
41	pow17		0.949460			
42	pow20	0.968020				
43	pow21	0.947480				
44	pow22			0.945250		
45	pow24		0.956640			
R^2	94.2%	42.9%	19.3%	17.0%	8.6%	6.4%

Interpretation of factors

Factor 1:	Exertion before first grip change
Factor 2:	Exertion at second grip change
Factor 3:	Exertion at first grip change
Factor 4:	Time of main peak exertion and height of peak velocity at main peak exertion
Factor 5:	Height of first grip change

Table A7.21: Results of confirmatory PCA of second pull Event factor structure using initial pull Event data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	45	6	96.7%	5	94.5%	0

Table A7.22: Factor structure (loadings > 0.3) from PCA of second pull data carried out to confirm the initial pull Events factor structure

Row	Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1	ti1	-0.9136				
2	ti7				0.96432	
3	ti14				0.96031	
4	ti21				0.96276	
5	ht8					0.98993
6	ht14				0.90437	
7	ht15					0.99199
8	ht22					0.9916
9	frc1	0.9743				
10	frc7	0.97816				
11	frc8		0.98518			
12	frc10			0.97044		
13	frc13	0.95897				
14	frc14	0.97617				
15	frc15		0.98638			
16	frc17			0.97842		
17	frc20	0.96752				
18	frc21	0.97812				
19	frc22		0.97329			
20	frc24			0.95303		
21	vel1	0.96678				
22	vel6	0.96184				
23	vel7	0.97827				
24	vel8		0.91397			
25	vel10			0.92339		
26	vel13	0.95415				
27	vel15		0.909			
28	vel17			0.88535		
29	vel20	0.95714				
30	vel21	0.97435				
31	vel22		0.95953			
32	vel24			0.95682		
33	pow1	0.97104				
34	pow6	0.96152				
35	pow7	0.97287				
36	pow8		0.93744			
37	pow10			0.9168		
38	pow13	0.95783				
39	pow14	0.9731				
40	pow15		0.9439			
41	pow17			0.92013		
42	pow20	0.96128				
43	pow21	0.97117				
44	pow22		0.95815			
45	pow24			0.92937		
R²	**94.5%**	**42.9%**	**19.4%**	**18.1%**	**7.8%**	**6.3%**

Interpretation of factors

Factor 1:	Exertion before first grip change
Factor 2:	Exertion at first grip change
Factor 3:	Exertion at second grip change
Factor 4:	Time of main peak exertion and height of main peak velocity
Factor 5:	Height of first grip change

Table A7.23: Results of PCA of all Range data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	70	5	94.9%	4	93.1%	29
Second	41	3	94.6%	3	94.6%	4
Third	37	3	96.1%	3	96.1%	1
Fourth	36	3	96.4%	3	96.4%	0

Table A7.24: Factor structure (loadings > 0.3) from PCA of all Range data

Row	Variable	Factor 1	Factor 2	Factor 3
1	Range26	0.923219		
2	Range27	0.965248		
3	Range28	0.987641		
4	Range29	0.990116		
5	Range30	0.954262		
6	Range32	0.972359		
7	Range33	0.985708		
8	Range34	0.982420		
9	Range38		0.979705	
10	Range41	0.959681		
11	Range42	0.978313		
12	Range43	0.984103		
13	Range47	0.967652		
14	Range48	0.972501		
15	Range52		0.970659	
16	Range55	0.956678		
17	Range56	0.980117		
18	Range57	0.982866		
19	Range58	0.954429		
20	Range60	0.965229		
21	Range61	0.985662		
22	Range62	0.979743		
23	Range66		0.951945	
24	Range70	0.987058		
25	Range71	0.989315		
26	Range72	0.955929		
27	Range75	0.984241		
28	Range76	0.981284		
29	Range78			0.967845
30	Range80		0.887893	
31	Range84	0.972934		
32	Range85	0.976334		
33	Range86	0.942043		
34	Range89	0.963234		
35	Range90	0.966308		
36	Range92			0.968549
R^2	**96.4%**	**79.9%**	**10.8%**	**5.8%**

Interpretation of factors

Factor 1: Exertion before first grip change

Factor 2: Exertion between second grip change and 1.45 m

Factor 3: Work and impulse between first grip change and 1.45 m

Table A7.25: Results of PCA of transformed Range data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	70	5	95.2%	4	93.2%	25
Second	45	3	94.3%	3	94.3%	4
Third	41	3	95.5%	3	95.5%	0

Table A7.26: Factor structure (loadings > 0.3) from PCA of transformed Range data

Row	Variable	Factor 1	Factor 2	Factor 3
1	Range26	0.925517		
2	Range27	0.964840		
3	Range28	0.988238		
4	Range29	0.992196		
5	Range30	0.955454		
6	Range32	0.969266		

7	Range33	0.985663		
8	Range34	0.984679		
9	Range38		0.987288	
10	Range41	0.958113		
11	Range42	-0.975525		
12	Range43	-0.984617		
13	Range44	-0.927803		
14	Range46	0.962320		
15	Range47	-0.963998		
16	Range48	-0.972340		
17	Range52		0.983555	
18	Range54	0.931175		
19	Range55	0.958228		
20	Range56	0.983276		
21	Range57	0.987367		
22	Range58	0.957454		
23	Range59	0.940681		
24	Range60	0.963975		
25	Range61	0.988143		
26	Range62	0.984389		
27	Range66		0.961454	
28	Range70	0.987798		
29	Range71	0.991525		
30	Range72	0.957055		
31	Range75	0.984465		
32	Range76	0.983697		
33	Range78			0.974404
34	Range80		0.854396	
35	Range84	-0.971497		
36	Range85	-0.976862		
37	Range86	-0.945471		
38	Range89	-0.961941		
39	Range90	-0.965776		
40	Range92			0.982870
41	Range93			0.956644
R^2	**95.5%**	**78.4%**	**10.2%**	**6.9%**

Interpretation of factors

Factor 1:	Exertion before first grip change
Factor 2:	Exertion between second grip change and 1.45 m
Factor 3:	Work and impulse between first grip change and 1.7 m

Table A7.27: Results of PCA of female Range data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	70	6	95.6%	4	91.5%	35
Second	35	3	93.8%	3	93.8%	5
Third	30	3	95.2%	3	95.2%	3
Fourth	27	3	95.7%	3	95.7%	0

Table A7.28: Factor structure (loadings > 0.3) from PCA of female Range data

Row	Variable	Factor 1	Factor 2	Factor 3
1	Range27	0.948061		
2	Range28	0.978716		
3	Range32	0.979638		
4	Range33	0.953398		
5	Range34	0.958487		
6	Range38		0.993277	
7	Range41	0.939325		
8	Range42	0.978273		
9	Range43	0.982500		
10	Range46	0.977889		
11	Range47	0.943383		
12	Range48	0.949724		
13	Range52		0.979527	
14	Range55	0.946013		
15	Range56	0.973307		
16	Range57	0.979757		
17	Range60	0.979586		

18	Range61	0.959901		
19	Range62	0.962475		
20	Range66		0.980264	
21	Range69	0.981379		
22	Range70	0.973316		
23	Range71	0.981883		
24	Range75	0.942872		
25	Range76	0.954661		
26	Range92			0.975192
27	Range93			0.949625
R²	**95.7%**	**77.4%**	**12.2%**	**6.1%**

Interpretation of factors

Factor 1: Exertion before first grip change
Factor 2: Exertion between second grip change and 1.45 m
Factor 3: Impulse between first grip change and 1.7 m

Table A7.29: Results of confirmatory PCA of female Range factor structure using male Range data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	27	3	94.2%	3	94.2%	0

Table A7.30: Factor structure (loadings > 0.3) from PCA of female Range data carried out to confirm the male Ranges factor structure

Row	Variable	Factor 2	Factor 2	Factor 3
1	Range27	0.94293		
2	Range28	0.97453		
3	Range32	0.95523		
4	Range33	0.97476		
5	Range34	0.96202		
6	Range38		0.99041	
7	Range41	0.93623		
8	Range42	0.9633		
9	Range43	0.97046		
10	Range46	0.94887		
11	Range47	0.94556		
12	Range48	0.94688		
13	Range52		0.98043	
14	Range55	0.93675		
15	Range56	0.96746		
16	Range57	0.97311		
17	Range60	0.95253		
18	Range61	0.98027		
19	Range62	0.96844		
20	Range66		0.96489	
21	Range69	0.91137		
22	Range70	0.97384		
23	Range71	0.97477		
24	Range75	0.97227		
25	Range76	0.95865		
26	Range92			0.98311
27	Range93			0.96656
R²	**94.2%**	**76.2%**	**11.5%**	**6.6%**

Interpretation of factors

Factor 1: Exertion before first grip change
Factor 2: Exertion between second grip change and 1.45 m
Factor 3: Impulse between first grip change and 1.7 m

Table A7.31: Results of PCA of male Range data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	70	6	94.9%	4	90.9%	39
Second	41	3	91.6%	3	91.6%	3
Third	38	3	91.8%	3	91.8%	1
Fourth	37	3	91.8%	3	91.8%	0

Table A7.32: Factor structure (loadings > 0.3) from PCA of male Range data

Row	Variable	Factor 1	Factor 2	Factor 3
1	Range27	0.910398		
2	Range28	0.959437		
3	Range29	0.964794		
4	Range30	0.927951		
5	Range33	0.954310		
6	Range34	0.945525		
7	Range36		0.934822	
8	Range38			0.942457
9	Range41	0.893787		
10	Range42	0.935664		
11	Range43	0.951680		
12	Range47	0.909717		
13	Range48	0.923425		
14	Range50		0.912967	
15	Range52			0.902783
16	Range55	0.907616		
17	Range56	0.955442		
18	Range57	0.961929		
19	Range58	0.937954		
20	Range60	0.909556		
21	Range61	0.964458		
22	Range62	0.953052		
23	Range70	0.960047		
24	Range71	0.964035		
25	Range72	0.930513		
26	Range75	0.953567		
27	Range76	0.944045		
28	Range78		0.938243	
29	Range79		0.872348	
30	Range81			0.935548
31	Range84	0.929173		
32	Range85	0.932151		
33	Range86	0.898250		
34	Range89	0.909144		
35	Range90	0.907379		
36	Range94			0.917391
37	Range95			1.003197
R^2	**91.8%**	**69.4%**	**12.8%**	**9.7%**

Interpretation of factors

Factor 1: Exertion before first grip change
Factor 2: Exertion above first grip change
Factor 3: Exertion above second grip change

Table A7.33: Reuslts of confiirmatpry PCA of the male Ranges factor structure using female data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	37	4	95.9%	4	95.9%	29
Second	8	3	99.0%	3	99.0%	0

Table A7.34: Factor structure (loadings > 0.3) from PCA of male Range data carried out to confirm the female Ranges factor structure

Row	Variable	Factor 1	Factor 2	Factor 3
1	Range30	0.99795		
2	Range38		0.98566	
3	Range52		0.98597	
4	Range58	0.99098		
5	Range72	0.99947		
6	Range78			0.98508
7	Range79			0.97775
8	Range86	0.98358		
R^2	**99.0%**	**49.7%**	**31.3%**	**18.0%**

Interpretation of factors

Factor 1: Exertion between 0.7 and 1.0 m.
Factor 2: Exertion between second change of grip and 1.45 m.

Factor 3: Work done above first change of grip

Table A7.35: Results of PCA of initial pulls Range data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	70	5	94.8%	4	93.1%	25
Second	45	3	94.1%	3	94.0%	4
Third	41	3	95.6%	2	93.1%	1
Fourth	40	2	95.1%	2	95.1%	0

Table A7.36: Factor structure (loadings > 0.3) from PCA of initial pulls Range data

Row	Variable	Factor 1	Factor 2
1	Range27	0.949234	
2	Range28	0.980493	
3	Range29	0.985768	
4	Range30	0.978479	
5	Range31	0.929705	
6	Range32	0.952645	
7	Range33	0.981910	
8	Range34	0.980490	
9	Range36		0.912112
10	Range40	0.915545	
11	Range41	0.943034	
12	Range42	0.969365	
13	Range43	0.979522	
14	Range44	0.961225	
15	Range45	0.939578	
16	Range46	0.945748	
17	Range47	0.961666	
18	Range48	0.969373	
19	Range50		0.898671
20	Range55	0.941681	
21	Range56	0.973112	
22	Range57	0.978302	
23	Range58	0.974399	
24	Range59	0.918396	
25	Range60	0.947732	
26	Range61	0.982744	
27	Range62	0.978724	
28	Range68	0.938977	
29	Range70	0.979723	
30	Range71	0.984494	
31	Range72	0.979187	
32	Range75	0.980355	
33	Range76	0.978756	
34	Range78		0.971182
35	Range84	0.966401	
36	Range85	0.971338	
37	Range86	0.967476	
38	Range89	0.957751	
39	Range90	0.961370	
40	Range92		0.931204
R^2	**95.1%**	**85.4%**	**9.7%**

Interpretation of factors

Factor 1: Exertion before first grip change

Factor 2: Exertion between first grip change and 1.45 m

Table A7.37: Confirmatory PCA of initial pulls factor structure using second pulls data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	40	2	94.1%	2	94.1%	2
Second	38	2	94.9%	2	94.9%	2
Third	36	2	95.1%	2	95.1%	0

Table A7.38: Factor structure (loadings > 0.3) from PCA of second pulls Range data carried out to confirm the initial pulls Ranges factor structure

Row	Variable	Factor 1	Factor 2
1	Range27	0.96913	

2	Range28	0.98566	
3	Range29	0.99075	
4	Range30	0.95499	
5	Range31	0.91767	
6	Range32	0.9769	
7	Range33	0.98273	
8	Range34	0.98255	
9	Range40	0.91455	
10	Range41	0.96397	
11	Range42	0.97646	
12	Range43	0.98489	
13	Range45	0.92408	
14	Range46	0.97239	
15	Range47	0.96518	
16	Range48	0.97382	
17	Range55	0.95916	
18	Range56	0.9775	
19	Range57	0.98248	
20	Range58	0.95202	
21	Range59	0.91017	
22	Range60	0.96682	
23	Range61	0.98207	
24	Range62	0.97817	
25	Range70	0.98517	
26	Range71	0.99016	
27	Range72	0.95705	
28	Range75	0.98129	
29	Range76	0.98164	
30	Range78		0.97593
31	Range84	0.96952	
32	Range85	0.97755	
33	Range86	0.94566	
34	Range89	0.95976	
35	Range90	0.9684	
36	Range92		0.97936
R^2	**95.1%**	**88.7%**	**6.3%**

Interpretation of factors

Factor 1: Exertion below first grip change

Factor 2: Work / Impulse above first grip change

Table A7.39: Results of PCA of second pulls Range data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	70	5	95.1%	3	90.6%	23
Second	47	4	96.2%	4	96.2%	6
Third	41	3	95.2%	3	95.2%	0

Table A7.40: Factor structure (loadings > 0.3) from PCA of second pulls Range data

Row	Variable	Factor 1	Factor 2	Factor 3
1	Range26	0.917589		
2	Range27	0.969095		
3	Range28	0.988411		
4	Range29	0.992561		
5	Range30	0.953171		
6	Range32	0.974136		
7	Range33	0.982870		
8	Range34	0.982112		
9	Range38		0.985488	
10	Range40	0.913724		
11	Range41	0.964374		
12	Range42	0.979979		
13	Range43	0.987195		
14	Range44	0.926215		
15	Range46	0.970264		
16	Range47	0.966405		
17	Range48	0.974077		
18	Range52		0.963762	
19	Range54	0.909489		
20	Range55	0.959394		

21	Range56	0.980400		
22	Range57	0.984678		
23	Range58	0.949926		
24	Range60	0.963736		
25	Range61	0.981733		
26	Range62	0.977475		
27	Range66		0.961173	
28	Range70	0.987871		
29	Range71	0.991999		
30	Range72	0.955166		
31	Range75	0.981368		
32	Range76	0.981238		
33	Range78			0.958724
34	Range80		0.895428	
35	Range84	0.971654		
36	Range85	0.978652		
37	Range86	0.944010		
38	Range89	0.959968		
39	Range90	0.967896		
40	Range92			0.967977
41	Range93			0.936920
R^2	**95.2%**	**77.8%**	**11.9%**	**5.5%**

Interpretation of factors

Factor 1: Exertion before first grip change

Factor 2: Exertion between second grip change and 1.45 m

Factor 3: Work and impulse between first grip change and 1.7 m

Table A7.41: Results of confirmatory PCA of second pylls factor structure using first pulls data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	41	3	96.2%	3	92%	0

Table A7.42: Factor structure (loadings > 0.3) from PCA of first pulls Range data carried out to confirm the second pulls Ranges factor structure

Row	Variable	Factor 1	Factor 2	Factor 3
1	Range26	0.94402		
2	Range27	0.96146		
3	Range28	0.98058		
4	Range29	0.98091		
5	Range30	0.96465		
6	Range32	0.96084		
7	Range33	0.97265		
8	Range34	0.96651		
9	Range38		0.9371	
10	Range40	0.94148		
11	Range41	0.95728		
12	Range42	0.96977		
13	Range43	0.97388		
14	Range44	0.93966		
15	Range46	0.95806		
16	Range47	0.9529		
17	Range48	0.95567		
18	Range52		0.91255	
19	Range54	0.93818		
20	Range55	0.95759		
21	Range56	0.97809		
22	Range57	0.97866		
23	Range58	0.96831		
24	Range60	0.95742		
25	Range61	0.97573		
26	Range62	0.96737		
27	Range66		0.92537	
28	Range70	0.97875		
29	Range71	0.97873		
30	Range72	0.96576		
31	Range75	0.96933		
32	Range76	0.96369		
33	Range78			0.95861

34	Range80		0.93363	
35	Range84	0.95961		
36	Range85	0.95973		
37	Range86	0.94711		
38	Range89	0.94434		
39	Range90	0.94381		
40	Range92			0.97429
41	Range93			0.94704
R^2	**96.2%**	**79.9%**	**10.6%**	**5.6%**

Interpretation of factors

Factor 1: Exertion below first grip change.
Factor 2: Exertion between second grip change and 1.45 m.
Factor 3: Impulse above first grip change.

Table A7.43: Results of PCA of all Event and Range data

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	191	16	95.8%	7	84.2%	98
Second	93	8	94.2%	8	94.2%	15
Third	78	7	94.9%	7	94.9%	2
Fourth	76	7	95.0%	7	95.0%	2
Fifth	74	7	95.0%	7	95.0%	0
Sixth	74	6		6		7
Seventh	67	6	92.9%	6	92.9%	0

Table A7.44: Six factor solution from PCA of all Event and Range data

Row	Variable	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6
1	ti1	-0.87540					
2	ti4	-0.85738					
3	ti5					0.95389	
4	ti12					0.96761	
5	ti19					0.93779	
6	ht8				0.95448		
7	ht12					0.94736	
8	ht15				0.95542		
9	ht22				0.95405		
10	frc1	0.95732					
11	frc7	0.95933					
12	frc8		0.98161				
13	frc10			0.98549			
14	frc13	0.89953					
15	frc14	0.95395					
16	frc15		0.98044				
17	frc17			0.98136			
18	frc21	0.95965					
19	frc22		0.96308				
20	frc24			0.97341			
21	vel1	0.95401					
22	vel7	0.95009					
23	vel8		0.89803				
24	vel14	0.94336					
25	vel15		0.88952				
26	vel17			0.88814			
27	vel21	0.94586					
28	vel22		0.94558				
29	vel24			0.93145			
30	pow1	0.95073					
31	pow7	0.94831					
32	pow8		0.92468				
33	pow10			0.93867			
34	pow14	0.94878					
35	pow15		0.93127				
36	pow17			0.93623			
37	pow21	0.94701					
38	pow22		0.94533				
39	pow24			0.94710			
40	Range27	0.96854					
41	Range28	0.98753					

42	Range29	0.98352					
43	Range30	0.92490					
44	Range32	0.94901					
45	Range33	0.95614					
46	Range41	0.96047					
47	Range42	0.97594					
48	Range43	0.97302					
49	Range44	0.88745					
50	Range46	0.93828					
51	Range55	0.97010					
52	Range56	0.99027					
53	Range57	0.98756					
54	Range58	0.93013					
55	Range60	0.94802					
56	Range61	0.96157					
57	Range70	0.98818					
58	Range71	0.98422					
59	Range72	0.92671					
60	Range75	0.95609					
61	Range78				-0.95779		
62	Range81						0.88224
63	Range84	0.96026					
64	Range85	0.95773					
65	Range86	0.91143					
66	Range93				-0.97602		
67	Range95						0.93244
R^2	**92.9%**	**54.1%**	**12.1%**	**11.3%**	**7.3%**	**5.3%**	**2.9%**

Interpretation of factors

Factor 1:	Exertion before first grip change
Factor 2:	Exertion at first grip change
Factor 3:	Exertion at second grip change
Factor 4:	Height of first grip change / subsequent drop in work & impulse
Factor 5:	Time of initial peak exertion and height of initial peak velocity
Factor 6:	Work and impulse between second grip change and 1.7 m

Table A7.45: Results of PCA of all Event and range data extracting four factors at the first step

PCA	Initial variables	Eigenvalues > 1.0	% variance	Scree test	% variance	Variables deleted
First	191	16	95.8%	4	72.7%	94
Second	94	9	94.3%	4	79.4%	5
Third	89	9	95.3%	3	77.1%	5
Fourth	84	8	94.9%	5	90.1%	2
Fifth	82	7	94.3%	5	90.9%	1
Six	81	7	94.3%	5	90.8%	0

Table A7.46: Five factor solution from PCA of all Event and Range data

Row	Variable	1	2	3	4	5
1	ti2	-0.78761				
2	ti3	-0.84475				
3	ti4	-0.87421				
4	ti5				0.95374	
5	ti7					0.90578
6	ti12				0.94522	
7	ti14					0.88803
8	ti19				0.94356	
9	ti21					0.90585
10	ht12				0.94095	
11	frc1	0.93836				
12	frc4	0.78039				
13	frc7	0.93291				
14	frc8		0.98358			
15	frc10			0.98771		
16	frc14	0.92838				
17	frc15		0.98012			
18	frc17			0.98156		
19	frc21	0.93336				
20	frc22		0.96128			
21	frc24			0.96728		

22	vel1	0.93796				
23	vel4	0.79289				
24	vel7	0.92128				
25	vel8		0.90050			
26	vel10			0.91713		
27	vel15		0.89191			
28	vel17			0.90632		
29	vel21	0.91658				
30	vel22		0.94808			
31	vel24			0.94420		
32	pow1	0.93097				
33	pow4	0.75014				
34	pow7	0.92038				
35	pow8		0.92561			
36	pow10			0.92345		
37	pow14	0.92120				
38	pow15		0.93117			
39	pow17			0.92046		
40	pow21	0.91896				
41	pow22		0.94687			
42	pow24			0.93246		
43	Range26	0.93941				
44	Range27	0.96670				
45	Range28	0.98793				
46	Range29	0.99074				
47	Range30	0.93845				
48	Range31	0.92751				
49	Range32	0.95936				
50	Range33	0.97388				
51	Range34	0.97400				
52	Range40	0.93415				
53	Range41	0.95943				
54	Range42	0.97682				
55	Range43	0.98146				
56	Range44	0.90441				
57	Range45	0.92348				
58	Range46	0.95024				
59	Range47	0.95332				
60	Range48	0.96009				
61	Range54	0.93542				
62	Range55	0.96399				
63	Range56	0.98552				
64	Range57	0.98865				
65	Range58	0.94174				
66	Range59	0.92293				
67	Range60	0.95591				
68	Range61	0.97689				
69	Range62	0.97439				
70	Range69	0.93863				
71	Range70	0.98843				
72	Range71	0.99134				
73	Range72	0.94017				
74	Range74	0.88583				
75	Range75	0.97383				
76	Range76	0.97441				
77	Range84	0.96825				
78	Range85	0.97316				
79	Range86	0.92563				
80	Range89	0.95039				
81	Range90	0.95750				
R^2	**90.8%**	**61.9%**	**10.8%**	**9.5%**	**5.2%**	**3.5%**

Interpretation of factors

Factor 1:	Exertion below first grip change
Factor 2:	Exertion at first grip change
Factor 3:	Exertion at second grip change
Factor 4:	Time of initial peak exertion and height of initial peak velocity
Factor 5:	Time of main peak exertion

APPENDIX 8

RELATED PUBLICATION

Pinder A.D.J. and Grieve D.W. (1997), "Hydro-resistive measurement of dynamic lifting strength", *Journal of Biomechanics*, **30**, 4, 399-402.

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TECHNICAL NOTE

HYDRO-RESISTIVE MEASUREMENT OF DYNAMIC LIFTING STRENGTH

A. D. J. Pinder and D. W. Grieve

Institute of Human Performance, RNOHT, Brockley Hill, Stanmore HA7 4LP, U.K.

Abstract—A device is described for measuring strength and power outputs of dynamic vertical lifts between heights of 0.4 and 2.2 m. The device is safe, robust, and easily transportable. It consists of a water-filled tube 2 m high and 200 mm internal diameter. The subject pulls vertically on a handle which is connected with flexible wire rope via a series of pulleys to a piston suspended inside the tube. The piston has holes which can be closed with bungs. The drag force is proportional to the square of the velocity. The constant of proportionality can be chosen over a more than 100-fold range and is independent of temperature. Manual force is measured using a strain gauged cantilever over which the rope passes. Rope movement is monitored with a shaft encoder. These devices are sampled synchronously by an interfaced computer. Velocity and power are derived from the measurements of displacement, time and force. The device is highly accurate. Power measurements are not significantly different on two separate days although repetitions on one day show a warming-up effect. This device allows the study of dynamic lifts ranging from slow, high force, quasi-isokinetic lifts to lifts where high velocities and accelerations occur. © 1997 Elsevier Science Ltd.

Keywords: Whole body exertion; Power output; Dynamometry; Human; Lifting.

INTRODUCTION

'Isokinetic' devices vary in the extent to which constant velocity is achieved (cf. Kumar *et al.*, 1988; Pytel and Kamon, 1981). Accommodating resistance devices (O'Hagan *et al.*, 1995) achieve pseudo-isokinetic modes which are effort-dependent. Hydrodynamometers (Grieve and van der Linden, 1986; Hortobagyi *et al.*, 1989) create a resistive drag due to motion of a body through an incompressible fluid. All these devices allow velocity or a velocity–effort relationship to be preset, and they fail safe if exertion ceases.

This Technical Note describes a fully instrumented version of the hydrodynamometer used by Duggan and Legg (1993), Fothergill *et al.* (1995, 1996) and Grieve (1993). This device allows the study of variable-velocity lifts which require maximal activation of the muscles over the full range. The exertions can range from slow, high force, quasi-isokinetic lifts to ones involving high velocities and accelerations.

MATERIALS AND METHODS

The resistance of a perfect hydrodynamometer would be solely due to viscous drag. An actual device possesses frictional losses and the masses of the moving parts give rise to inertial resistance. The viscous drag of a rigid object drawn through an incompressible fluid is proportional to the square of velocity. If flow is turbulent, the drag will be independent of Reynolds number and therefore of temperature (Fox and McDonald, 1994). Viscous drag is the predominant source of resistance in an effective device.

A vertical, water-filled, open-topped nylon tube is mounted on a strong baseboard upon which the subject stands (Fig. 1). A steel framework stabilises the tube and supports bearings for pulleys and a handle rest. The handle is connected by stainless steel stranded rope, via pulleys, to a piston suspended in the tube. The piston (Fig. 1 inset) comprises a nylon disc (12 mm thick, 199 mm diameter) on a central pillar, terminated in a spider which stabilises its motion. The disc has an array of 17 mm diameter holes. Bungs placed in the holes allow the piston frontal area to be altered. A lead collar on the pillar ensures prompt return to the start after a pull. A handle height of 2.2 m is possible before the bungs reach a splash plate.

Force is measured using a strain gauged cantilever on which is mounted pulley P2. The rope passes over P2 at approximately 42°. The gauges (RS Components 632–168) form a full wave bridge with a calibration resistor parallel to one arm. The bridge output was calibrated by suspending known weights from the pulley ($R^2 = 99.8\%$). The elasticity of the cantilever gives rise to force-dependent changes in the angle of the rope so that the force in the rope, F_r, is a non-linear function of the cantilever force, F_c. Figure 2 shows the errors that would occur if infinite stiffness of the cantilever was assumed.

Rope displacement is measured using a shaft encoder (RS Components 341–581) pinned coaxially to the shaft of pulley P3 (Fig. 1). Two TTL outputs, phase shifted by 90°, provide a total of 1440 changes of state ('edges') per revolution, allowing the direction of motion to be found from the sequence of pulses. Rope travel between 'edges' is 278 μm.

Data is collected using an Archimedes A310 computer (Acorn Computers Ltd, Cambridge, U.K.) with a Wild Vision ADC1208-16 interface card (Computer Concepts Ltd., Hoddesdon, U.K.). Machine code routines built into the card act as extensions to the operating system, allowing direct control of its ports. These are a 12 bit A–D convertor (able to sample up to 166 kHz), and a bidirectional digital port. The card is memory mapped in the Archimedes and maintains a parameter block.

One analogue (force) channel is sampled at 12499 Hz for 8 s as a background task under fast interrupts. During this period, a machine code loop continuously reads two digital channels connected to the shaft encoder, storing the value read at a memory location calculated from the number of analogue samples still to be collected. The digital port is usually read several times during each A–D conversion, though in about 0.3% of all cases, typically very early in the sampling period, no value is stored.

When sampling is complete, the digital input array is scanned. When an 'edge' is found, the digital value and its associated analogue value are stored elsewhere. 'Edges' representing fixed distances of rope travel, but occurring at variable times, are therefore associated with individual analogue values collected at a fixed frequency. Analogue values are converted to force. The address where the force in the rope first exceeds 50 N is found and the start of movement identified as the next upward 'edge'. The initial rise of force is described using every 10th force sample before movement occurs. Handle height is calculated at each 'edge'. Velocity is found as the average slope over a range of 10 'edges' on either side of the point of interest, i.e. a height range of 5.838 mm. This procedure greatly reduces the noise compared with the use of instantaneous slopes.

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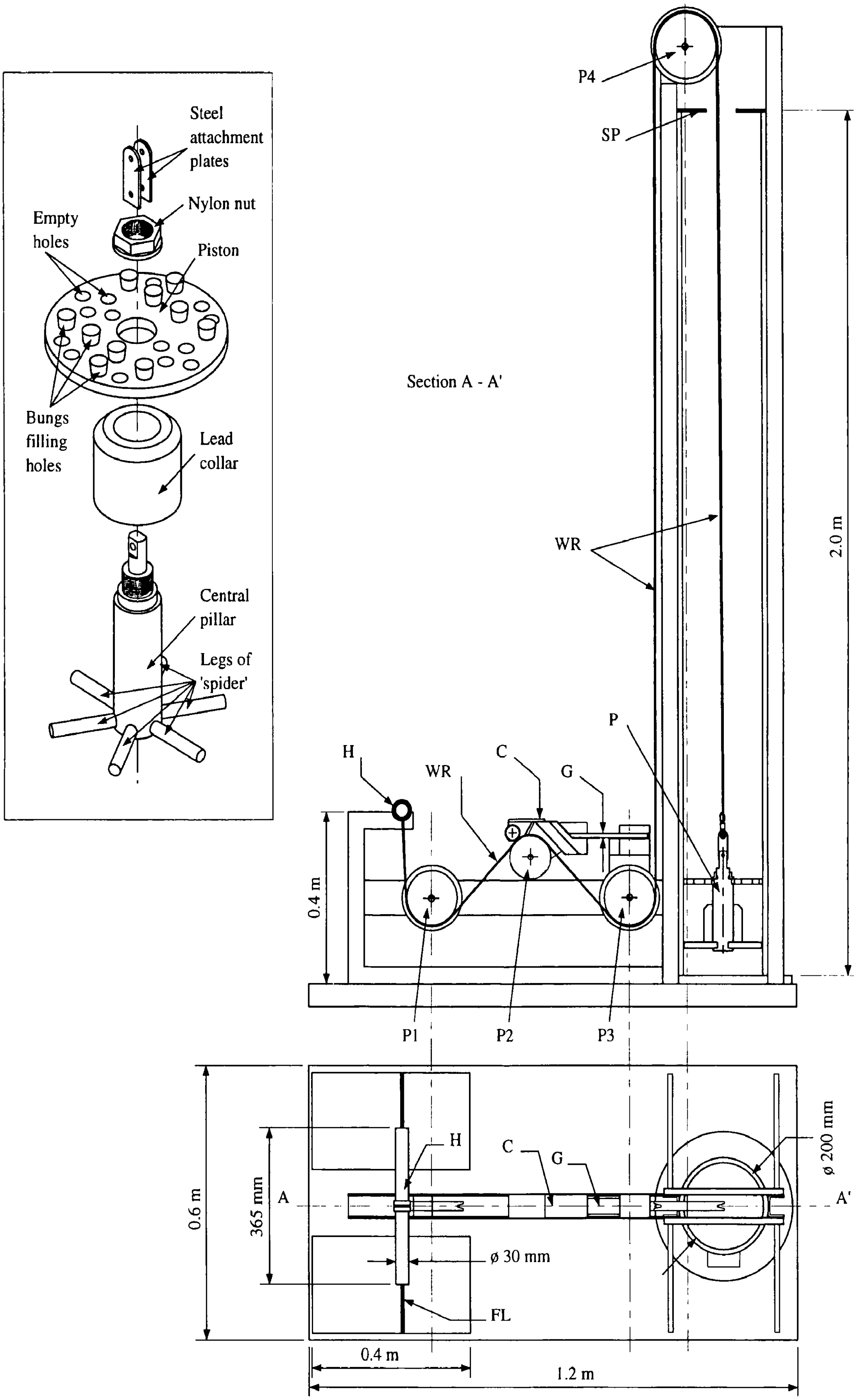

Fig. 1. Vertical section on plane A–A′ and plan view of the hydrodynamometer, showing important dimensions. H is the handle grasped by the subject; P is the piston assembly (both H and P are shown in their resting positions); P1–P4 are pulleys the wire rope, WR, passes around; C is the cantilever; G is the site of the strain gauges; FL is the footline marked beneath the handle; SP is the splash plate. The tube is filled with water to just below the splash plate so that the piston cannot leave the water. Inset: exploded isometric view of the piston assembly (total mass 5.85 kg). The lead collar (mass 4.55 kg) slides down the central pillar and rests against the legs of the spider. The piston rests against the shoulder at the top of the pillar and the nut is screwed down to hold it. A bolt holds the steel plates to the cheeks at the top of the pillar and a further bolt through the top of the plates passes through an eye in the end of the wire rope.

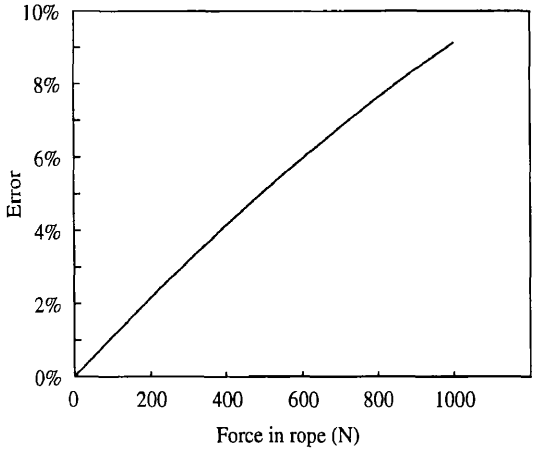

Fig. 2. Relationship between the force in the rope and the errors that would occur if no correction was made for the deformation of the cantilever. A linear ring transducer ($R^2 = 100.0\%$) was inserted between the handle and the rope during pulls by one subject (five exertions with 14 holes). Non-linear regression of F_r on F_c using the geometrically based equation, $F_r = F_c/(2 \cdot \cos(\tan^{-1}(l/(h - k \cdot F_c))))$, yielded empirical estimates for l and h (constants of the pulley geometry) of 96.13 and 103.595 mm, and for k (cantilever stiffness) of $-0.017120\ \mathrm{mm\,N^{-1}}$.

When instructing a subject, the nature of the device is explained, the method of lifting demonstrated and the need to alter grip when passing through the shoulder region mentioned. It is emphasised that 'the harder you pull, the harder it gets' and that the objective is to measure maximum power output. The subject stands with feet approximately 400 mm apart and the toes vertically below the handle, ensuring that the force vector passes through the foot base, thus minimising its distance from the low back. The subject is allowed to practice and then performs maximal efforts, separated by rest pauses. At the end of each pull, the subject keeps hold of the handle and allows it to descend to its start position.

RESULTS

Drag force was demonstrated to be proportional to the square of velocity, V^2, using data from 78 subjects who performed a total of 228 pulls on a 14 hole piston from 0.4 m to at least 1.8 m. Acceleration was calculated as the average slope of velocity over 5.838 mm. Values of F_r and V, obtained at points where the acceleration was zero, were used in a regression of the form $F_r = aV^b$. A value of 2.0264 (standard error = 0.00284) was obtained for b. Figure 3 illustrates typical force, velocity and power profiles.

The relationship between force and velocity was shown to be independent of temperature using data from two subjects who each performed three pulls on a 14 hole piston at six water temperatures between 5 and 26°C. Linear regressions of F_r on V^2 (when acceleration was zero) showed no trend with temperature and a mean regression coefficient of 1549 (S.D. 8.6) $\mathrm{kg\,m^{-1}}$ giving a mean value of the drag coefficient, C_D (Fox and McDonald, 1994) of 111 (S.D. 0.6).

The effect of changing piston frontal area on the drag coefficient was demonstrated using data from one subject who performed three pulls on each of eight pistons with varying numbers of holes. Regression of F_r on V^2 (when acceleration was zero) gave regression coefficients of 488, 726, 1167, 1524, 2005, 3948, 10,742 and 63,447 $\mathrm{kg\,m^{-1}}$ (equivalent to C_D values of 38, 55, 85, 109, 141, 270, 712 and 4080) for 24, 20, 16, 14, 12, 8, 4 and 0 holes, respectively. Standard errors ranged from 0.1 to 0.4% of the regression coefficients, except for 0 holes, where it was 1.2%.

The repeatability of the device was demonstrated in two studies (Table 1). In the first, 72 of the 78 subjects mentioned above completed three pulls. Peak power, mean power between 0.7 and 1.0 m and mean power between 0.4 and 1.7 m all showed significant increases ($P < 0.0001$) with repetition. This was confirmed ($P < 0.01$) with a further group of 20 subjects (10 females, 10 males) who each performed two pulls on two separate days. The latter group showed no significant differences ($P > 0.05$) between the two days of testing. The males in that group were significantly more powerful than the females ($P < 0.0001$).

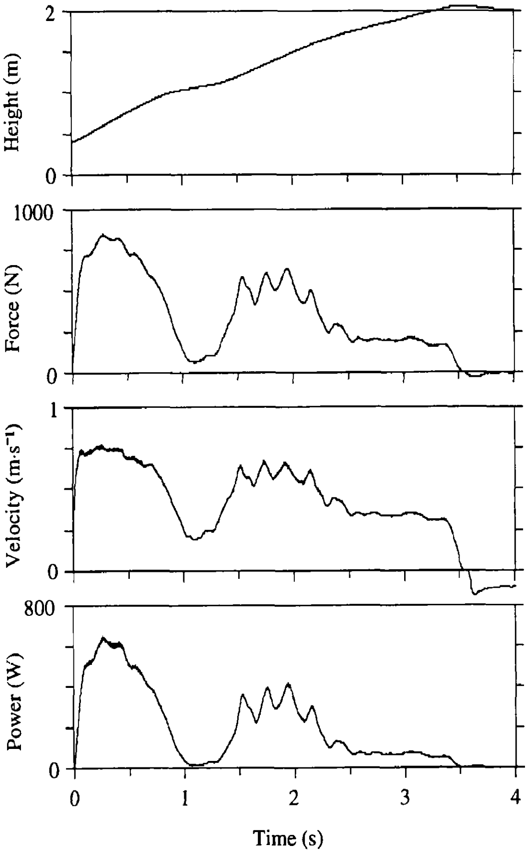

Fig. 3. Example of the time histories, from the start of movement, of the handle height, force in the rope, velocity of pull and power produced during one pull. Neglecting friction and moments of inertia, which are small, force and velocity are related by the equation $F_r = ma + C_D \frac{1}{2} \rho V^2 A_P$, where m and a are the mass and acceleration of the moving parts of the device, C_D is the drag coefficient, ρ is the density of water, and A_P is the cross-sectional area of the piston.

Table 1. The effect of repetition and gender on power output. Values are given for instantaneous peak power and mean power over two height ranges

	Instantaneous peak power Mean (S.D.)	Mean power 0.7–1.0 m Mean (S.D.)	Mean power 0.4–1.7 m Mean (S.D.)
Study 1 ($n = 78$)			
1st repetition	694(232)	443(167)	306(101)
2nd repetition	763(237)	476(177)	337(108)
3rd repetition	818(244)	505(188)	358(114)
Study 2 ($n = 20$)			
1st repetition	591(199)	342(174)	257(101)
2nd repetition	665(246)	377(199)	287(121)
Day 1	641(238)	365(193)	273(118)
Day 2	615(214)	354(181)	270(107)
Males ($n = 10$)	812(150)	520(129)	371(65)
Females ($n = 10$)	444(112)	199(59)	173(42)

DISCUSSION

The use of a 24 hole piston allows fast pulls with high power outputs in the 0.7–1.0 m height range. Higher speeds are feasible with 30–50 hole pistons. It would then be essential to minimise the inertial masses to ensure that viscous drag remained the principal source of resistance. The proven temperature independence of the device negates earlier statements (see, for example, Grieve, 1993), and is of obvious benefit under field conditions. Hundreds of men and women have performed thousands of pulls without injury. The observation that no significant differences between power outputs are found on separate days suggests that whole-body dynamic lifting strengths of individuals can be reliably classified. Increases in power output with repetition on one occasion and the dependence of power output on the resistance of the dynamometer indicate the importance of protocol and standardisation for classification purposes.

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