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THE EFFECT OF NEOPRENE ATHLETIC SUPPORTS ON CRICKET BOWLING AND JAVELIN THROWING.

by Paul David Hurrion

<u>Doctor of Philosophy</u>

September 1997

This thesis has been completed as a requirement for a higher degree of the University of Southampton.

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ABSTRACT

SPORTS STUDIES

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This thesis has been completed as a requirement for a higher degree of the University of Southampton.

This study investigated the technique of the individual, using an integrated biomechanical approach, to assess injury potential and performance. The effects of five neoprene athletic supports were investigated for the cricket bowl and javelin throw. A significant improvement in distance thrown and an increase in linear speed of body segmental movements were found for a lumbar support belt during the javelin throw. A two-handed overhead throwing activity was designed to investigate the effect of this lumbar support belt during the hyperextension - flexion movement of the torso. Significant differences in the distances thrown and segmental timing during the belt condition were found for both novice and experienced athletes. An integrated approach (three-dimensional cinematography, ground reaction forces and electromyography) was then used to analyse the effect of this lumbar support belt during the delivery phase of both sporting activities. The rate at which the torso uncoiled, (the relative peak shoulder to peak hip speed) was found to be significantly different during the belt condition for both activities. The results of these experiments suggest that the lumbar support belt enabled a more efficient transfer of speed to the upper body. A significant improvement in distance thrown during the lumbar support belt condition was found for the javelin throw.

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Chapter 1

INTRODUCTION

Introduction

In the competitive world of cricket bowling and javelin throwing athletes push themselves to the limits of their physical and mental capabilities. Peak performance involves athletes continually operating close to their injury threshold. The very nature of the two explosive events, when combined with the cumulative effect of training, competition and the competitive drive of the athlete is often responsible for overuse injuries. Athletic supports are increasingly being used because of the belief that they may help prevent injury. By maintaining a greater temperature than that supplied by the body, athletic supports allow an increase in flexibility due to the muscles being kept warm and supple (Vulkan 1996). A neoprene support may also aid compression to that area of the body covered. Many of the world's top javelin throwers wear different types of lumbar supporting belts. The reason for the adoption of the lumbar support belt is the belief that it helps to prevent lower lumbar injuries.

This thesis reports on a series of biomechanical investigations used to examine the effect of support usage (specifically the lumbar support) during fast-medium bowling and javelin throwing. With the aid of sports biomechanics it is possible to investigate the athletic performance of an individual. Improved technique, performance and injury prevention are all important aspects of biomechanical research. Analysis of an individual's technique could identify certain characteristics of their action, which may be potentially dangerous and therefore increase the likelihood of injury. The athlete could then be advised to develop a new and improved technique. However, there is rarely only one factor that contributes towards any particular injury (Vulkan 1996). For example, failure to warm up, failure to stretch, a poor (or injury prone) technique, high impact forces, over training, muscles overused, repetitive movements, inferior equipment and lack of specific training all are factors linked to injury occurrence.

The optimal technique for the fast-medium bowler is open to debate. There is agreement amongst scientists and coaches on the importance of the ball release speed. However, there is no consensus of opinion on the elements of the bowling technique, which contribute most to the final release speed. It is not surprising that injuries occur, even though the forces generated are within the limits that can be tolerated by the body. Many of the world's top fast bowlers, past and present, are plagued with injuries, which they have sustained whilst competing. Dennis Lillee, the Australian international fast bowler, suffered continually throughout his career from injuries such as bruising of the heel, shin soreness and, more seriously, stress fractures of the third and fourth lumbar vertebrae (Foster and Elliot, 1985). Lillee (1977) himself described a career in fast bowling,

> "like committing the body in a masochistic manner, day after day on the rack, interspersed with periods of relaxation in the ring with Muhammad Ali"

Most studies investigating the biomechanical principles of the javelin throw have focused upon body segment kinematics, release parameters and the flight characteristics of the javelin (for example Komi and Mero, 1985; Hubbard and Alaways, 1987; Bartlett and Best, 1988; Whiting *et al.*, 1991 and Mero *et al.* 1994). Javelin throwing is a 100% maximum effort every throw requiring fast explosive movements from extensive stretching and the pre-tension of muscles.

During the final delivery phase a fast bowler and javelin thrower have similar techniques. Once the initial shock of landing has been absorbed (for a right-handed athlete), both the left leg and torso must brace against a thrusting right leg action. A braced left side is essential if the active right side is to accelerate around it. The speed of the torso is closely related to the speed of the arm (Jones, 1996). A key factor during the delivery stride is the speed at which the torso moves from a hyper-extensive to a flexed position. This movement creates the initial stage of acceleration. The power for the final 'whipping' action of the upper body is derived from the legs, causing the active side of the body to rotate around the vertical axis in the final delivery phase (Jones, 1987). A high release speed is considered to be of prime importance in determining the distance the javelin is thrown. A high release speed is also considered to be of prime importance in cricket bowling (Bartlett *et al.* 1996). The faster the cricket ball is delivered, the less time the batsmen has available to make the correct decisions regarding the path, flight and swing of the ball. This increases the demands on the batsmen in the execution of the shot.

The physical requirements of the fast bowler and javelin thrower are major concerns to the athlete. Launder (International Amateur Athletic Federation, 1993) stated that the lower back is particularly at risk for elite javelin throwers, with common injuries occurring in the fourth and fifth lumbar region. Elliott and Foster (1984), Foster and Elliott (1985) and Foster *et al.* (1989) all reported serious lower back injuries, including stress fractures of the third, fourth and fifth lumbar vertebra, to elite fast bowlers in cricket. Whitbread (1993) reported the use of weight-lifting belts during javelin throwing.

> "National Squad Javelin throwers have all experienced lower back problems at some point in their throwing career. It is a big problem. The use of supports is ever increasing!"
>
> Jones, M (1996) British Athletic Federation,
> National throwing coach.

A number of first class cricketers use athletic supports to help prevent injury,

> "There are a number of bowlers today that wear a corset or back support whilst training, warming up and actually performing in order to avoid injury. Bowlers also wear them to protect an old injury and hopefully prevent new ones occurring".
>
> Leaham, N. (1995) Sussex County Cricket Club.

In weight training, support belts have been shown to be associated with a rise in intra-abdominal pressure, as the trunk muscles are supported in the abdominal region (Landers *et al.* 1992). However, scientific investigations into the effectiveness of athletic supports are limited.

The biomechanical investigations reported throughout this thesis were used to examine the effect of neoprene athletic support usage (specifically the lumbar support) on injury potential and athletic performance during fast-medium bowling and javelin throwing.

The specific aims of this thesis were to : -

(1) Establish those aspects of an individual's technique that are related to injury potential.

(2) Determine the effect of neoprene athletic supports on the performance of the individual during the delivery phase of the fast-medium cricket bowling and of javelin throwing.

The first of these aims was to be achieved by using an integrated biomechanical approach to investigate the effect of neoprene athletic supports during the delivery phase of the fast-medium cricket bowler and of the javelin thrower. Combinations of biomechanical analysis techniques were used throughout this thesis. These included high-speed two and three-dimensional cinematography, ground reaction forces with associated temporal data (back and front foot contact) and electromyographic activity of selected contributing muscles of the leg and torso region. These techniques allowed an in-depth biomechanical analysis of athletic performance of the individual during the final delivery phase of the bowling and throwing action in a manner not previously investigated.

A retrospective survey of injury undertaken during this thesis highlights the ankle, knee, shoulder, elbow and the lumbar region as the areas most vulnerable to injury in fast-medium bowling and javelin throwing. With the ever-increasing use of neoprene supports in sport, the first biomechanical investigation focused on the effect of four different neoprene supports (ankle, knee x2 and lumbar) during the delivery phase of the fast-medium bowler. Ground reaction forces (front foot contact) and electromyography activity of selected contributing muscles of the leg and torso region were used to analyse the effect of the four neoprene supports during the delivery phase of the fast-medium bowler. The ground reaction forces and associated temporal data experienced by fast-medium bowlers were used to indicate the loads imposed on the human body during the delivery phase.

A second experiment investigated the effect of two different types of lumbar support belt upon javelin throwing. An unexpected result from this experiment showed that athletes, who used one particular type of lumbar support, developed a significant improvement in throwing distance. A difference in the sequencing of body segmental movements was also found during the belt conditions. However, the javelin study can only be considered a preliminary investigation because of the limited number of successful throws obtained from each subject.

These two preliminary investigations highlighted the high ground reaction forces and loading rates exhibited during front foot contact for both sporting activities. No differences in ground reaction forces and peak muscular activity were found between any of the neoprene support conditions and the no support condition. Due to these findings it is reasonable to assume that athletic supports do not increase the risk of injury to the fast-medium bowler or javelin thrower. The emphasis of the research progressed to a study of the possible reasons for the improvement in performance observed when a lumbar support belt was worn. Further biomechanical investigation focused upon the second aim of this thesis, the performance of the individual and analysed the effect of this lumbar support belt on athletic performance.

A specific experiment was designed to concentrate solely on the effect of a re-designed lumbar support on the trunk hyperextension - flexion movement which, occurs in the final delivery phase of both actions. The re-designed lumbar support was able to contour the 'natural' curvature of an individual's lumbar region. An overhead two-handed throw of a medicine ball was used as the basis for this study. The experiment was designed to eliminate the majority of the external variables that affect the final release speed of a cricket ball and the final distance thrown of a javelin. A significant improvement in distance thrown was found during the belt condition for both novice and experienced athletes. A difference in segmental timing was also observed during the belt condition for both subject groups.

Two further biomechanical studies of fast-medium bowling and javelin throwing were then undertaken in an outdoor environment to analyse the effect of the re-designed lumbar support belt on athletic performance. The rate at which the torso moved from a hyper-extensive to a flexed position prior to release (the relative peak shoulder to peak hip speed) was significantly greater during the belt condition for both activities. This increase in upper torso speed was, however, not able to be transferred to the lighter, faster moving body segments during the release of the cricket ball or javelin. This was due to a change in the timing brought about by the wearing of the lumbar support belt for both the bowling and throwing actions. During the javelin experiment, a significant improvement in the distance thrown was also found when subjects wore the lumbar support belt.

Chapter 2

REVIEW OF LITERATURE

2.1 Fast Bowling in Cricket

2.2 Javelin Throwing

2.3 The use of athletic supports in sport

2.4 Summary

This review of literature covers the biomechanical and experimental research carried out for fast bowling in cricket and javelin throwing. The majority of studies investigating the biomechanical principles have focused upon descriptive analysis of an individual's technique. The most common method of recording is that of high-speed cinematography. This type of analysis predominately focuses on the release parameters, peak linear speeds and angular displacements of key joints critical to performance. Research is limited into ground reaction force measurements and electromyographic analyses during the delivery phase of the fast bowler and javelin thrower. Bartlett, Stockill, Elliott and Burnett (1996) have reviewed the biomechanical research that has been carried out in men's fast bowling in cricket. Particular attention has been given to areas of the bowling technique which contribute towards a fast ball release. The aerodynamics and technique of swing bowling, plus the association between fast bowling and lower back injury, are also addressed in their review. One recommendation made by Bartlett *et al.* (1996) was for future research to include intra-player studies to establish the bowler-specific factors which contribute to fast ball release. A further recommendation was to focus on body segment dynamics during the final delivery phase of the fast bowler's action.

Bartlett and Best (1988) and Morriss and Bartlett (1996) have reviewed the biomechanical research on javelin throwing. They report on the key biomechanical factors critical for javelin throwing performance and concentrate on the areas of the throwing technique that contribute to the final release speed of the javelin.

These three review papers form the core of this literature review which is needed for comparisons during biomechanical investigations into the effect of neoprene athletic supports on athletic performance undertaken in this thesis. The final section discusses the use of athletic supports in sport. Albright, Saterbak and Stokes (1995) reviewed the effectiveness of prophylactic knee braces. Whitbread (1993) reported on the use of weightlifting belts during javelin throwing. Landers, Simonton and Giacobbe (1990) and Landers, Hundley and Simonton (1992) reported that the wearing of weightlifting belts during the squat exercise was associated with a rise in intra-abdominal pressure.

2.1 Fast Bowling in Cricket

Cricket has not been significantly investigated by biomechanical researchers despite it being a major participative and spectator sport. The majority of biomechanical research on cricket is associated with the fast bowler. Many of the biomechanical studies have focused on the areas of the bowling technique which contribute most towards a high ball release speed. In addition, research has also focused on injury occurrence during fast-medium bowling and the possible causes of recurring injuries.

Elliott *et al.* (1992), Stockill and Bartlett (1992) and Bartlett *et al.* (1996) have all identified and classified three main techniques used in cricket fast bowling. These are the side-on, front-on and mixed bowling techniques. The side-on technique has been advocated, over the years, as the correct and most effective way to bowl. It is described in detail in Appendix A. The side-on technique is characterised by a rear foot position, which is parallel to the bowling crease and a shoulder position at back foot contact that points down the length of the wicket. A higher run-up speed, a back foot angle of 270° and a more open chested position at rear foot contact (shoulders greater than 180°) characterises the front-on bowling technique (Bartlett *et al.* 1996). A mixed bowling technique has also been identified in a large percentage of fast bowlers (Foster *et al.* 1989 and Elliott *et al.* 1992). This type of bowler adopts the front-on style of bowling at back foot contact for foot and shoulder orientation. This is followed by a realignment of the shoulders to a more side-on bowling technique during the delivery stride. The mixed bowling technique is more likely to lead to a higher incidence of lower back injury because of the spine adopting a twisted and hyperextended position during front foot contact (Foster *et al.* 1989). Rasch (1989) identified trunk rotation, hyperextension and high axial compression (load bearing) as three potential causes of lower back pain. Bartlett (1992) recognised that all three of these components are present in the mixed technique.

The bowing action can be divided into four distinct stages as described by Bartlett *et al.* (1996): the run-up, the pre-delivery stride, the delivery stride and the follow through.

The Run-up

Length and Speed of Run-up

The length of the run-up varies between bowlers with no agreement as to its optimal length. The run-up speed is not a factor in differentiating between international and club standard fast bowlers (Bartlett, 1992). Davis and Blanksby (1976a), reported that a run-up of fourteen paces is sufficient to release the ball at 37 m s^{-1}. Elliott and Foster (1989) suggested the run-up length should be between 15 and 30 m for the fast bowler, with specific emphasis on a balanced and rhythmical running technique. The build up of speed should be gradual with maximum speed being reached during the final strides from the end of the run-up. Mason *et al.* (1989) analysed fifteen medium-fast junior bowlers in an attempt to determine how their speed varied as they approached the wicket. The results suggested that the bowlers reached maximum speed at 8-16 m from the crease and then slowed down slightly in preparation for the pre-delivery stride. Lillee (1977) believed that no further deceleration should take place until after ball release.

The majority of studies report the run-up speed at the end of the pre-delivery stride (back-foot contact). Run-up speeds (mean ± S.D.) of 7.5 ± 1.8 m s^{-1} (n=4 International seniors: Penrose *et al.*, 1976), 4.3 ± 0.3 m s^{-1} (4 International seniors: Elliott and Foster, 1984), 5.4 m s^{-1} 1 International senior: Foster and Elliott, 1985), 4.6 ± 0.8 m s^{-1} (15 A-grade to International seniors: Elliott *et al.*, 1986) and 5.1 ± 0.9 m s^{-1} (15 Representative juniors: Elliott *et al.*, 1992) have been reported in the literature. Elliott and Foster (1984) suggested that run-up speeds should be sufficient to produce as high a linear velocity of the body as possible for ball release. However, the correct delivery technique must still be adopted. Run-up speeds for Australian representative fast bowlers of 3.9 ± 0.1 m s^{-1} (side-on) compared to 4.5 ± 0.1 m s^{-1} (front-on) were reported by Elliott and Foster (1984). They concluded that a slower run-up speed enabled a better "turning – rotational" movement of the torso prior to the delivery stride. The majority of studies report the horizontal component of the bowler's mass centre or hip velocity at the end of the pre-delivery stride or back foot strike. Bartlett *et al.* (1996) reported that, owing to the individuality of running styles, the hip joint centre would give a better reflection of the bowler's mass centre.

Effect of Run up Speed on Ball Release Speed

There is no conclusive evidence in the literature to suggest that run-up speed has any direct effect upon the ball release speed. Davis and Blanksby (1976a) and Elliott *et al.* (1986) both calculated the percentage contribution of the run-up to ball release speed. By subtracting the bowler's mass centre speed at the point of release and referring to it as a percentage of final ball speed both authors reported similar results, 19%, Davis and Blanksby (1976a) and 15%, Elliott *et al.* (1986). Elliott and Foster (1984) stated that considerable differences in styles of delivery action and run-up speed, means that the percentage contribution of the run-up to ball release speed is dependent upon the bowler's technique.

Pre-Delivery Stride

The pre-delivery stride for a right handed bowler is initiated with a jump off the left foot and is completed as the bowler lands on the right or back foot contact. The Marylebone Cricket Club (1976) describes the pre-delivery stride as;

> "the shoulders are sideways, pointing down the pitch. The right foot is passing in front of the left and the right foot is turning so that it will land parallel to the bowling crease."
>
> The Marylebone Cricket Club Cricket Coaching Book (1976)

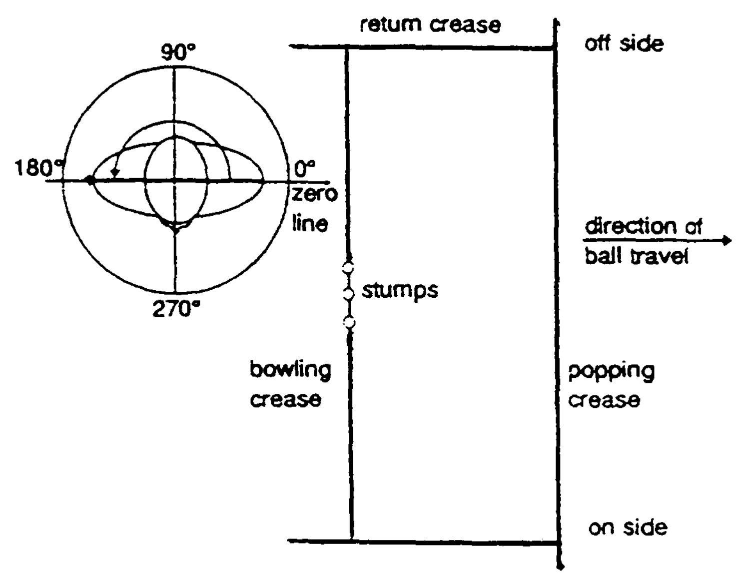
The optimum length of the pre-delivery stride must allow time for the feet to cross in preparation for the right foot of the side-on bowler to land in a side-on position. The front-on bowler does not, however, need to make significant adjustments to his stride length (Bartlett *et al.* 1996). If the bowler continued to accelerate during the pre-delivery stride, then there would be insufficient time to transfer from a front-on position in the approach to a more side-on delivery position. This would result in an inefficient delivery technique (Davis and Blanksby 1976b).

Delivery Stride

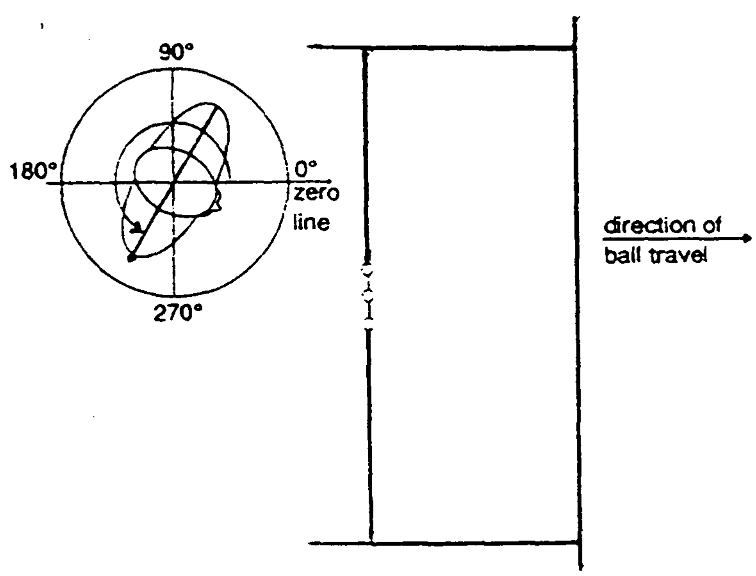
Bartlett *et al.* (1996) defines how the angles are measured for the back foot, hips and the shoulders alignment during the delivery phase of the bowling action. (See figure 2.1: adapted from Bartlett *et al.* (1996)).

Figure 2.1 Plan view showing how hip and shoulder alignments are defined. Typical shoulder alignment of (a) a side-on bowler (180°) and (b) a front-on bowler (240°).

(a)



(b)



In order to attain a perfect side-on position the back foot should land parallel to the popping crease (270°) with the hip and shoulder alignments down the pitch, right angles to the popping crease. Davis and Blanksby (1976b) stated that only four out of the twelve bowlers; Elliot and Foster (1984), two out of five bowlers; Elliott *et al.* (1992), three out of twenty bowlers and Stockill and Bartlett (1992) three out of seventeen bowlers, actually attained these positions. Average back foot angles of between 280° and 300° were reported. This suggests that a more open bowling action is being adopted than is recommended. Davis and Blanksby (1976b) and Elliot and Foster (1984) have reported certain bowlers with back foot angles of less than 270°. Stockill and Bartlett (1992) highlighted one bowler who had a back foot angle of 210°.

The angle of the shoulders in relation to the wicket provides additional information as to the type of action adopted by the bowler. Foster *et al* (1989) proposed a classification system using shoulder angles, reporting on the levels of trunk rotation during the delivery stride. Foster *et al.* (1989) defined a front-on bowler as having a shoulder alignment of greater than 200° at back foot or front foot strikes. Foster *et al.* (1989) investigated eighty-two potentially high performing injury free male fast bowlers (mean age, 16.8 years, range 15-22). The kinematic analysis revealed that only nine of the eighty-two (11%) were side-on (shoulder angle less than 190°) fifty-six (68%) front-on and seventeen, (21%) mixed. The mixed action, referred to those subjects who rotated their trunk greater than 40° to achieve a more side-on orientation between back foot and front foot strikes. Only one of the nine side-on bowlers and eight front-on bowlers, sustained some form of back injury. However, six of the bowlers with a mixed action sustained a stress fracture and a further seven sustained a soft tissue injury during the season. It is interesting to note that the bowlers who were not injured only counter-rotated their trunk 16° during the delivery stride. Foster *et al.* (1989) reported no significant relationship between the type of bowling technique and ball release speed.

Elliott *et al.* (1992) suggested that a side-on bowler should be characterised as having shoulder alignment of less than 190°, a back foot angle of less than 280°. A front-on bowler should be categorised by adopting a shoulder alignment of greater than 190° and a back foot angle greater than 280°. A mixed action was characterised as having a shoulder alignment of greater than 190° any foot placement and a counter-rotation of the shoulders of greater than 10°. Burnett *et al.* (1995) determined that the side-on bowling technique by shoulder alignment at back foot impact only (shoulder alignment <200°). The front and mixed techniques were determined by the shoulder-to-pelvis separation angle at back foot impact . The counter-rotation of the shoulder alignment between back foot impact and the minimum shoulder alignment was also a factor in classification of the front and mixed bowling techniques (Front-on <20° ; Mixed >20°).

The boundaries that classify the three types of bowling techniques are not fixed, despite much biomechanical research into the categorising of a particular bowling technique. Bartlett *et al.* (1996) indicated that they exist within a continuum of techniques with an optimal fast bowling technique defined as one that allows the bowler to bowl fast with a relatively low risk of injury. There is evidence in the literature to suggest a link between the mixed bowling technique and injury to the lower back. The mixed bowling technique requires the spine to adopt a twisted and hyperextended position during front foot contact. The majority of bowlers develop their bowling technique as a result of coaching at school or at a local club. Coaches and teachers should avoid young bowlers acquiring the mixed bowling technique and ensure bowlers who are found to adopt this technique be advised to change. In addition, there is a need for coaching manuals to be re-written focusing on the side-on and front-on bowling techniques. The dangers associated with the mixed bowling technique need to be highlighted with these coaching manuals. These views are similar to those described by Bartlett *et al.* (1996). Table 2.1 is adapted from Bartlett *et al.* (1996) and is repeated in this thesis since it summaries the current knowledge and research to date on the important kinematic variables of the fast-medium bowling technique.

Table 2.1 : A summary of the published literature on important kinematic variables of the fast-medium bowling technique. (mean ± S.D.)

Authors	Subjects	Run-up Speed[1] (m s^{-1})	Back Foot Angle BFS(°)	Shoulder Alignment Angle °				Stride Length (m or %)	Stride Alignment (m)	Release Height (% height)	Ball Release Speed (m s^{-1})
				BFS[2]	FFS[3]	BR[4]	Change FFS to BR				
Davis and Blanksby (1976a)	6 Low, 6 high ability, seniors										H=36.4 L=31.7 Av: 34.1±3.32
Penrose *et al.* (1976)	6 International seniors	7.53±1.81									40.0±2.76
Elliot and Foster (1984)	4 International seniors	4.3±0.3	272±30	195±11	198±9	299±4	101±8	1.54±0.12	-0.014 ±0.028	119±2	36.3±1.7
Foster and Elliott (1985)	1 International senior	5.4	280	200		300		1.37		118	34.8
Elliott *et al.* (1986)	15 elite seniors	4.6±0.8	306±26.4	232±18	217±8	300±8	83	1.29±0.1	0.0032 ±0.017	116±5	30.6±2.0
Foster *et al.* (1989)	82representative juniors age 16.8	4.95±1.37	314±20.1	219±21	203±16						
Mason *et al.* (1989)	15 Medium fast juniors	5.6						1.3			
Burden and Bartlett (1989)	10 college players	5.95±0.56									
Elliott *et al.* (1992)	20representative juniors age 17.9	5.1±0.9	293±41.7	206±32	201±16	309	109±18	86±9%	-0.109 ±0.0133	114±6	31.7±1.6
Stockill and Bartlett (1992)	17 elite seniors	6.81±1.7	294±38	223±17	209±10	291±15					37.4±1.87
Elliott *et al.* (1993)	24 juniors Gp1	4.5±0.6	287±36	213±12	209±18	319±19		83±10%		119±10	24.4±2.1
	age 13.7 Gp2	4.6±0.6	295±27	219±14	199±8	312±12		83±10%		114±10	24.8±1.4
Burnett *et al.* (1995)	9 elite seniors	5.5±0.5		221±22	200±11	297±13		85±8%	-0.02±0.18	111±4	32.6±1.7

[1] At back foot strike ; [2] back foot strike ; [3] front foot strike ; [4] ball release
Data within this table has been extracted from Bartlett *et al.* (1996).

Back Foot Contact

At the start of the delivery stride the bowler's weight is on the previously planted back foot with the body leaning away from the batsmen. The degree of trunk hyperextension and rotation is a function of the type of action used. The angle is more pronounced in side-on bowlers, due to lateral flexion and rotation of the spine (Bartlett *et al.* 1996). In front-on bowlers, the angle of the torso is more restrictive due to less hyperextension of the spine (Penrose *et al.* 1976 and Elliott *et al.* 1986). It may be hypothesised that an increase in the acceleration path is less a requirement for the front-on bowler than the side-on bowler. The front-on bowler receives a greater contribution to ball release speed from the run-up and as a result may rely less on the contribution from trunk flexion.

The different requirements for side-on and front-on bowlers may have implications for the height of the bound during the pre-delivery stride, (Andrew, 1986). The height of the bound in the delivery stride is an important consideration for fast bowlers. It may not only be inefficient and a waste of effort, but may heighten the risk of injury as a result of increased ground reaction forces at back and front foot contacts.

Front Foot Contact : Ground reaction forces

As the delivery stride proceeds the front foot strikes the ground. This results in a large ground reaction force being experienced by the bowler. Eight previous studies have investigated the ground reaction forces generated by the bowler at front foot contact. Three of these studies also investigated ground reaction forces during back foot contact. These three studies used one force platform. Table 2.2 is adapted from Bartlett *et al.* (1996) and is repeated in this thesis since it summaries the current knowledge on ground reaction forces during the delivery stride. No investigations have been found that address ground reaction forces of both back and front foot contact during the same delivery stride using two force platforms.

Table 2.2 : Summary ground reaction forces during the delivery stride (BW means ± S.D.)

		Back Foot Contact		**Front Foot Contact**	
Authors	Subjects	Peak Vertical force	Peak Horizontal (braking) force	Peak Vertical force	Peak Horizontal (braking) force
Elliott and Foster (1984)	4 International seniors			4.7 ±0.4	1.7 ±0.3
Foster and Elliott (1985)	1 International senior			3.8	1.4
Elliott *et al.* (1986)	15 elite seniors			4.1 ±0.9	1.6 ±0.4
Foster *et al.* (1989)	82 representative juniors (age 16.8)			5.43	2.45
Mason *et al.* (1989)	15 fast-medium juniors	2.0	1.0	9.0	2.0
Saunders and Coleman (1991)	7 fast-medium	2.77	1.07	4.13	1.8
Elliott *et al.* (1992)	20 juniors (age 17.9)	2.9 ±0.8	1.1 ±0.2	6.4 ±1.1	1.9 ±1.2
Elliott *et al.* (1993)	24 representative juniors (age 13.7)				
	Group 1			4.8 ±1.4	2.1 ±0.7
	Group 2			5.2 ±0.9	2.6 ±0.7

All the results in the above table represent the current scientific literature on ground reaction forces in the field of fast bowling. They all must be treated with caution because only one force platform was used during each study. Three studies have investigated ground reaction forces during back foot and front foot contact by ensuring each bowler adjusted their starting positions so as to contact the force platform with the correct foot. Abendroth-Smith (1996) reported that the force platform artificially induced stride patterns for twelve experienced middle distance runners. The stride pattern was not characteristic of normal running because of the athletes targeting the position of the force platform.

Elliott and Foster (1984) investigated the ground reaction forces generated by four Australian international fast bowlers. Mean vertical ground reaction forces were 4.7 BW, while the mean maximum anterior-posterior force was 1.76 BW. Foster *et al.* (1989) reported mean vertical ground reaction forces of 5.43 times BW and mean maximum braking force of 2.45 BW for eighty two young potentially high performance fast bowlers. The mean values for peak vertical ground reaction forces from the majority of studies are in the range of 3.8 and 6.4 BW, with anterior and posterior braking forces approximately 2.0 BW.

Impact forces in human locomotion are forces that result from a collision of two objects reaching their maximum earlier than 50 ms after the first contact of the two objects (Nigg and Herzog 1994). The rate of change of this impact force with time or loading rate allows further comparisons in technique to be addressed. The time occurrence and the magnitude of the impact force peaks depend on a number of factors, including, approach speed, material properties of the shoe, geometrical constructions of the shoe sole (Nigg *et al.* 1987) and running style (Cavanagh and Lafortune 1980). No research has reported on loading rates for fast-medium bowlers, although Mason *et al.* (1989) reported a mean peak vertical force of 9 BW occurring 0.01 seconds after impact. This would equate to a mean loading rate of 900 BW s^{-1}. By way of a comparison, Munro *et al.* (1987) reported loading rates of 113 BW s^{-1} at an approach speed of 5.0 m s^{-1} for middle distance running. A run-up speed of five metres per second is also a typical approach speed for the fast-medium bowler. However, the calculated loading rates for the cricket bowler are much greater than those reported during middle distance running. Mason *et al.* (1989) reported that the three bowlers who produced the greatest vertical ground reaction forces (maximal value of 12.3 BW) had a fully extended knee, raised to or above the horizontal before front foot contact. This resulted in a vigorous front foot strike with a fully extended knee. Despite this, vertical ground reaction forces of 12 BW are exceptionally high (approximately twice the value of the rest of the reported ground reaction force literature) and raises the question of the level of experimental error in the results reported by Mason *et al.* (1989).

Saunders and Coleman (1991) reported peak forces values from both the front and back foot. The experimental conditions during this study involved seven medium-fast bowlers performing their typical bowling action indoors with a limited run-up. Despite this, the peak ground reaction force values obtained in this study are similar to those documented by Bartlett *et al.* (1996). In addition, Saunders and Coleman (1991) found no significant correlation between peak ground reaction force values and any kinematic parameter they studied (delivery stride length, release height, angular displacement and ball release speed). Elliott and Foster (1984) and Elliott *et al.* (1992) also found no differences between peak ground reaction forces for the different bowling techniques.

Front knee angle

The angle of the front knee during the delivery stride is believed to be strongly linked with impact forces during front foot contact. Three different front knee angles at front foot strike have been recorded in the literature.

(1) Straight Leg Technique : This technique is characterised by a fully extended front limb at front foot contact which remains at or near to this angle during release. This technique is believed to be advantageous in terms of maximising ball release speed because it provides a stable lower body, which the bowler may use as an effective lever. Elliott *et al.* (1986) suggested that an angle greater than 150° would be sufficient to provide these benefits. Davis and Blanksby (1976b) and Elliott and Foster (1984) recognised the use of the front leg as a fulcrum over which the torso pivots. However effective the straight leg technique is, in terms of maximising ball release speed, it may be potentially more prone to injury. The knee joint does not play an effective role in the attenuation of impact forces. Flexion of the knee upon impact would reduce the stress placed on the bones, cartilages, tendons and muscles of the knee and hip joint and hence reduce the risk of injury (Nigg, 1983). Elliott and Foster (1989) suggested that it seems desirable that some knee flexion occurs following front foot strike to assist in the absorption of the force when the front foot makes contact with the ground. This view contrasts with Tyson (1976) who recommends that the bowler should "stamp the foot and stand up straight", "brace the leg".

(2) Flexed Knee – braced or collapse at release : Bowlers who land with a flexed knee (approximately 150°) and either maintain this angle (braced) or flex the knee further (collapse) after front foot strike, represent a second classification of front knee activity in cricket bowling. In both cases the knee fails to extend after front foot strike. Knee flexion on impact provides obvious benefits in terms of force attenuation. The vertical ground reaction force may be reduced to 2.0 BW at ball

release, if the front knee is flexed (Mason *et al.* 1989). The lack of subsequent knee extension fails to provide the beneficial aspects of bowling over a straight front leg. Elliott *et al.* (1986) reported knee angles (mean ±S.D.) of 168 ±18° at front foot impact. The knee angles at release were 159 ± 29°, indicating that the group as a whole tended to collapse at release.

(3) Flexed Knee - straightening on release : The third type of front knee activity involves the knee flexing slightly on landing (reducing the high impact forces) and subsequently extending to a near straight or straight front leg (180°). This technique, it could be argued, would be the optimal technique for the front knee activity during the delivery stride. Stockill and Bartlett (1992) identified two out of seventeen bowlers who flexed on impact and subsequently extended to a knee angle of greater than 150°. Burden and Bartlett (1990a) reported a significant relationship between ball release speed and front knee angle at ball release. It is interesting to note that bowlers who did not flex their front leg on contact, released the ball significantly faster ($P<0.02$) than those who did. Davis and Blanksby (1976b) found that the knee angle for the six fastest bowlers was 25° closer to full extension (180°) than the six slower bowlers. In a comparative study between elite fast bowlers and college fast-medium bowlers, Burden and Bartlett (1990a) stated;

> "probably the most distinct difference between the two groups of bowlers was the behaviour of the front knee between front foot contact and ball release".

They suggested that seven of the elite bowlers investigated landed with an almost straight front knee (173 ± 3.2°), flexed the knee by 6.6° and then extended the limb again to an angle of 173 ± 11.2° at release. Four of the seven bowlers did not flex at all on impact. Three released the ball over a hyperextended front knee. Only four of the nine bowlers were able to subsequently extend following such large amounts of flexion, as shown by the mean knee angle at release (135 ± 20.2°). Stockill and Bartlett (1994) found no differences in mean knee angles between the two groups of twelve international standard junior and senior fast bowlers.

Delivery Stride length

The length of the delivery stride is dependent upon the speed of approach into the delivery stride and also the physique of the bowler (Elliott *et al.* 1986). Elliott and Foster (1984) reported that the bowler with the slowest approach speed (3.8 m s^{-1}) also had the smallest delivery stride (1.34 m). Whilst the bowler who possessed the greatest approach speed (4.6 m s^{-1}) had the largest delivery stride (1.67 m). Elliott and Foster (1989) further suggested that bowlers who approached the crease with an excessive approach speed, often have a reduced delivery stride. This "uncontrolled" approach may inhibit the ability of the bowler to attain a side-on delivery position.

Shoulder and hip orientation

Elliott and Foster (1984) reported the degree of shoulder rotation towards the batsmen to be greater for the side-on bowlers than the front-on bowlers. Elliott and Foster (1984) reported that the adoption of the side-on bowling technique allowed for a more effective summation of segmental velocities than a more front-on bowling approach. During the side-on bowling technique, the cricket ball travels through a greater acceleration path than it does during the front-on technique. Lillee (1977), Elliott *et al.* (1986) and Foster *et al.* (1989) suggested that the trend towards a more front-on alignment of the shoulders was a contributory factor to the apparent increase in lower back injuries. This was due to bowlers striving to attain a perfect side-on position with their upper torso, but often failing to achieve a side-on position with their lower body. Elliott *et al.* (1992) stated that counter rotation of the shoulders during the delivery stride was a contributing factor in lower back problems. The movement of the shoulders between back foot and front foot strike is widely agreed to be of prime importance in predisposing the lumbar spine to injury (Elliott *et al.* 1986 and Foster *et al.* 1989). Foster *et al.* (1989) reported a difference of shoulder and hip angles in excess of 40°. Stockill and Bartlett (1992) reported counter-rotation angles for a group of seventeen elite seniors of 28.2 ± 13.2°, with a range of 0-47°. Three bowlers counter-rotated by more than 40°. As a result, Stockill and Bartlett (1992) suggested that,

> "it may be inadvisable to state an absolute figure (to classify the mixed action) which is applicable to all bowlers. It may also not be wise to view the shoulders with disregard for the angle of the hips, as the hips may be rotating away from the batsmen to the same degree as the shoulders, thus reducing the risk of lower back damage. The analysis of hip to shoulder separation angles may provide more conclusive and informative results than simply viewing the shoulder angle alone."
>
> Stockill and Bartlett (1992)

The orientation of the hips during the final delivery stride has received little attention. Previous studies have either viewed the bowling action as two-dimensional, having used only one laterally positioned camera (Davis and Blanksby 1976b; Penrose *et al.* 1976; Burden and Bartlett 1990b). Several studies have used an independent overhead camera to provide information about back foot and shoulder orientation (Elliot and Foster, 1984; Elliott *et al.*, 1986; Foster *et al.*, 1989 and Elliott *et al.*, 1993). Stockill and Bartlett (1992) reported hip angles of 209 ± 15.5° and 225 ± 10.3° at back foot and front foot strikes respectively. Burnett *et al.* (1995) reported equivalent angles of 295 ± 16° at back foot strike and 222 ± 14° at front foot strike demonstrating that the initiation of hip rotation occurred prior to front foot strike.

Non-bowling arm

The action of the front, non-bowling arm is an important feature in the fast bowling technique. The rapid adduction and extension of the non-bowling arm, which occurs before and during trunk rotation, aids in the summation of segmental forces. Davis and Blanksby (1976b) suggested that the non-bowling arm aids the lateral flexion and lean back position of the torso during the coil position. By raising the front arm high, the torso will automatically lean back to facilitate the movement. Elliott and Foster (1989) emphasised that the non-bowling arm and the front leg must be thrust down together. This in turn brings about the flexion and rotation of the trunk and rotation of the bowling arm.

Torso movement during the delivery phase

The torso flexes from its extended position at back foot strike to enable the body to prepare for the rotation of the bowling arm. The role of torso flexion contributes to the rhythm and fluidity of the bowling action. Torso flexion has also been found to provide a significant contribution to the speed of the ball. Davis and Blanksby (1976b) and Elliott *et al.* (1986) calculated that torso flexion contributed 11% and 13% respectively to final ball release speed. Burden and Bartlett (1990a) reported a difference in the higher rate of torso flexion for a group of nine college bowlers compared with a group of seven County and International bowlers. The difference in the two groups of athletes occurred between front foot strike and ball release. Maximum trunk velocities of 9.23 ± 1.40 rad s^{-1} for the County and International bowlers were reported compared to that of 6.20 ± 1.03 rad s^{-1} for the college bowlers.

Sequence of Segmental Movements

The sequencing of segment movements has not been widely reported according to Bartlett *et al.* (1996). In a study of nineteen club level fast bowlers, Davis and Blanksby (1976a) attempted to calculate the percentage contributions of various body segments to ball release speeds by restraining and restricting the movements of certain body segments. They calculated percentage contributions of run-up, hips, shoulders, bowling arm and hand. The authors did not account for the effect of the preceding segment upon the movement. The delivery action relies on the summation of forces, with the contributing muscles coming together as one to deliver the ball as quickly, accurately and efficiently as possible.

Stockill and Bartlett (1994) investigated the peak linear speeds of the major joints in the kinematic chain from right hip to right bowling hand in two groups of twelve international bowlers with significantly different release speeds (juniors: 32.1 ± 1.9 m s^{-1}; seniors 38.1 ± 1.4 m s^{-1}; $P<0.005$). The peak linear speeds were significantly greater for the seniors for whom these peak speeds, except the right hip, occurred at a time significantly closer to ball release ($P<0.01$). When these times were normalised for the duration of the delivery stride the temporal differences became non-significant. Bartlett *et al.* (1996) indicated that more research is needed into segmental contributions, including energy transfers between segments and other aspects of segment kinetics. Using electromyography as the analysis tool may help to identify the sequencing of segmental movements of the fast-medium cricket bowler. Only one previous electromyographic study of fast-medium bowling has been found. Burden and Bartlett (1990b), utilising electromyography from selected torso and glenohumeral joint muscles, synchronised with two-dimensional cinematography aimed to determine the sequential and temporal patterns of muscular activity of four fast-medium bowlers. The mean (± S.D.) ball release speed of the four bowlers was 29.3 ± 0.63 m s^{-1}. Intra and inter bowler differences in muscle patterns were also addressed.

Ball Release

Abernethy (1981), classified cricket bowlers into four categories based on ball release speed, see table 2.3.

Table 2.3: Classification of Bowlers by Release Speed (Abernethy, 1981)

Ball Release Speed (m s^{-1})	**Bowler Classification**	**Time to Travel 17.63m (ms)**
>40.5	Express	<439
36.0 – 40.5	Fast	439 – 493
27.0 – 36.0	Fast-medium	493 – 657
18.0 – 27.0	Slow-medium	657 – 986

The final contribution made by the hand action of the bowler may still make a difference to the final release speed of the cricket ball. The action of the fingers, wrist and hand action requires further investigation. The use of the wrist is permitted during the delivery action.

"A ball shall be deemed to be thrown if, in the opinion of either umpire, the process of straightening the bowling arm, whether it be partial or complete, takes place during the part of the delivery swing which directly precedes the ball leaving the hand."

Marylebone Cricket Club (1976)

The above definition is the official note accompanying 'Law 26' with regards to what constitutes a cricket bowl compared with a throw. Davis and Blanksby (1976b) suggested that fastest bowling was associated with extending the hand at the wrist as far as possible and then rapidly flexing the fingers and hand just prior to the release of the ball. Elliott and Foster (1984) reported a flexion of 17.7 ± 8.5° to an extended position (180 ± 8.7°) after release. Elliott *et al.* (1986) reported that the wrist flexed by 7.0 ± 19.8° to reach almost full extension of 177 ± 30° after the release of the ball.

The height of ball release relative to standing heights range from 114% (Elliott *et al.* 1992) to 116% (Elliott and Foster, 1984) to as high as 118% (Foster and Elliott, 1985). Bartlett *et al.* (1996) indicated that the height of release is likely to be related to the length of the delivery stride, the knee angle at release and the extent of trunk flexion and lateral flexion. No research has been reported as to the relationship between these factors.

Follow Through

Limited data is available on the follow through, as the majority of the biomechanical analysis ceases shortly after the ball is released. Tyson (1976) suggested that the first stride of the follow through should be behind the line of the ball, before running off the wicket for a further two or three strides. If a bowler were able to continue running behind the line of the ball for a much greater period, the rotational forces acting upon the body may be reduced. This is, however, not permitted since the bowler would run down the wicket.

2.2 Javelin Throwing

The main research into javelin throwing focuses on the release parameters of the javelin (Gregor and Pink, 1985; Rich *et al.*, 1985a; Rich *et al.*, 1985b; Bartlett and Best, 1988; Whiting *et al.*, 1991 and Morriss and Bartlett, 1996). Research has specifically focused on the subject's technique, body position and release of the javelin, establishing specific release parameters for each athlete. This phase of the throw is called the delivery phase. An effective technique is critical for an elite thrower. The javelin throwing technique can be broken down into six stages. These stages are described in Appendix A.

For any given thrower there is a set of release parameters that will produce the greatest distance thrown. The terminology relating to the release and subsequent flight of the javelin is described in figures 2.2 and 2.3. These diagrams are adapted from Bartlett and Best (1988). Release parameters typically include release speed (*vo*), release angle (*ao*), release angle of attack (*bo*), release attitude angle (*co*), release height (*zo*) and front foot to foul line distance (*do*). The aerodynamic characteristics of the javelin are determined by the velocity vector of the javelin's mass centre relative to the air (*voa*). Body segment kinematics of ankle, knee, hip, shoulder, elbow and wrist joints together with angular displacements of the elbow, shoulder, torso and knee are commonly reported in the scientific literature (Bartlett and Best 1988 and Whiting *et al.* 1991). The majority of literature in this area focuses on cinematographic analysis recorded during top class competition, with authors reporting on the critical performance characteristics of the athlete's throwing technique.

Biomechanical research has also investigated the flight phase of the javelin throw with particular emphasis upon the aerodynamics of the javelin (Terauds, 1978; Hubbard and Rust, 1984; Best and Bartlett, 1988). Best and Bartlett (1988) indicated that three fundamental factors influence the javelin after release. The angular velocity components about the longitudinal axis of the javelin, (spin, *so*) about a perpendicular horizontal axis, (pitch rate, *wo*) and about a third axis which is mutually perpendicular to the other two (yaw rate, *yo*).

Figure 2.2 Javelin release parameters.

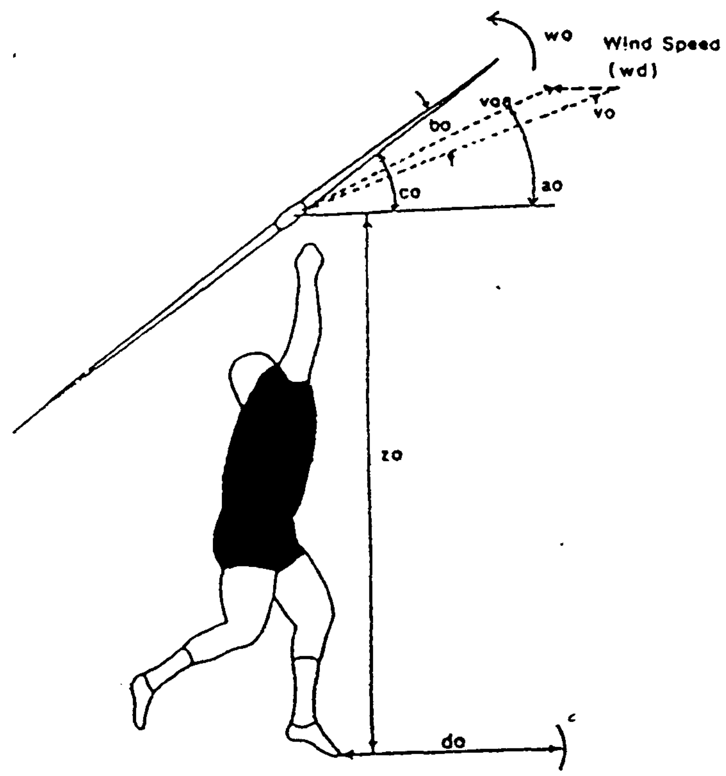
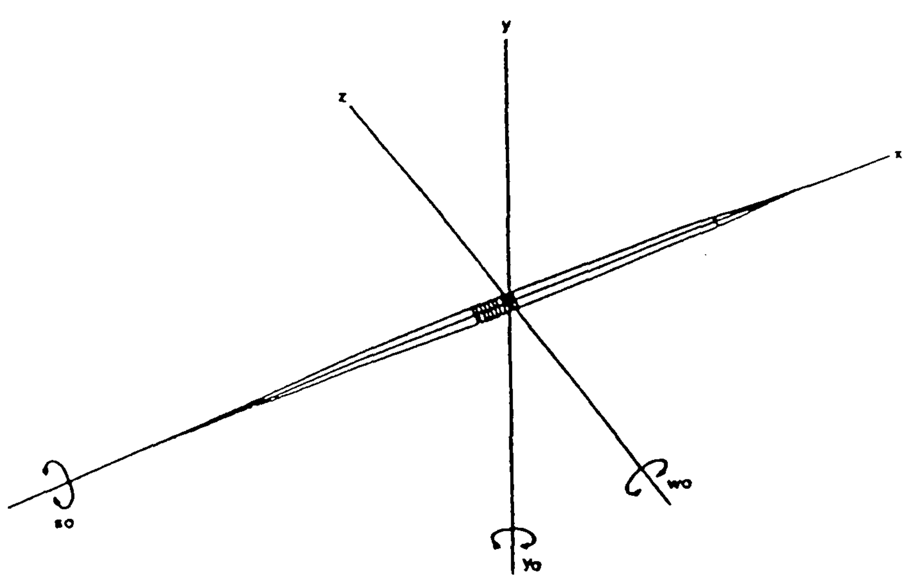


Figure 2.3 Javelin angular velocity components.



Other important factors are the flutter of the javelin at release, environmental conditions, especially wind velocity and air density, and the physical characteristics of the javelin, e.g. mass, principal moments of inertia and shape. All of these influence the distance the javelin is thrown and relate to aerodynamic forces and moments acting on the javelin during flight. The interaction of all the above variables results in a flight time of approximately two and a half times longer than it would be with no aerodynamic forces acting upon the javelin (Hubbard and Rust 1984).

The introduction of the new-rules javelin (International Amateur Athletic Federation 1986) saw specification of the men's javelin change in order to reduce the distances thrown by the athletes. A new set of optimal release parameters resulted and as a consequence slight modifications to the throwing technique were required. The new javelin's flight path was closer to a parabola, resulting in a negative attitude angle at landing, thus eliminating flat landings. Best and Bartlett (1988) stated that as a result of the modifications, even more importance was now placed on the release speed of the javelin in comparison with other release parameters. Subsequently there has been a trend towards more powerful throwers since the introduction of the new-rules javelin.

This review focuses on the aspects of the javelin thrower's technique that are related to improved throwing performance. A number of fundamental mechanical principles make up the javelin throw and the most important is the speed of release. The release angle, release height and body segment dynamics have also been investigated (Bartlett and Best, 1988 and Whiting *et al.*, 1991). The throwing action can be divided into three distinct stages, which are described by Morriss and Bartlett (1996): run-up including crossover strides, delivery stride and recovery. The delivery phase of the javelin throw has received the majority of attention from scientific analysis.

The Run-up

The run-up and its control are of great importance to the production of maximal release speed. The length of run-up should be such that the speed achieved is the maximum that can be controlled by the physical strength of the thrower. This is particularly important during the delivery phase of the throw (Morriss and Bartlett 1996). This is often achieved by bounding strides or by a smooth acceleration into the throw. The elite thrower tends to start the run-up 30-35 m behind the foul line. A preliminary run-up of 10-12 forward steps is followed by the transition period of between three to seven sideways steps prior to release (Hay, 1985 and Bartlett and Best, 1988). A series of crossovers are performed in which the thrower can maintain the initial velocity of the run-up and prepare for the delivery stride. No literature has reported on the relationship between the technique of the thrower during the crossovers and the delivery stride.

In the 1984 Olympic javelin finals, Komi and Mero (1985) reported average ± S.D. run-up speeds of 5.2 ± 0.6 m s^{-1}, (n=5) for men and 5.4 ± 0.7 m s^{-1} (n=6) for women. Run-up speeds of 5.3 ± 0.7 m s^{-1} (n=7) and 5.6 ± 1.0 m s^{-1} (n=11) have been reported by Ikegami *et al.* (1981) and Mero *et al.* (1994) respectively. Typical horizontal velocities for the thrower's centre of mass at various positions of the run-up have been reported to range between 5.2 to 7.0 m s^{-1} for elite throwers (Komi and Mero, 1985; Best *et al.*, 1993 and Mero *et al.*, 1994). Run-up speed is typically reported at back foot contact prior to the delivery stride, although this measurement position is not standard throughout the literature. Komi and Mero (1985) found no significant correlation between run-up speed and distance thrown. They suggested that the length and speed of the run-up are dependent on the technique and control of the athlete and is the personal preference of the athlete.

The Delivery Stride

The delivery stride begins with the back foot contact. The momentum gained in the run-up is transferred into vertical and horizontal components throughout the upper body and throwing arm during the delivery phase of the throw.

The Block

During the delivery stride of a right handed javelin thrower the left leg must first absorb the initial shock of landing and then brace or block to support the left side of the body against a forward thrusting right leg action. A braced left side is essential if the active throwing right side is to accelerate around it. Few studies have investigated the ground reaction forces experienced during javelin throwing. Deporte and van Gheluwe (1988) measured the ground reaction forces on lead and rear legs during the delivery stride for a group of eight elite Belgian throwers. The push-off (rear) leg was subjected to a maximum vertical ground impact load of up to 9.1 times BW (6.65 kN) with an anterior-posterior impact force up to 4.71 kN. The maximum ground contact forces measured on the front foot of their throwers was up to 4.8 kN (vertical) and 2.0 kN (anterior-posterior). Bartlett *et al.* (1995) measured the pressure distributions on the plantar surface of the foot during front foot contact. They reported final foot contact forces of 2.8BW. A preliminary investigation conducted by Hurrion (1992), which examined the ground reaction forces experienced by three elite javelin throwers, measured the ground reaction force at three different contact phases during the final delivery stride. Both back and front foot contacts during the delivery stride were recorded as well as the follow through recovery stride. Mean vertical forces of 2.69 BW, 2.79 BW and 5.97 BW respectively were reported. The large resultant force of the third stage (recovery stride) was due to the athlete checking his residual forward momentum, before reaching the foul line. The results recorded by Hurrion (1992) are much lower in magnitude than those of Deporte and van Gheluwe, but the vertical forces recorded during front foot contact are similar to those reported by Bartlett *et al.* (1995). Nonetheless, these high impact loads indicate that the athlete is experiencing high levels of stress during the javelin throw.

Morriss and Bartlett (1996) stated that the athlete should only flex the left (front) knee slightly after foot strike and then extend just prior to release. This has implications not only for the ground reaction force, but also release height. The angle of the front knee at release is a result of run-up speed and the extensor muscles of the left leg being able to not only withstand foot contact, but also the drive from the right hand side of the body. Morriss and Bartlett (1996) indicate that most studies do not explain the mechanism that links a strong block, at final foot contact, to the athlete's ability to accelerate the javelin around it. The lack of electromyographical studies allows only speculation as to the contraction of individual muscles during the final phase of the javelin throw.

Speed of Release

Of all the throwing events in track and field athletics, the javelin throw is the one in which the highest release speeds are attained. Typical release speeds for elite athletes range from between 25 and 31 m s^{-1}. The basic natural attribute for javelin throwing is a fast arm. Popular opinion suggests that such a quality is more an act of nature than nurture (Jones 1994). The speed of release is "the single most important factor governing successful performance" (Miller and Munro, 1983). This statement is generally agreed and is well supported by cinematographic evidence (Best and Bartlett 1986). For elite male throwers correlations between release speed and distance have been reported by Kunz and Kaufman (1980) 0.79, Miller and Munro (1983) 0.94, Komi and Mero (1985) $P<0.001$ and Rich *et al.* (1985b) 0.72. Kunz (1974) reported a 0.84 correlation between the personal best throw (old-style javelin) and release speed. It is not too surprising that such high correlations should be widely reported, given that the distance thrown is basically a function of the square of the release speed (Hubbard and Alaways, 1987).

Komi and Mero (1985) performed a two-dimensional film analysis on nine subjects competing in the Los Angles Olympic Games of 1984. The results showed a significant relationship between release speed and distance thrown. High impact loading was specific to the leading front foot contact and was characterised by a short duration and a high knee flexion velocity. Whiting *et al.* (1991) using high speed film (two-dimensional) reported on eight male elite javelin throwers, throwing the new-rules javelin, during five competitions (including the U.S.A Olympic Trials - 1988) over a two year period. Body segment analysis was assessed relative to the throw; the greatest distances were typically characterised by higher release speeds, less flexion in the front left bracing leg and steady increase of peak speeds at the hip, shoulder, elbow and wrist joint. If all other release parameters remained constant any increase in release speed is accompanied by an increase in the distance thrown. Preliminary speed, run-up speed, natural speed of arm, strength, balance, withdrawal timing, drive and skill represent the factors which determine the release speed (Miller and Munro 1983; Best and Bartlett 1986 and Bartlett and Best 1988).

Sequencing of Segmental Movements

The javelin throwing action consists of co-ordinated accelerations and decelerations of body segments. The timing of the peak linear speeds of body segments occur in a temporal sequence from left lead foot to the right throwing arm, all acting to produce maximum throwing speed. Proximal segments should reach their peak speeds first, followed by those more distal (Whiting *et al.* 1991). Ariel (1973) and Terauds (1978) have reported this temporal sequencing for single throws. Best *et al.* (1995) reported an orderly progression in peak linear speeds from proximal to distal segments for the 22 finalists in the men's and women's javelin finals of the 1992 Olympic Games.

The contribution made to the final release speed of the javelin by each body segment is particularly relevant to this study. Mero *et al.* (1994) reported the peak joint speed and time from final foot strike to release for the hip, shoulder, elbow, wrist and hand of the throwing side of the body. The resultant javelin release speeds were very similar, but the way each athlete achieved the release speed was considerably different. This resulted in two very different throwing techniques. Morriss and Bartlett (1996) support this idea of markedly different movement patterns from data recorded during the men's javelin final at the 1995 national championships. These results suggest that the muscular activation used to accelerate the javelin is unique to the individual.

Two studies have been reported which utilised electromyography as a means of investigating the javelin throw. Tanner (1982) investigated the specific training activities for javelin throwing with the view to establishing their relevance to training and coaching of javelin throwers. One subject underwent a number of javelin specific training activities, that is, medicine ball throw, shot throw, 1 kg javelin ball and throwing a 150 g javelin. These simulated throwing tasks and additional strength exercises were studied by electromyographic analysis. The triceps and pectoralis major were the two muscles analysed. Tanner (1982) reported that the exercises produced a considerable amount of overload of the muscles involved in throwing the javelin. All activities were deemed specific to the event. The speed of the majority of activities measured did not relate, however, to that of the javelin throwing action. He reported similar electromyograms for the pectoralis major and the triceps brachii muscles, for throws with the 1 kg throwing ball and the javelin (800 g).

Salchenko and Smirnov (1982) compared the muscle activity of skilled and beginner javelin throwers during the crossover steps and the final delivery stride. They stated that neuro-muscular co-ordination in skilled throwers is characterised by a gradual increase in bioelectric activity of leg and throwing arm muscles in proportion to the execution of the final stage of the throw. The greatest effort is observed in the final delivery stage. Activity in beginners is characterised by greater activity in the preparatory phase of the throw rather than the final stages of delivery. Deltoid, latissimus dorsi, pectoralis major and flexor carpi radialis from the throwing arm were all synchronised with cinematograms. Salchenko and Smirnov (1982) reported that latissimus dorsi and pectoralis major muscles display very slight activity during the phase of final effort. They concluded that possibly these muscles do not play an important role in javelin throwing.

Ariel *et al.* (1980) found a significant positive correlation between maximal right hip speed and distance thrown. A large hip angular velocity precedes hyperextension and powerful rotation of the trunk about the vertical axis (Bartlett and Best 1988). Extending the left arm horizontally and the laterally flexing the torso assist rotation of the upper torso (Miller and Munro 1983 and Rich *et al.* 1985b). The speed of the torso is closely related to the speed of the arm. A key factor of the throw is the speed at which the torso can uncoil creating the initial stage of javelin acceleration (Jones 1987). With greater emphasis on release speed for the new-rules javelin, it is possible that slight increases in the angular displacement of the torso may occur in order to increase the acceleration path via a longer carry. This demonstrates the need for excellent flexibility in the javelin thrower, particularly in the trunk, shoulder and hip joints. Once this stable throwing base is established, commonly referred to as the bow position, (see Appendix A) the right shoulder horizontally flexes and abducts. This occurs with the elbow flexing, which reduces the moment of inertia about the shoulder axis, thus permitting a faster movement (Jones 1987 and Bartlett and Best 1988). These actions, combined with the lateral rotation of the humerus, give the characteristic elbow lead position. This refers to the thrower maintaining an elbow position which is ahead of the javelin's mass centre.

Release Height

Best and Bartlett (1988) summarised the release of the javelin as being directly overhead with an extended throwing elbow, an extended leading-leg knee and a torso, which is both hyperextended and laterally flexed. Miller and Munro (1983), Gregor and Pink (1985) and Rich *et al.* (1985b) stated that all the above factors would allow the javelin to be released close to the maximum possible height, 15-30 cm above normal standing height. Typical reported release heights range between 1.90 and 2.25 m. Rich *et al.* (1985b) found release height to be strongly correlated (r = 0.72) with normal standing height. Best and Bartlett (1988) stated that an increase in release height would result in an increase in distance thrown if all other release parameters remained constant. Attig (1981) and Hay (1985) suggested that the release height is an important determinant of the distance thrown. There is no reported optimum value for release height at which distance would be maximised. Hubbard and Rust, (1984) indicated that deviations from the normal release height are likely to lead to a decrement in an individual's release speed and possibly hinder the precise control of other parameters.

Rich *et al.* (1985b), reported a significant correlation ($P<0.05$) between release height and release speed. Terauds (1978) found correlations of zero between release height and range and (r = 0.14) between release height and release speed. Hubbard and Rust (1984) ignored the effect of release height totally in his computer optimisations, keeping it constant at 2 m.

The larger release angle, which is associated with the new-rules javelin, will mean a trend away from the round-arm 'rotational or wrap around' throwing style and a move towards and a more linear 'over the top' method. This would increase the release height of the javelin and reduce the injury risk associated with round arm throwing. Nonetheless, the world's number one javelin thrower, Jan Zelezny utilisies the round arm throwing style to near perfection. The 'over the top' more linear throwing style is supported by John Trower (British Athletics Federation's National Senior coach for the javelin throw). In 1987 Trower began coaching S. Backley (GBR No.1), former world record holder (91.46 m 1993) and M. Hill (GBR No.2) personal best 86.94 m.

> "My preference is for a more linear style of throwing, as it tends to reduce the *room for error* factor and offers throwers the opportunity to be more consistent once the technique has been mastered. To my mind, on the basis that simplicity is the best policy the linear style of throwing wins every time".
>
> J. Trower (1996)

Javelin throwing requires similar movement patterns to those of fast bowling. Similarities do exist between the crossing of the right foot during the delivery phase of the bowling action and that of the crossover stride in javelin throwing. The foot patterns for the crossovers were similar to the foot patterns commonly seen in cricket bowling. Komi and Mero (1985) analysed 11 Olympic finalists (five males, six females) at the 1984 Games using two-dimensional cinematography. They reported that knee flexion of 17° and 13° following impact with the front foot from the men and women respectively, was followed by extensions of 12° and 8° to produce knee angles at release of 153° and 151°. Three male throwers flexed their knee in excess of 10° and still managed a knee angle at release of greater than 170°. Many of the top athletes land with a slightly bent front leg and then straighten it to produce the highest possible height of the throw (Trower 1996). Coaches and athletes commonly refer to this effect as 'topping'.

Release Angle

Bartlett and Best (1988) indicate that comparisons between studies in the literature are made difficult because the majority of studies do not report on environmental factors such as wind speed and direction which have a direct bearing on results. The release angle, release angle of attack and pitch rate all have received significant attention with regards to the optimisation of the release parameters. The effect of the wind speed, direction, air density, air temperature and even the vibration of the javelin all play an important part in obtaining the optimal release angle. Bartlett and Best (1988) state that the release parameters even varies for different types of javelins used in competition. The release angle of attack cannot be calculated without wind speed and direction. The angle between the javelin's velocity vector relative to the ground and the long axis of the javelin is not equal to the angle of attack unless the wind speed is zero (Morriss and Bartlett 1996). Whiting *et al.* (1991) indicated that arm and wrist angle position and the direction of drive and height of height are the main factors determining the release angle.

With the introduction of the new-rules javelin the optimal release angle has typically increased (Best and Bartlett, 1988). Reported release angles are between 30 and 40°. It must be stressed that the optimal release angle is not constant but is a result of all the above factors. It may well change from throw to throw during the competition. This is an additional factor that the athlete must take into consideration.

The Recovery

Unlike the fast bowler, the javelin thrower after releasing the implement must stop their forward momentum prior to the foul line. This creates a third large impact with the ground, typically the right foot (right-handed thrower). A preliminary investigation conducted by Hurrion (1992) examined the ground reaction forces experienced by three elite javelin throwers during this final follow through recovery stride. Mean vertical ground reaction forces of 5.97 BW were reported. The large resultant force of the recovery stride is due to the athlete checking their residual forward momentum, before reaching the foul line. This highlights the importance of an effective front leg block in reducing the horizontal velocity of the mass of the athlete (Morriss and Bartlett 1996). A number of studies report the distance from the final front foot contact to the foul line. Reported figures range from between 1.76 m and 3.85 m (Miller and Munro 1983) and 1.46 m and 4.05 m (Kemio and Mero, 1985). Morriss (1995) highlighted this fact during a study of the 1994 European Championships men's final. The bronze medal athlete actually threw the javelin 0.10 m further than the silver medal throw. However, he released the javelin 0.42 m further back from the foul line, recording a throw 0.32 m less than the silver medal throw.

2.3 The use of athletic supports in sport

There has been a sharp rise in the use of neoprene supports over the last decade. The prime purpose of the neoprene support is to prevent injury or provide support following an injury. The rate at which damaged tissue heals itself cannot be accelerated. However, by increasing the local temperature the metabolic rate is increased. As a result local blood flow dissipates the heat and supplies additional oxygenated blood to the damaged area. Local heat also aids rehabilitation of soft tissue injuries. By maintaining a greater temperature than that supplied by the body, the range of motion of the joint may increase due to increased flexibility and muscular efficiency (Vulkan 1996).

Literature regarding the use of and effectiveness of neoprene supports during sporting activities is limited. Albright *et al.* (1995) reviewed the biomechanical and functional performance of prophylactic knee braces. They reported that knee braces can provide up to 20 to 30% greater resistance to a lateral blow. However, the presence of a knee brace may slow an athlete's running speed and cause early fatigue. Albright *et al.* (1995) indicated that the weight of the brace, resultant friction of the hinges, completeness of fit and tightness of straps were important in the design of the knee support. Thorwesten *et al.* (1996) investigated the effects of ankle bracing on sports-specific capabilities. Improved proprioceptive control resulted from the tested orthoses, significantly improving the capabilities of the injured ankle. Thorwesten *et al.* (1996) stated that prophylactic bracing for uninjured ankles does not seem to have any significant impact on sports-specific abilities.

Several studies have investigated the use of back, abdominal, lumbosacral corsets, the immobilizing efficiency of back braces/support devices for corrective measures and for the relief of lower back pain amongst the general population.

Whitbread (IAAF, 1993) reported the use of weightlifting belts during javelin throwing. The majority of the world's top javelin throwers and others of lower standard wear a supporting belt whilst throwing. The prime purpose of the lumbar support belt is to prevent back injury or provide support following injury. Launder (IAAF Round Table, 1993) stated that the lower back is particularly at risk with common injuries occurring in the fourth and fifth lumbar region. Such belts may alter the physical performance and strain experienced by the thrower.

Landers *et al.* (1990) reported weightlifting belts during the squat exercise were associated with rise in intra-abdominal pressure ($P<0.05$). Integrated electromyographic activity of the rectus abdominis, external oblique and erector spinae showed greatest activity during the no belt condition. No significant differences were reported for any of the kinematic and force platform variables measured. This would indicate that subjects used a similar lifting technique regardless of belt usage. Landers *et al.* (1992) investigated the effectiveness of weightlifting belts during multiple repetitions of the squat exercise. As with the single lift, weightlifting belts aided the trunk by increasing intra-abdominal pressure during the eight repetitions ($P<0.05$). The no-belt condition recorded intra-abdominal pressure values of 25-40% lower than the weightlifting belt condition. No differences were observed between the two conditions for external oblique and erector spinae maximal electromyographic activity. Maximal electromyographic activity was significantly higher for the vastus lateralis and biceps femoris during the weightlifting belt condition. Both papers indicate that weightlifting belts increase intra-abdominal pressure during the squat exercise.

2.4 Summary

There is agreement on the importance of ball release speed in fast bowling and the release speed in the javelin throw. Researchers are still divided on elements of the athletes' technique which most contribute to this. On the basis of the data reported in this review, the order of importance of the release parameters considered for the fast bowler is primarily speed and secondly height of release. The important release parameters for the javelin thrower are primarily speed of release and secondly, angle of attack, angle of release and height of release. The relative importance of these parameters is dependent on the athletes' technique, physical characteristics and strength.

The majority of the javelin studies were performed under competitive conditions. Further research into javelin throwing and fast bowling in cricket requires the use of sufficiently large groups of subjects to allow generalisation in a controlled experimental environment. An integrated biomechanical approach utilising three-dimensional cinematography analysis, electromyography and ground reaction forces will allow detailed analysis of the technique of individuals. There is also a need to establish the specific factors that contribute most to the final release speed of the javelin/cricket ball. Future studies must also report on the sequencing of segmental movements, the timing of these segments and the net joint muscle moments. All future kinematic based studies need to address the estimation of experimental errors.

Biomechanical research has greatly aided the understanding of the javelin throwing techniques and the principles associated with them. Several studies have investigated body segment kinematics and release parameters, drawing upon cinematography film analysis and computer simulation combined with field data. Successful throws, as judged by distance thrown, are characterized by higher release speeds, less flexion of the front-leg knee during the final plant phase and an orderly progression of peak speeds at the hip, shoulder and elbow from the onset of the 'Bow Position'. Studies by Hubbard and Alaways (1987), Gregor and Pink (1985) and Best *et al.* (1993) all identified limitations in two-dimensional analysis and highlighted the need for three-dimensional analysis to further improve biomechanical investigations into the javelin throw. Best *et al.* (1993) did indicate that the major release parameter values obtainable in two-dimensional analysis were generally good estimations of the true three-dimensional values. Kinematic studies of javelin throwing have provided relevant data, which have identified release speed of the javelin as the greatest determinant of distance. Other release parameters, such as the angle of release, front knee flexion and release height, are of secondary importance. Further assessments, using ground reaction forces and associate temporal data during delivery, using electromyography, of muscle recruitment patterns during the javelin throw are necessary to assess injury potential.

One recommendation made by Bartlett *et al.* (1996) for future biomechanical research in cricket bowling was to establish the bowler-specific factors which contribute to fast ball release. A further recommendation was to focus on body segment dynamics and segmental contributions to the final delivery of the fast bowler's action. Ground reaction forces have been investigated during the final phase of the cricket delivery allowing assessment of potential injury risk. However, due to the wide range of results reported in the literature during front foot contact, further biomechanical investigation is required. In addition, further studies should investigate the simultaneous measurement of back and front foot ground reaction forces. Biomechanical research of the electromyograms of muscle recruitment patterns during the cricket bowl is limited.

The prime purposes of athletic supports are to prevent injury and to provide support following an injury. However, it will always be difficult to prove whether or not a certain device will afford a greater amount of protection or resistance to injury. Athletic supports may alter the physical performance and strain experienced by the athlete. Weightlifting belts have been shown in weight training to be associated with a rise in intra-abdominal pressure as the trunk muscles are supported in the abdominal region (Lander *et al.* 1990, 1992). The use of knee supports has also been documented in running activities (Albright *et al.* 1995).

Despite their ever-increasing use, there is little scientific evidence to show that the wearing of athletic supports prevents injury during athletic performance. Throughout this thesis, integrated biomechanical analysis techniques are used to investigate the effect of athletic supports on fast-medium cricket bowling and javelin throwing.

Chapter 3

SPORTING INJURIES IN MALE FAST-MEDIUM CRICKET BOWLERS AND JAVELIN THROWERS.

A RETROSPECTIVE SURVEY OF INJURY.

3.1 Introduction

3.2 Sporting injuries in male fast-medium cricket bowlers and javelin throwers

3.2.1 Fast-medium cricket bowling

3.2.2 Javelin throwing

3.3 Method

3.4 Results and Discussion

3.5 Summary

3.1 Introduction

Fast bowling in cricket and javelin throwing require explosive athletic movements. These actions often result in a range of injuries. There is a shortage of descriptive information on the incidence of sports related injuries in fast-medium cricket bowling and javelin throwing. Information on the incidence, prevalence, extent and range of injuries forms an important aspect of this thesis. The nature and extent of such injuries was investigated during the summer of 1996 by a retrospective survey of injury.

The first aim of this study was to establish the amount of cricket bowling and javelin throwing injuries that had occurred over the 'lifetime' of an athlete. Secondly, the survey aimed to highlight the number and severity of injuries from recreational, club, county and national level athletes. Finally, the survey aimed to determine the level of injury recurrence and reported upon the use of athletic supports in both sporting activities.

3.2 Sporting injuries in male fast-medium cricket bowlers and javelin throwers.

Both the cricket bowling and javelin throwing actions have many similarities. They require fast, explosive movements to produce optimal bowling and throwing forces. There are however, a number of differences that need to be emphasised in relation to the injury questionnaire.

3.2.1 Fast-Medium Cricket Bowling: Typically the bowler will bowl at 80 to 90% maximal effort with, however, the occasional all out effort. The release speed of the cricket ball is very important, yet it is not the only factor that will ensure a good delivery. Accuracy, line and length, swing, reverse swing, movement of the seam and spin of the ball all play a part to ensure a good delivery. The objective being to deceive the batsmen. The physical demands on the bowler are ever increasing. Typically the county and international standard bowler will bowl up to ten or more six ball overs a day, between four and five days a week, for as many as forty weeks a year. When combined with training sessions, it makes the life of a fast bowler a very strenuous one. Elliott and Foster (1984) state that fast bowling is an explosive action, which results in severe biomechanical stresses on the body. This in turn may produce injuries. Fast bowling in cricket is one of the non-contact sporting activities which has a very large risk of injury (Fitch, 1989). Fast bowling has been implicated in a multitude of injuries (Foster *et al.*, 1984; Payne, 1987; Tucker, 1990 and Crisp and King, 1994). The line of stress identified by Payne *et al.* (1987) from the bowling hand, wrist, elbow, shoulder, spine, hip, knee, ankle to the front foot, rotates around the lower lumbar spine. Many elite fast bowlers have had serious lower back injuries during their career. Stress fractures of the third, fourth and fifth lumbar vertebra, are reported by Elliott and Foster (1984); Foster *et al.* (1989) and Foster and Elliott (1985). There is also evidence to suggest that these injuries were not found exclusively in senior players. Elliott *et al.* (1992) suggested that a possible reason for the high incidence of injuries was that young athletes are being forced to train longer, harder and earlier in life to excel in their chosen sports. They suggested that the sheer number of repetitious hours of practice might produce gradual deterioration in specific parts of the body. It is therefore not surprising that physicians are diagnosing an increased number of overuse injuries. Bell (1992) stated that the combination of incorrect technique, poor preparation, overuse and clinical features all increased the risk of injury to the bowler.

3.2.2 Javelin Throwing: To throw the javelin 100% maximal effort is required. Distance is the only measurement that counts. As a consequence the speed of release is paramount for a good throw. Unlike the fast bowler, the javelin thrower has only three throws per competition, with a further three if they finish in the top eight. Typically each athlete uses between three and six of their permitted throws. During the summer competitive season an athlete may throw in as many as ten competitions. Athletes will typically aim to reach their peak throwing performance for the most important competition of the season.

To enable the javelin to travel long distances, very strenuous fast explosive movements involving stretching and pretension of the muscles are required. The high physical demands placed upon the body during the javelin throw are a major concern to the athlete, particularly because of the need to avoid body injury. Many athletes experience a number of traumatic injuries particularly around the joints of the throwing arm, knee and foot (International Amateur Athletics Federation (IAAF) Round Table, 1993), with injuries to the back considered by some to be the most common (Whitbread, 1993). Indeed it can be argued that the line of stress, identified by Payne *et al.* (1987) is just as applicable to the javelin throw as it is to the fast bowlers action.

3.3 Method

A retrospective injury questionnaire survey was conducted during the summer of 1996. An injury was categorised for the purpose of this study as an incident arising from training or competition that prevented participation in training or competition for seven days or more.

Eighty-six male athletes (52 bowlers and 34 throwers) responded representing an 86% return. Only male subjects were used during this study due to the lack of female subjects participating in both activities. Each athlete was categorised according to the level of competition at the time of the injury survey. A series of closed-ended questions were used throughout the questionnaire, with each question offering a set of answers asking the respondent to choose the one that most closely represented their views. The structure of the closed-ended questionnaire followed that outlined by Frankfort-Nachmias and Nachmias (1996). Semi-structured interviews were considered as an alternative option, however due to the time frame and number of subjects involved in this survey, the closed-ended questionnaire approach was considered the most suitable. A copy of the two questionnaires used in this chapter can be seen in Appendix B.

3.4 Results and Discussion

Table 3.1 and 3.2 summarises the injury incidence and the usage of athletic supports for male fast-medium cricket bowlers and javelin throwers. Appendix B contains details of the preliminary data.

Table 3.1. Injury incidence and usage of athletic supports for male fast-medium cricket bowlers.

	All (n=52)	Recreational (n=10)	Club (n=24)	County (n=12)	National (n=6)
Age (years) ± S.E.	27.5 ± 0.9	30.5 ± 4.1	27.1 ± 1.6	24.6 ± 1.0	27.7 ± 1.1
Height (m) ± S.E.	1.81 ± 0.02	1.79 ± 0.01	1.81 ± 0.01	1.84 ± 0.01	1.87 ± 0.02
Mass (kg) ± S.E.	83.0 ± 1.1	81.7 ± 1.8	83.5 ± 0.9	87.3 ± 1.3	88.5 ± 2.0
% Injured	73	40	75	83	100
Injuries per bowler	3.8	2.4	2.9	3.8	9.7
Recurrent %	82	75	83	80	83
Muscular injuries	50	5	17	13	15
Ligament injuries	49	8	23	10	8
% using supports	29	30	25	42	17

Table 3.2. Injury incidence and usage of athletic supports for male javelin throwers.

	All (n=34)	Club (n=16)	County (n=12)	National (n=6)
Age (years) ± S.E.	25.4 ± 1.0	25.9 ± 1.6	23.3 ± 1.1	26.5 ± 1.7
Height (m) ± S.E.	1.83 ± 0.02	1.81 ± 0.01	1.83 ± 0.01	1.85 ± 0.03
Mass (kg) ± S.E.	87.2 ± 1.7	84.8 ± 1.2	85.4 ± 2.1	95.3 ± 2.7
% Injured	91	88	92	100
Injuries per athlete	4.7	3.6	4.5	8.2
Recurrent %	87	86	91	83
Muscular injuries	54	20	16	18
Ligament injuries	51	22	13	16
% using supports	56	50	50	83

In both cricket and javelin more injuries were reported at the higher competition levels. Overall 73% of fast-medium cricket bowlers and 91% of javelin throwers reported injuries. This equates to on average 3.8 injuries per bowler and 4.7 injuries per thrower.

In total fifty muscular injuries were reported throughout the four groups of cricket bowlers. The back represented the highest proportion of injury with 32% followed by the groin (29%), hamstring (15%) and shoulder (6%). The majority of ligament/joint injuries in the cricket bowlers occurred at the knee (38%), back (34%) and ankle (22%). Thirty-one cricket bowlers, (82%) had a recurrent episode of an original injury. The percentage figure for a recurrent episode of an original injury is very similar throughout all four groups of bowlers. For the six national players, fifty-eight injuries were reported. This represents 9.7 injuries per person compares to the recreational and club player of 2.4 and 2.9 respectively. The twelve county bowlers averaged 3.8 injuries per person. Of the fifty-two bowlers that participated in this study, only twenty nine percent wore any type of athletic support or taping, either during training or during a match. The cricket bowlers used mostly knee (40%) and back (33%) supports.

The most common muscular injuries to the javelin thrower were to the back (34%), groin (24%), hamstring (15%) and shoulder (10 %). The three areas with the highest ligament/joint injury rates were back (32%), elbow (28%) and knee (26%). In total 160 injuries were reported by the 34 javelin throwers who took part in the study. On average this represents 4.7 injuries per thrower. Twenty-seven athletes (87%) had a recurrent episode of an original injury. In total 56% of javelin throwers used an athletic support during either training or in competition. This figure was as high as 83% for the national group. The back (42%), elbow (32%) and knee (21%) represented the areas of the body where javelin throwers most commonly wore athletic supports.

The main resources accessed for treatment by both groups were general practitioners (26%) and physiotherapists (33%). National and county competition level subjects in both groups indicated that massage was used also, due largely to the accessibility of such treatments at this level.

3.5 Summary

The first aim of this chapter was to investigate the amount of cricket bowling and javelin throwing injuries that had occurred over the 'lifetime' of the athlete. 73% of the cricket bowlers and 91% of the javelin throwers indicated that they had suffered an injury that had prevented participation in training or competition for a seven day period.

This study highlights injury rates having doubled for javelin throwers and almost tripled for cricket bowlers at the national level compared to the county level bowlers and athletes. The average number of injuries for the national level cricket bowler is 9.7 injuries, compared to 3.8 injuries at county level. The average number of injuries for the national level javelin thrower is 8.2 injuries, compared to 4.5 injuries at county level. Questions must be asked as to the amount of cricket matches and athletic competitions that are performed at national level.

The high percentage of injuries reported is not surprising due to the nature of the two sporting events. However, there are alarmingly high numbers of recurrent injuries for the cricket bowlers (75%) and for the javelin throwers (87%). This suggests that benefits would be gained by paying greater attention to initial remedial treatment and rehabilitation procedures. It is also interesting to note the percentage of people using an athletic support of some description during both cricket bowling (29%), and javelin throwing (54%). The cricket bowlers used mostly knee (40%) and back (33%) supports whilst the javelin throwers used back (42%), elbow (32%) and knee (21%) supports.

Chapter 4

A BIOMECHANICAL INVESTIGATION INTO FAST-MEDIUM BOWLING IN CRICKET.

The effect of athletic support location on ground reaction forces and electromyography during the delivery stride of fast-medium bowlers in cricket.

4.1 Introduction

4.2 A biomechanical investigation into the ground reaction forces of fast-medium bowlers in cricket.

4.2.1 Method

4.2.2 Results and Discussion

4.2.3 Summary

4.3 Experiment 1 - The effect of athletic support location on ground reaction forces and electromyography during the delivery stride of fast-medium bowlers in cricket.

4.3.1 Method

4.3.2 Results and Discussion

4.3.3 Summary

4.1 Introduction

Fast-medium bowling in cricket is a difficult and complex action that requires the bowler to produce optimal muscular forces in order to deliver a ball at a maximum and controllable speed. Appendix A describes the bowling technique in detail. Repeated exposure to high impact forces occurring during a day, a match and over a season may result in injury. The injury survey reported in the proceeding chapter found that for the fast-medium bowler, most muscular injuries occurred in the back (32%), while the majority of ligament/joint injuries occurred at the knee (38%), back (34%) and ankle (22%). The survey also found that 40% of the bowlers wore a knee support and 33% a back support.

As the delivery stride proceeds the front foot strikes the ground, resulting in a large ground reaction force being experienced by the bowler. Eight previous studies have investigated the ground reaction forces generated by the cricket bowler during front foot contact. However, due to the variation in the results of these eight studies (3.8 BW to 9.0 BW) this thesis also investigated the ground reaction forces and associated temporal data during front foot contact during the delivery stride. Bartlett *et al.* (1996) stated that no biomechanical studies have investigated the peak rate of change of the external force acting on the bowler (peak loading rate), despite often being associated with injury for activities such as running (Nigg and Herzog, 1984).

The first experiment reported in this thesis considered the effect of neoprene athletic supports to those areas of the body highlighted by the injury survey (Hurrion *et al.* 1997a). The effect of the different athletic supports were measured primarily by the ground reaction forces occurring during front foot contact and secondly, investigating selected muscular activity of the lower torso and lead leg during the delivery stride.

4.2 A biomechanical investigation into the ground reaction forces of fast-medium bowlers in cricket.

One reason for the high prevalence of injury to the fast bowler may be due to the high impact forces that occur during the delivery phase. Bartlett *et al.* (1996) suggested that a high initial peak ground reaction force during front foot contact, coupled with a high degree of lateral flexion, hyperextension and rotation of the lower back to be a major cause of lower lumbar injuries. Eight previous studies have investigated ground reaction forces generated by the cricket bowler at front foot contact. Elliott and Foster (1984) investigated the ground reaction forces generated by four Australian international fast bowlers. Mean maximum vertical forces were 4.7 times body weight (BW), whilst the mean maximum anterior-posterior force was 1.76 BW. Foster *et al.* (1989) reported mean maximum vertical forces of 5.43 BW and mean maximum braking force of 2.45 BW for eighty two, young potentially high performance, fast bowlers. Mason *et al.* (1989) reported a much greater mean peak vertical value of 9 BW occurring 0.01 seconds after impact with a maximal value of 12.3 BW. This would equate to a mean loading rate of 900 BW s^{-1}.

The initial study described in this thesis examined the ground reaction forces and loading rates of eight club standard fast-medium bowlers during their delivery stride. The study was undertaken in outdoor conditions so that each subject had a full match run-up. The aims of this study were to : -

(1) Determine the ground reaction forces experienced during front foot contact. This would allow comparisons to be drawn with the eight previously reported studies.

(2) Establish the elapsed time to peak ground reaction forces and vertical loading rates. The rate of change of ground reaction force with time (dF/dt) is referred to as the loading rate.

4.2.1 Method

Subjects Eight male subjects of collegiate or 1st team club standard bowlers (Mean ± S.E. age 21.6 ± 1.6 yrs: height 1.82 ± 0.05 m: body weight 861 ± 35 N) performed their typical bowling action using their full match run-up. Table 4.1 summarises the physical characteristics and standard of the eight bowlers used in this investigation.

Table 4.1: Subject characteristics

Subject	Age (yrs months)	Body Weight (N)	Height (m)	Standard
1	20 6	927	1.90	Club 1st
2	24 8	958	1.93	U21 / Club
3	23 11	790	1.79	Y / Club
4	22 6	990	1.94	Club 1st
5	24 0	880	1.80	F/C
6	23 4	730	1.72	Club 1st
7	23 8	743	1.77	Y / Club 1st
8	23 5	866	1.85	(F/C) Club
Mean ± S.E.	**21.6 ± 1.6**	**861 ± 35**	**1.82 ± 0.05**	

F/C - First Class/County U21 - Under 21years/County team Y - Youth

Experimental Conditions Each subject bowled at a set of stumps positioned at the standard pitch length (22 yards). Every effort was made to ensure each subject was bowling as near to his typical match effort as possible. Subjects wore their personal outdoor cricket shoes and clothing. The weather conditions during the testing period consisted of nil or little wind with temperatures in the range of 10 to 15°C. The ground was firm underfoot. All trials were carried out over a period of three months, during the pre-season. Each subject completed thirty successful trials. A successful trial occurred when the subject's front foot made contact with the force platform during their typical bowling action.

Data Acquisition Ground reaction forces of the front foot strike during the delivery stride were measured. Data were sampled at 500 Hz using Orthodata provec 3.0 software running on a Viglen computer. Force platform data acquired was converted to digital form and sampled at 500 Hz for a one second period. A 33 MHz 386 Viglen personal computer running Orthodata Pro-vec data acquisition software was used. Approach velocity was recorded using an infrared timing device, positioned at hip level. To aid data interpretation a video recording (Sony Hi8 EVO 9100 P) of the experimental work was also made. This provided a complete record of events.

Ground reaction forces The vertical (Fz), anterior-posterior (Fy) and medio-lateral (Fx) ground reaction forces occurring during the delivery stride for the front foot were measured. One 0.6 m by 0.4 m Kistler type 9851 piezoelectric force platform was situated within a section of a specially designed outdoor polyflex surface (IAAF Standard), 25 m by 1.5 m. The platform was positioned beneath the surface of the track, with a 0.013 m covering of polyflex on an aluminium sheet mounted to the platform. Figure 4.1 shows a diagrammatic representation of the experimental setting.

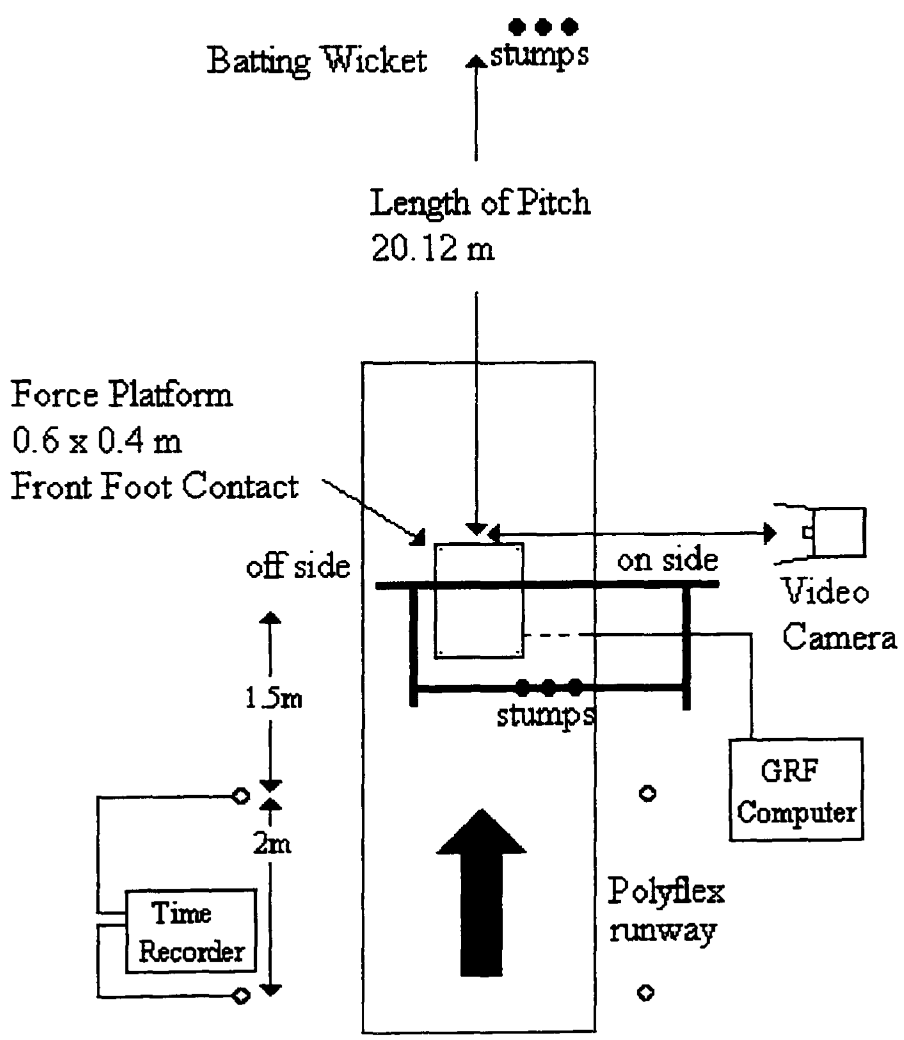


Figure 4.1 : Diagrammatic representation of experimental setting.

4.2.2 Results and Discussion

Table 4.2 summarises the ground reaction forces (30 trials per subject) and associated temporal data for each of the eight fast-medium cricket bowlers.

Table 4.2 : Front foot mean peak ground reaction forces and associated temporal data : Body Weight (BW) : Time in seconds to peak ground reaction force (s).

Subject No.	Medial BW s	Lateral BW s	Braking BW s	Propulsive BW s	Vertical BW s	Loading Rate BW s^{-1}	Approach Velocity m s^{-1}	Time Conta s
1	0.91 0.01	0.08 0.02	1.96 0.01	0.28 0.09	4.24 0.01	424	5.19	0.15
2	1.13 0.02	0.32 0.03	3.14 0.03	0.26 0.29	5.05 0.02	253	5.31	0.48
3	0.95 0.08	0.10 0.01	3.86 0.03	0.39 0.07	5.16 0.04	129	5.79	0.38
4	0.46 0.01	0.06 0.08	0.86 0.03	0.40 0.07	3.15 0.01	315	3.74	0.40
5	0.33 0.02	0.36 0.03	3.17 0.02	0.38 0.14	8.67 0.02	434	4.83	0.41
6	1.11 0.03	0.10 0.02	1.36 0.03	0.36 0.19	4.83 0.02	241	4.55	0.36
7	1.19 0.02	0.06 0.01	1.65 0.02	0.40 0.18	5.24 0.02	262	4.13	0.36
8	1.12 0.03	0.08 0.02	3.73 0.03	0.22 0.18	6.19 0.04	155	5.16	0.39
Mean ± S.E.	0.90 0.03 ±0.01 0	0.15 0.03 ±0.04 0	2.47 0.03 ±0.41 0	0.34 0.15 ±0.03 ±0.03	5.32 0.02 ±0.57 0	277 ±39.3	4.84 ±0.24	0.37 ±0.0

The mean ± S.E. approach velocity was 4.84 ± 0.24 m s^{-1} with a mean peak vertical ground reaction force of 5.32 BW ± 0.57 with a range of 3.15 to 8.67 BW. Mean peak braking force ranged from 0.86 to 3.86 BW with a mean of 2.47 ± 0.41 BW. The propulsive force was much lower at 0.34 ± 0.03 BW. Peak vertical ground reaction forces were reached on average within 0.02 seconds of heel contact. Mean peak vertical loading rate recorded were 277 BW s^{-1} ± 39.3 (range 129 to 434 BW s^{-1}).

Subjects three and eight have the slowest time to peak force 0.04 seconds, even though their approach velocities are in excess of 5 m s^{-1}. Subject one has the lowest time in contact with the platform, 0.15 seconds (heel contact to toe off) in which the delivery action is completed and the ball released.

The mean peak forces obtained in this study, vertical 5.32 BW ± 0.57 : horizontal 2.47 ± 0.41 are similar to those reported by Foster *et al.* (1989) 5.43 BW and 2.45 BW where the mean approach velocity was 4.95 m s^{-1} compared to 4.84 m s^{-1}. The ground reaction forces reported in this study are also similar to Elliott *et al.* (1993) 5.0 BW but considerably lower than those obtained by Mason *et al.* (1989). The mean peak vertical loading rates of 277 BW s^{-1} indicate one possible reason why injury rates are so high in fast-medium bowling. High loading rates, coupled with peak forces of five times body weight, indicate that injury occurrence is a distinct possibility during the delivery stride. Munro *et al.* (1987) reported much lower loading rates (113 BW s^{-1}) for middle distance runners at 5.0 m s^{-1}. Vertical loading rates at front foot contact in this study are 2.5 times greater than those reported by Munro *et al.* (1987), despite a similar approach velocity.

The physical demands on the bowler are ever increasing. Typically the county and international standard bowler will bowl up to ten or more six ball overs a day, between four and five days a week, for as many as forty weeks a year. On average, with each delivery producing a peak ground reaction force of 5 BW and a loading rate of 277 BW s^{-1}, when combined with training sessions, running and even fielding, the forces on the fast-medium bowler are very strenuous. Elliott *et al.* (1992) suggested that a possible reason for the high incidence of injuries amongst bowlers was that they were being forced to train longer, harder and earlier in life to excel in their chosen sport. They suggested that the sheer number of repetitious hours of practice might produce gradual deterioration in specific parts of the body. It is, therefore, not surprising that physicians are diagnosing an increased number of overuse injuries. Bell (1992) stated that the combination of incorrect technique, poor preparation, overuse and clinical features all increased the risk of injury to the bowler.

4.2.3 Summary

This initial study highlights the ground reaction force experienced by the fast-medium bowler during front foot contact. On average the peak ground reaction force is reached 0.02 seconds after contact. Mean peak vertical loading rate recorded for the eight subjects was 277 BW s^{-1} ± 39.3 (range 129 to 434 BW s^{-1}). These results indicate that the role of additional shock absorbency materials in the bowler's cricket boot may reduce the time to peak force, which would have a marked effect on loading rates. The majority of the technical advances in cricket have been associated with batting.

Lightweight equipment, clothing, helmets and even the actual bat have all benefited the batsman over the last few decades. Limited research into the footwear of fast-medium bowlers has been undertaken. Many club, county and even national standard bowlers cut a hole in their front foot big toe area of the shoe to prevent injury. Further biomechanical studies should focus upon the ground reaction forces of the bowler, especially the high impact loading rates on the lead leg during the delivery stride.

4.3 Experiment 1: The effect of athletic support location on ground reaction forces and electromyography during the delivery stride of fast-medium bowlers in cricket.

Athletic supports are widely believed to reduce the risk of injury. However, there is no scientific evidence reported to sustain this belief. The aim of this experiment was to investigate the effect of four neoprene athletic supports during the delivery stride of the fast-medium bowler. Key biomechanical measures derived from ground reaction forces and electromyogram recordings will allow detailed analysis of the individual's bowling technique. Only one previous electromyography study of fast or fast-medium bowling has been reported (Burden and Bartlett 1990b). They recorded electromyograms from selected trunk and glenohumeral joint muscles, synchronised with cinematography data in order to determine sequential and temporal patterns of muscular activity during the delivery stride. Eight previous studies have investigated ground reaction forces generated by the bowler at front foot contact. No previous study has examined synchronised ground reaction force and electromyogram recordings during the delivery stride of the fast-medium bowler.

The neoprene support maintains body temperature which keeps the muscles supple and effective. This is made possible by the insulation provided by cellular neoprene. A common cause of injury to any athlete is a result of cold muscles. Muscles can cool down during training and even during a match, thus reducing their flexibility, power and efficiency. This is all too applicable for the fast-medium bowler who may spend long periods of bowling inactivity and then at short notice be called upon to bowl.

An indoor test condition was chosen for this experiment because of the extra preparation time needed to obtain electromyogram recordings. A second reason for the indoor location was to compare ground reaction forces and associated temporal data recorded indoors and outdoors. The injury survey in the previous chapter highlighted the ankle, knee and back as areas of the body susceptible to injury.

The aims of this experiment were to : -

(1) Establish the effect of four neoprene athletic supports on the fast-medium bowling technique in comparison to the 'normal bowling condition' of the individual.

(2) Determine the effect of four neoprene athletic supports on ground reaction forces and associated temporal data during front foot contact.

(3) Establish the effect of four neoprene athletic supports on selected trunk and lower limb muscles and to determine the sequential and temporal patterns of muscular activity during the delivery phase.

Four research hypotheses were formulated: H1(1) $\rightarrow$ H1(4) and the following four null hypotheses were tested: Ho(1) $\rightarrow$ Ho(4) during this experiment.

Ho: There will be no significant difference in ground reaction forces experienced at front foot contact between the five test conditions.
H1: There will be a significant difference in ground reaction forces experienced at front foot contact between the five test conditions.

Ho: There will be no significant difference in loading rates BW s^{-1} experienced at front foot contact between the five test conditions.
H1: There will be a significant difference in loading rates BW s^{-1} experienced at front foot contact between the five test conditions.

Ho: There will be no significant difference in approach velocity m s^{-1} between the five test conditions.
H1: There will be a significant difference in approach velocity m s^{-1} between the five test conditions.

Ho: There will be no significant difference in the muscle recruitment patterns and magnitude between the five test conditions.
H1: There will be a significant difference in the muscle recruitment patterns and magnitude between the five test conditions.

4.3.1 Method

Subjects Eight male subjects of collegiate or 1st team club standard bowlers (Mean ± S.E. age 21.6 ±1.6 yrs: height 1.82 ± 0.05 m: body weight 861 ±35 N) performed their typical bowling action, with a limited run-up (12 metres) under the five test conditions. The eight subjects used in experiment 1 are the same eight subjects used in section 4.2. None of the eight subjects trained or competed in any of the four types of neoprene supports.

Support Test Conditions

Test Condition 1 :	No Support	
Test Condition 2 :	Vulkan Ankle Long Pro 3006	(Ankle)
Test Condition 3 :	Vulkan Knee Pro Diamond 3052	(Knee 1)
Test Condition 4 :	Vulkan Knee Braced Pro	(Knee 2)
Test Condition 5 :	Vulkan Back 3013	(Back)

Experimental Conditions Each subject was limited to a 12 m run-up in an indoor, wooden sprung floored gymnasium. Every effort was made to ensure each subject was bowling as near to his typical match effort as possible. Subjects wore their personal indoor cricket shoes and clothing. As well as having a limited run-up in the indoor condition, the size of the gym did not permit the subjects to bowl at a set of stumps (20.12 m) in the same way as the outdoor experiment. Instead each subject had to release the cricket ball into a target located at a position calculated in order to reproduce a 'good length' ball. The location of the target was calculated by using a release height of 2 m and a release speed of 30 m s^{-1}. The follow through of the subject's delivery stride was not altered. All trials were carried out during the pre-season over the period of three months. Six successful attempts were recorded for each test condition per subject. A successful trial was characterised by the fact that the front foot made contact with the force platform during a typical bowling action.

Data Acquisition Two methods of data collection were used to analyse the effect of the five test conditions. Ground reaction forces of the front foot contact and electromyographic activity of the six muscles on the torso and lead leg were recorded during the delivery phase. Electromyographic data was recorded simultaneously with the ground reaction force data. Approach velocity was recorded for each trial using an infrared timing device, positioned at hip level, 2 metres apart down the length of the run-up, 1.5 m from the centre of the platform. To aid data interpretation a video recording (Sony Hi8 EVO 9100 P) of the experimental work was also made. This provided a complete record of events. Figure 4.2 is a diagrammatic representation of the experimental set-up.

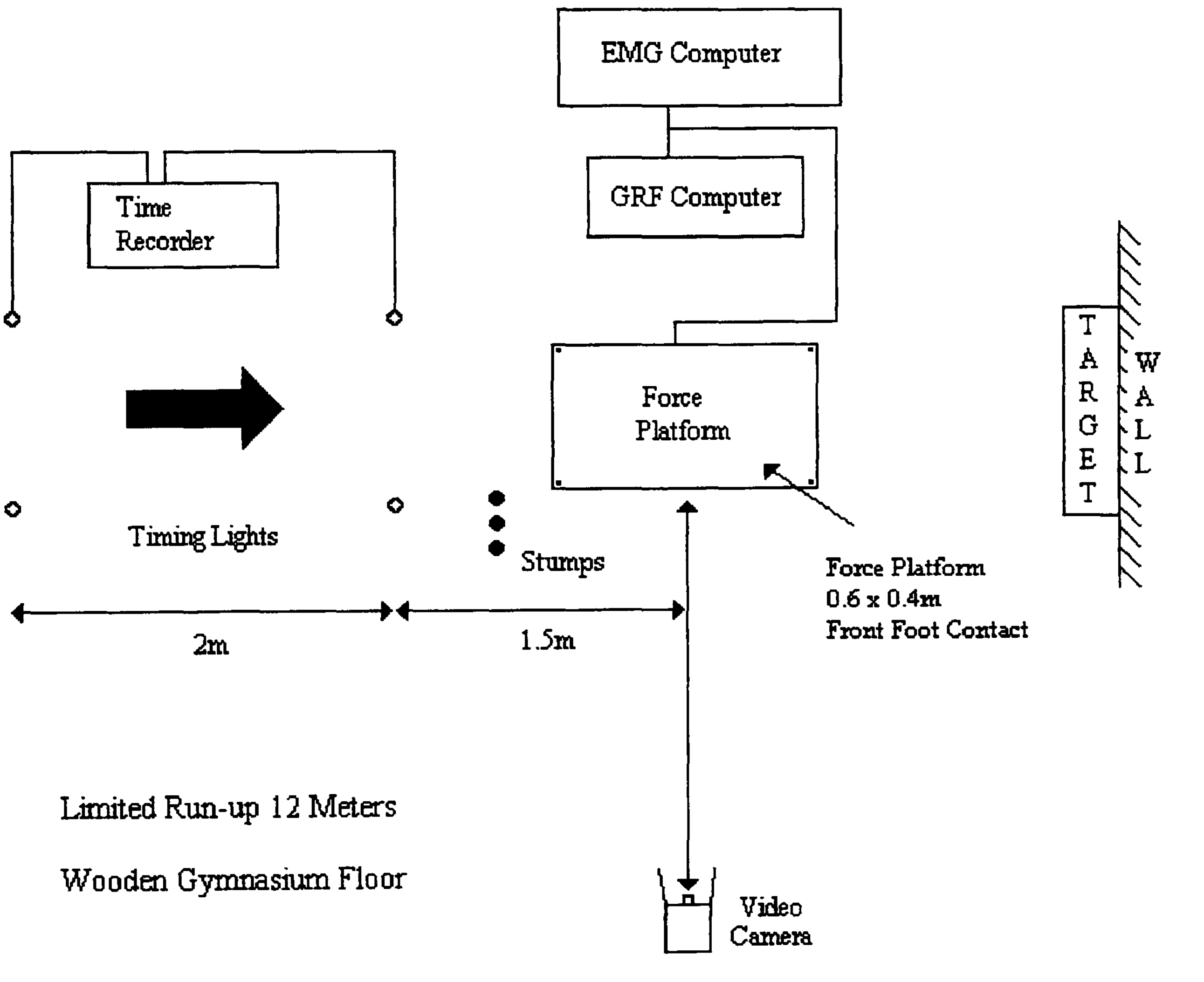


Figure 4.2 : Diagrammatic representation of experimental setting

Ground reaction forces The vertical (Fz), anterior-posterior (Fy) and medio-lateral (Fx) ground reaction forces occurring during the final delivery stride for the front foot was recorded. One 0.6 m by 0.4 m Kistler type 9851 piezoelectric force platform was located beneath the wooden gymnasium floor. Force platform data acquired was converted to digital form and sampled at 500 Hz for a three second period. A 33 MHz 486 Viglen (IBM compatible) personal computer running Orthodata Pro-vec data acquisition software was used.

Electromyography Due to the importance of the bracing front leg and torso throughout the delivery stride, the following muscles were chosen for analysis : Rectus Abdominis (RA), Right Lower Latissimus Dorsi (RL), Left Lower Latissimus Dorsi (LL), Biceps Femoris (BF), Rectus Femoris (RF) and Gastrocnemius (GA). Medicotest N-50-E disposable electrodes were attached to the skin surface in order to record the electromyogram. Following skin preparation and application procedure detailed in Buchanan *et al.* (1996) skin impedance of typically less than 10 kΩ were routinely achieved. Pairs of electrodes were placed 0.05 m apart over the centre of each muscle with three muscles sharing a reference point. The reference point for the lower body was the patella. The reference point for the lumbar region was the right illiac crest. Each muscle was located by asking the subject to perform appropriate actions against hand resistance (Daniels *et al.* 1956). Each muscle electrode pair was connected to a 4-kΩ pre-amplifier and the pre-amplifier referenced. Each pre-amplifier was connected to a biomedical radiotelemetry transmitter (MIE Medical Research Ltd, Leeds, UK). The transmitter was attached to a belt, worn around the waist of the subject. Pre-amplifiers and wires were secured to the subject with tape ensuring that no restriction was imposed on the subject's movement. The transmitted signals were received by a MTR8 bio-medical telemetry unit positioned beside the runway. The transmitted signals were converted to digital form by an Amplicon PC26AT analogue-to-digital converter. All electromyograms were sampled at 500 Hz. The information was visually scanned and stored on a 33 MHz 486 Viglen (IBM compatible) personal computer running Orthodata Myo-Dat 3.0 software. The computers running the electromyographic and force plate data acquisition programs were synchronised. A single switch started simultaneous data collection on both systems.

Statistical Analysis

The mean and standard error were calculated for each of the five test conditions for all eight subjects. The means of the six trials for each test condition for each of the eight subjects were used for a repeated measure ANOVA. The ANOVA is a robust test regarding normality violations, providing sample sizes are equal (Howell, 1992). A stem-and-leaf diagram was used to check the shape of the distributions. The ratio of the largest to the smallest variance was used to test for normality. If the ratios of variances between groups do not exceed four (Howell, 1992) then it is possible to assume homogeneity of variance and normality of data which is required for the repeated measures ANOVA. A further assumption for repeated measure designs is the compound symmetry of the covariance matrix or sphericity. The Mauchly sphericity test was used for tests involving condition within-subject effect. (See Appendix C).

A one way analysis of variance with repeated measures compared the significance of ground reaction forces (with reference to each subjects body weight), loading rates and approach velocities for the five test conditions (see table 4.3). A further one way analysis of variance with repeated measures compared the significance of maximal electromyography activity of the six muscles analysed for each of the five test conditions (see table 4.4). Detailed results and analysis can be found in Appendix C.

4.3.2 Results and Discussion

The mean approach velocity measured 4.78 m s^{-1} and the peak mean vertical ground reaction force was 5.32 times body weight (BW) ± 0.06 with a range of 5.12 to 5.48 BW. The peak braking force ranged from 2.10 to 2.31 BW with a mean of 2.17 BW ± 0.33 for the no support condition. The ground reaction forces for all test conditions were very similar and there were no significant differences at the 5% (P=0.05) level between any of the five test conditions. The mean peak ground reaction forces reported in this study are similar to those reported by Foster *et al.* (1989) when mean approach velocity was 4.95 m s^{-1} compared to 4.78 m s^{-1} in this study. The ground reaction forces reported in this study are also similar to Elliott *et al.* (1993). The mean loading rates for the four support conditions were all lower than the no support condition (221 ± 24 BW s^{-1}). The lowest reported loading rate reported was from test condition Knee (1) 184 ± 18 BW s^{-1}. Table 4.3 summarises the ground reaction forces during front foot contact for the five test conditions in the indoor situation.

Table 4.3 : Comparison of front foot mean peak ground reaction forces ± S.E of eight fast-medium cricket bowlers. (5 test conditions)

	Medial (BW)	**Lateral (BW)**	**Braking (BW)**	**Propulsive (BW)**	**Vertical (BW)**	**Approach Velocity (m s^{-1})**	**Loading Rate BW s^{-1}**
No Support	0.88 ± 0.13	0.16 ± 0.05	2.17 ± 0.33	0.37 ± 0.06	5.48 ± 0.44	4.85 ± 0.28	221 ± 24
Ankle	0.83 ± 0.10	0.15 ± 0.07	2.31 ± 0.39	0.32 ± 0.04	5.32 ± 0.46	4.75 ± 0.24	186 ± 21
Knee (1)	0.86 ± 0.10	0.12 ± 0.05	2.22 ± 0.36	0.31 ± 0.05	5.39 ± 0.43	4.75 ± 0.22	184 ± 18
Knee (2) (n=7)	0.91 ± 0.13	0.19 ± 0.11	2.14 ± 0.40	0.37 ± 0.09	5.40 ± 0.49	4.55 ± 0.19	185 ± 21
Back	0.84 ± 0.10	0.16 ± 0.08	2.10 ± 0.37	0.31 ± 0.04	5.12 ± 0.49	4.80 ± 0.28	198 ± 17
P Value	0.41	-	0.43	-	0.30	0.72	0.07

Electromyographic data recorded during this chapter and throughout the thesis was not normalised. Normalisation is achieved by dividing the processed electromyographic data by a reference value, or typically the maximal isometric voluntary contraction. Lawrence and De Luca (1983) and Enoka and Fuglevand (1993) stated that isometric maximal voluntary contraction lacks repeatability and may not truly represent the maximal activation level of the muscle. Mirka (1991) indicated that maximal voluntary contractions should ideally be recorded at the same muscle length and rate of shortening or lengthening to that during athletic performance. It is not practical to perform a number of maximal voluntary contractions at varying angles and angular velocities in order to reproduce the activity of the muscle during the performance of the fast-medium bowler and javelin thrower.

Maximal electromyographic activity during the five test conditions were very similar with none of the test conditions significantly different at the 5% (P=0.05) level. The raw electromyography traces showed clear sequential and temporal patterns for each individual bowler, allowing identification of the muscle recruitment patterns during their bowling action (Appendix C). The average maximal electromyography activity in the left latissimus dorsi indicated a 4% reduction during the back condition compared to the no support condition. The right latissimus dorsi showed no differences, whilst there was an increase of 7.5% activity for the rectus abdominis. The average maximal electromyography activity in the no support condition indicated that there was a 2% trend to lower activity in the hamstring (42 trials) with the braced knee support (test condition 4) compared to the no support condition.

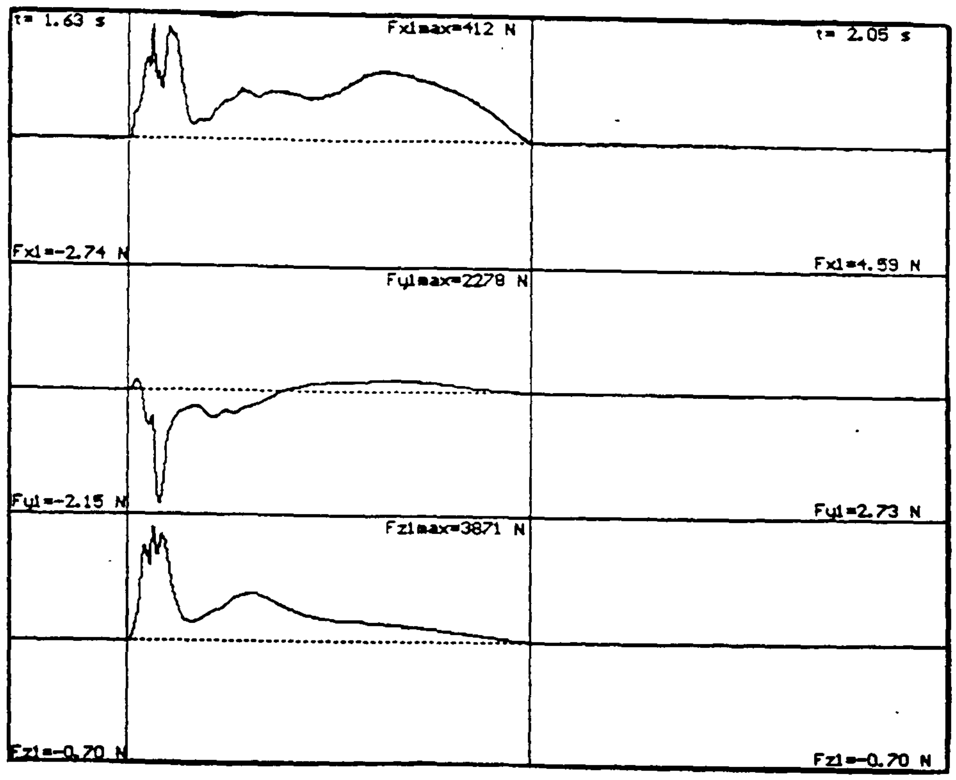
Table 4.4 summarises the maximal peak to peak electromyography recordings during the five different test conditions of the eight fast-medium bowlers obtained in the indoor situation.

Table 4.4 : Maximal peak to peak electromyography recordings ± S.E. for eight fast-medium cricket bowlers. (5 test conditions)

	Gastrocnemius (GA)	Rectus Femoris (RF)	Biceps Femoris (BF)	Right Latissimus Dorsi (RL)	Left Latissimus Dorsi (LL)	Rectus Abdominis (RA)
No Support	2753 ± 95	3065 ± 30	3092 ± 41	2756 ± 137	2700 ± 107	2215 ± 151
Ankle	2769 ± 87	3110 ±39	3086 ± 40	2745 ± 136	2651 ± 136	2222 ± 181
Knee 1	2748 ± 100	3065 ± 35	3081 ± 32	2744 ± 194	2584 ± 124	2260 ± 168
Knee 2 (n=7)	2660 ± 109	3086 ± 21	3052 ± 25	2551 ± 206	2568 ± 115	2252 ± 196
Back	2751 ± 100	3065 ± 41	3125 ± 44	2754 ± 138	2627 ± 109	2351 ± 114
P Value	0.16	0.63	0.10	0.07	0.59	0.56

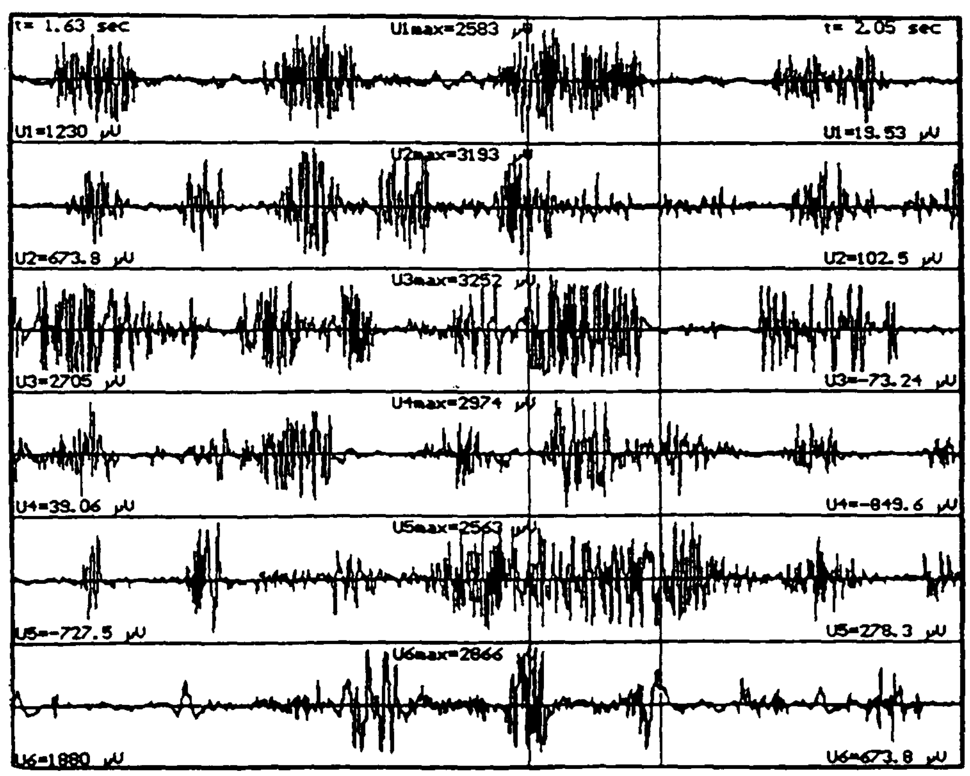
Figure 4.3 shows a typical example of the synchronised ground reaction force 'front foot contact' and the electromyogram recording during the final stage of the fast-medium bowler's delivery stride.

Figure 4.3 : Subject No.1 : Synchronised ground reaction force and electromyography recordings during the delivery stride. (No Support Condition) : Body Weight 927 Newtons : Ground Reaction Force: 1 second time base
Fx: Medio–Lateral Fy: Anterior–Posterior Fz: Vertical



Electromyography : 3 second time base: (HC = Heel contact : TO = toe off)
1) Gastrocnemius (GA) 2) Rectus Femoris (RF) 3) Biceps Femoris (BF)
4) Right Lower Latissimus Dorsi (RL) 5) Left Lower Latissimus Dorsi (LL)
6) Rectus Abdominis (RA)

HC TO



4.3.3 Summary

This study aimed to establish the effect of the four neoprene athletic supports on the delivery stride of fast-medium cricket bowlers in comparison with their 'normal bowling condition'. No significant differences were found for any of electromyogram recordings during the five test conditions. There was an indication that the back support altered muscle activity (mean values) in the lumbar region. It was clear from subjects' feedback that some supports felt different, especially the back support condition during the delivery phase of the bowling action. Certain individuals showed differences in maximal electromyographic activity whilst using the supports. This may be related to the individual's muscle recruitment patterns during their bowling action. Electromyography recordings for latissimus dorsi and rectus abdominis are similar in timing and duration to those described by Burden and Bartlett (1990b).

The mean peak ground reaction forces obtained in this study are similar to those reported by Foster *et al.* (1989) when mean approach velocity was 4.95 m s^{-1} compared to 4.78 m s^{-1} in this study. The ground reaction forces reported in this study are also similar to Elliott *et al.* (1993) and are within the general bands documented by Bartlett *et al.* (1996). Although the results for the mean loading rates are not significant, at the 5% level, the four support conditions all have a lower average loading rate than the no support condition. If the wearing of a support can reduce the loading rates the occurrence of injury may be curtailed. Neoprene supports may, therefore, have a contribution to make to fast, explosive movements such as the fast-medium bowling action. This warrants further investigation.

Table 4.5 summarises the mean ± S.E for the indoor ground reaction forces and associated temporal data (no support condition) and the outdoor test condition.

Table 4.5: Comparison of front foot contact : mean ± S.E. Peak ground reaction forces : Indoor (n=6) Outdoor (n=30) : No support condition.

	Medial (BW)	**Lateral (BW)**	**Braking (BW)**	**Propulsive (BW)**	**Vertical (BW)**	**Approach Velocity ($m\ s^{-1}$)**	**Loading Rate $BW\ s^{-1}$**
Indoor	0.88 ± 0.13	0.16 ± 0.05	2.17 ± 0.33	0.37 ± 0.06	5.48 ± 0.44	4.85 ± 0.28	221 ± 24
Outdoor	0.90 ± 0.12	0.14 ± 0.04	2.47 ± 0.41	0.34 ± 0.03	5.32 ± 0.57	4.84 ± 0.24	277 ± 39

Despite the limitations placed on the bowlers in terms of space, the figures in the above table indicate that the ground reaction forces and loading rates experienced were similar indoors to those occurring in the outdoor situation where a full run-up was available. In the outdoor situation, the force platform was covered with 13mm of polyflex, allowing subjects to use their personal spiked cricket boots. During the indoor experiment, the subject's indoor cricket shoes directly contacted the top surface of the force platform. This difference in force platform top plate does not allow direct comparisons between the two test conditions. However, upon close examination of the ground reaction forces, both indoor (n=6) and outdoor (n=30) force profiles are remarkably similar for the eight bowlers (Appendix C). The outdoor test condition allows far greater ecologically validity. It allows subjects to wear their personal cricket shoes and to bowl at a set of stumps off a full run-up. The mean ± S.E. figures of the outdoor and indoor conditions are very similar. Eight previous studies have investigated ground reaction forces generated by the fast-medium bowler at front foot contact. However, different surfaces were used on top of the force platform which may account for the large range of ground reaction forces and associated temporal data published in the literature. A standard surface that allows the use of spiked cricket boots should be used in future data collection.

During this experiment no differences were found between the magnitude of the indoor and outdoor ground reaction forces and loading rates. This suggests that cricket bowlers could realistically maintain a degree of physical and technical training in an indoor situation during the closed-season. The participation in such activity could make a notable contribution to the training and conditioning of bowlers during the closed-season. Foster *et al.* (1989) highlighted the importance of physical fitness.

Poor physical preparation can predispose the bowler to mental and physical fatigue which results in detrimental performance. During the playing season physical fitness is less of a problem. However Foster *et al.* (1989) conclude that at the start of a new season, a sudden escalation in training frequency or length of bowling spell during a match may predispose the bowler to injury. Greater emphasis during the competitive season should be placed on conditioning, stretching and flexibility. The closed-season fitness programs should concentrate on the bowlers' strengths and rectification of any weaknesses. In reality, only a handful of bowlers undertake a structured fitness programme, although the majority have access to indoor net sessions during the closed-season.

The inclusion of three-dimensional cinematography together with the use of ground reaction force profiles and electromyographic analysis could further investigate the effect of neoprene supports on the fast-medium cricket bowler. Experiment 1 has identified slight differences in muscular activity when bowlers wore the lumbar support belt. By integrating the use of cinematography, ground reaction force profiles and electromyographic analysis it may be possible to identify the subtle changes caused by the wearing of athletic supports.

Chapter 5

EXPERIMENT 2

A BIOMECHANICAL INVESTIGATION INTO JAVELIN THROWING.

5.1 Introduction

5.2 Experiment 2 - A biomechanical investigation into the effect of two lumbar supports during the javelin throw.

5.3 Method

5.4 Results and Discussion

5.5 Summary

5.1 Introduction

Many of the world's top javelin throwers and others of lower standard wear support belts during both training and competition. Whitbread (1993) reported the use of weight-lifting belts during javelin throwing. The prime purpose of a lumbar support belt is to prevent back injury or provide support following injury. Launder (1993) stated that the javelin thrower's lower back is particularly at risk with common injuries occurring in the fourth and fifth lumber region. However, such belts may alter the physical performance and strain experienced by the athlete. Support belts have been shown in weight training to be associated with a rise in intra-abdominal pressure as the trunk muscles are supported in the abdominal region (Landers *et al.* 1992).

The majority of studies investigating the biomechanical principles of the javelin throw have focused upon the technique of the thrower, reporting on release parameters critical for throwing performance. (Komi and Mero, 1985; Hubbard and Alaways, 1987; Bartlett and Best, 1988; Whiting *et al.* 1991; Mero *et al.*1994 and Morriss and Bartlett, 1996). To enable the javelin to travel long distances very strenuous, fast explosive movements involving extensive stretching and pretension of the muscles are required. The high physical demands placed upon the body during the javelin throw are a major concern to the athlete, particularly because of the need to avoid body injury. Many athletes experience a number of traumatic injuries particularly around the joints of the throwing arm, knee and foot (International Amateur Athletics Federation Round Table, 1993), with injuries to the back considered by some to be the most common (Whitbread *et al.* 1993).

During the final delivery stride of a right handed javelin thrower the left leg must first absorb the initial shock of landing, and then brace to support the left side of the body against a forward thrusting right leg action. A braced left side is essential if the active throwing right side is to accelerate around it. The torso acts as a lever during the javelin throw, the speed of which is closely related to the speed of the arm. A key factor of the throw is the speed at which the torso can uncoil creating the initial stage of javelin acceleration (Jones, 1987). A high release speed of the javelin is considered to be of prime importance in determining the distance the javelin is thrown (Miller and Munro, 1983; Bartlett and Best, 1988 and Morriss and Bartlett, 1996).

5.2 Experiment 2 - A biomechanical investigation into the effect of two lumbar supports during the javelin throw.

The objective of this preliminary biomechanical study was to analyse the technique of the javelin throw utilising high speed cinematography, ground reaction forces during the final front foot strike and electromyography analysis of selected contributing muscles during the delivery phase. A further objective of this study was to examine the effect of two different lumbar support belts on three experienced male javelin throwers. All the biomechanical equipment used to record the throwers final delivery stride was synchronised so that the techniques of two-dimensional cinematography, front foot ground reaction forces and electromyography could be used in an integrated study.

The majority of biomechanical research regarding javelin throwing has focused upon cinematography studies during competitive events, (Komi and Mero, 1985; Hubbard and Alaways, 1987; Bartlett and Best, 1988; Whiting *et al.*, 1991; Mero *et al.*, 1994 and Best *et al.*, 1993). Only two studies have examined ground reaction forces/pressures acting on the front foot during the final delivery phase of the javelin throw, Deporte and van Gheluwe (1988) and Bartlett *et al.* (1995). A similar limited amount of research has examined muscle activity during the javelin throw, Tanner (1984) and Salchenko and Smirnov (1992). No previous study has examined synchronised cinematography, ground reaction forces and electromyography analysis during the delivery stride of the javelin thrower.

There are many international and national athletes who wear lumbar support belts during training and competition. This study aims to establish the effect of two different lumbar supports on throwing performance. Three test conditions were considered, test condition *A* was a Vulkan neoprene belt, test condition *B* was a Vulkan pro neoprene belt, which has additional supporting bars, while test condition *C* was the control, no belt condition.

The aims of this experiment were to: -

(1) Establish the effect of wearing two neoprene lumbar supports on javelin throwing.
(2) Determine the effect of two neoprene lumbar supports on ground reaction forces and associated temporal data during front foot contact.
(3) Establish the effect of two neoprene lumbar supports on selected trunk and lower limb muscles and to determine the sequential and temporal patterns of muscular activity during the throwing phase.
(4) Determine aspects of the individuals throwing technique that are related to injury.

5.3 Method

Subjects Three experienced right-handed male javelin throwers were the subjects of the study. Height and weight for subjects 1,2, and 3 were 1.85 m 912 N, 1.87 m 896 N and 1.77 m 781 N respectively. Due to the time required to prepare each subject for the study each subject was tested individually. Each subject was shown the study location, scientific equipment and the study procedures were fully explained. An opportunity to ask questions was provided. Written informed consent to participate in the study was obtained and finally the subject was reminded that he could withdraw from the study at any time. Each of the three subjects were familiar with test condition A.

Test Conditions

A. Vulkan 3013 neoprene belt.

B. Vulkan Pro 3049 neoprene belt

C. No belt.

Experimental Conditions

Subjects threw an International Amateur Athletic Federation standard 800 g new type javelin on an outdoors javelin runway for each of the belt test conditions in a random order following familiarisation. Every effort was made to ensure each subject was throwing as near to his typical competition effort as possible. Subjects wore their personal javelin boots and clothing. The weather conditions during the testing period consisted of nil or little wind with temperatures in the range of 14 to 18°C (Chichester Institute of Higher Education). All trials were carried out over the period of a month, during the athletic competitive season.

After habituation to the experimental setting and warm-up, each subject completed one successful throw for each test condition. A successful trial occurred when the subject's front foot made contact with the force platform, an electromyography recording and cinematography film was recorded during a typical throwing action. Subject feedback was necessary to state whether the throw was typical. One successful throw per condition was only possible due to the explosive nature of the javelin throw and the fact that subjects had difficulty in making contact with the force platform during a typical throwing action.

Data Acquisition

Three methods of data collection were used to enable an objective analysis to be made of the way in which the belts influenced throwing performance. Individual throws were filmed using a high-speed cinematographic camera. Electrical activity of a number of selected muscles on the torso and front leg (left) was also recorded during the throw. Ground reaction forces of the front leg during the final delivery stride were measured to provide information about the forces to which the body was exposed. The length of the javelin throw was recorded from the foul line using a tape measure. To aid in data interpretation a video recording (Sony Hi8

EVO 9100 P) of the experimental work was made to provide a general record of events.

A diagrammatic representation of the experimental set-up is shown in Figure 5.1. Figures 5.2, 5.3 and 5.4 are photographs taken during the testing sessions and show the experimental set-up.

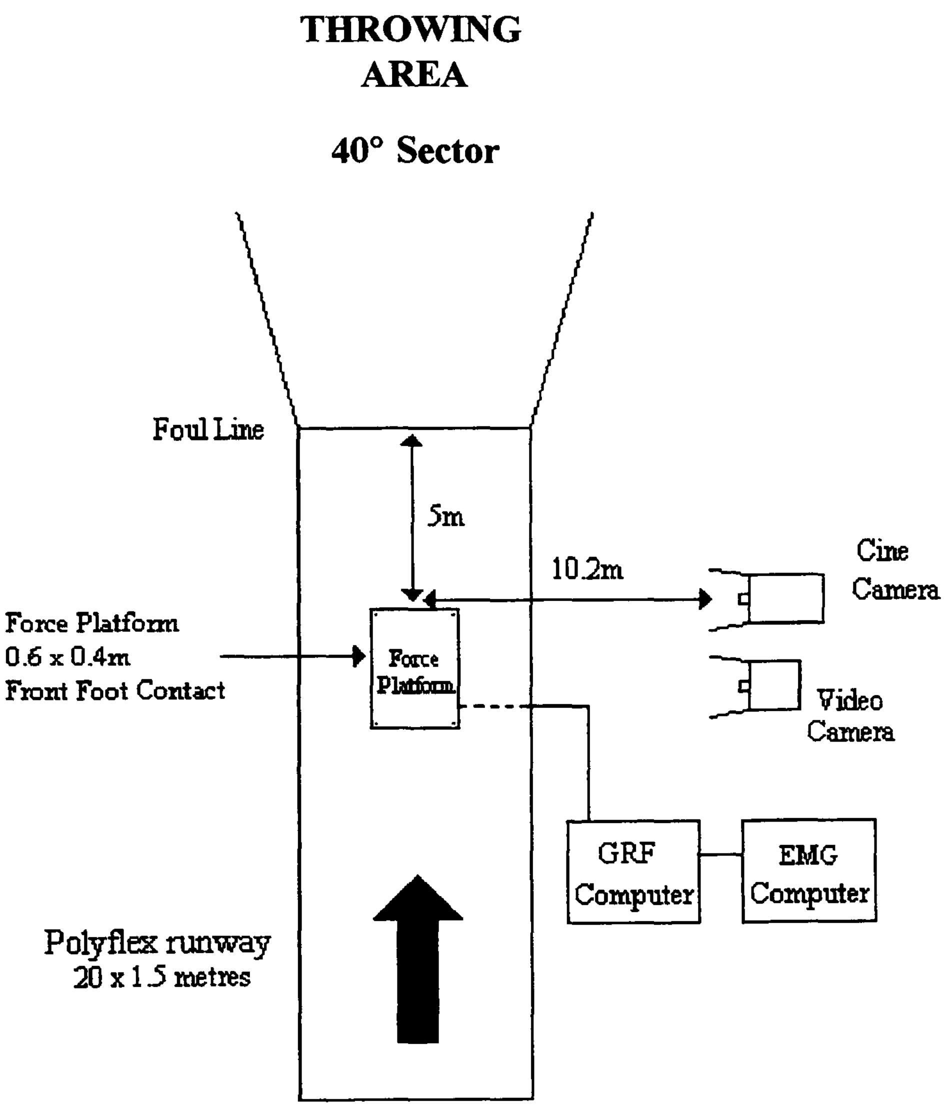


Figure 5.1 : **Diagrammatic representation of experimental setting**

Figure 5.2

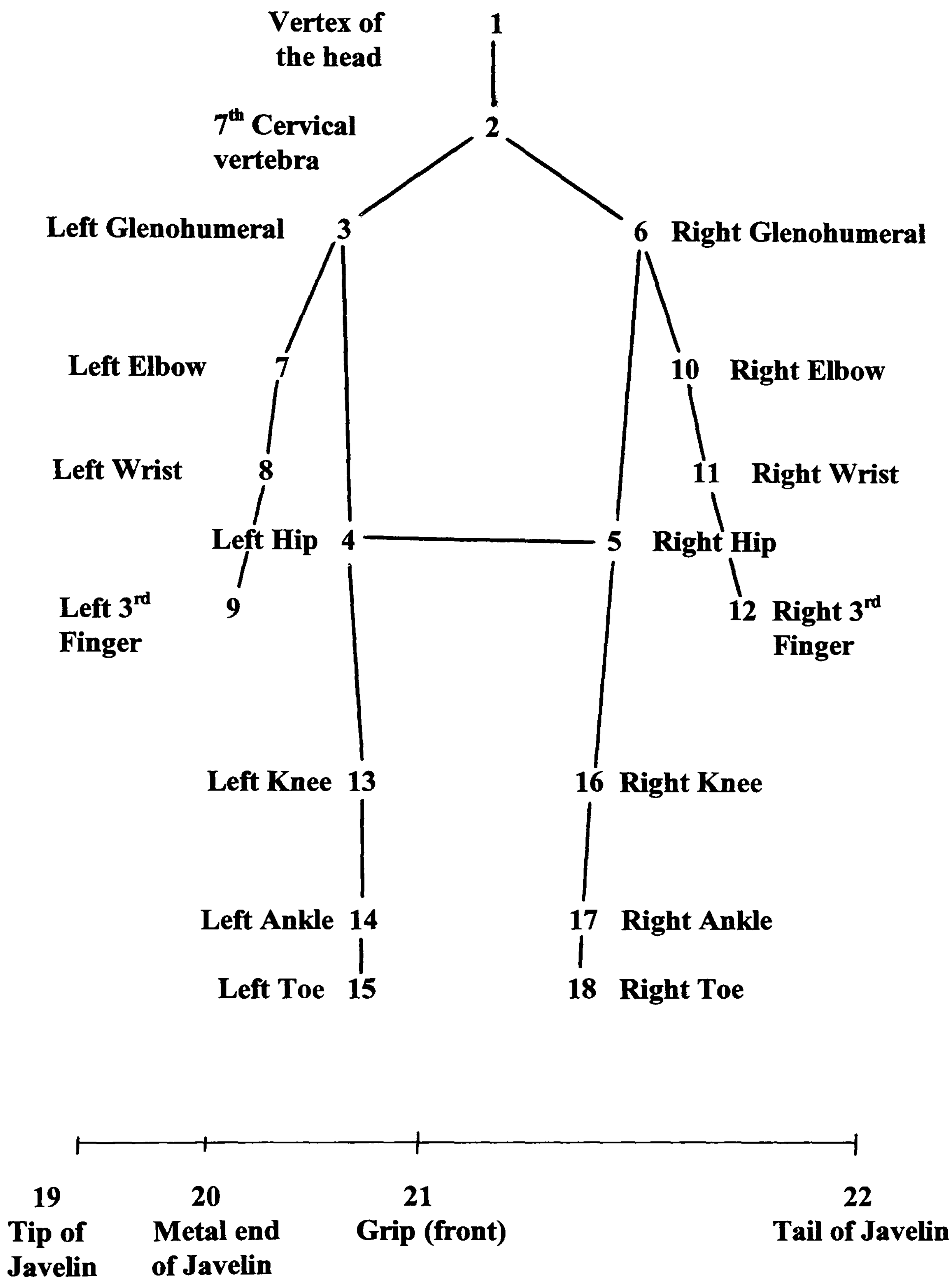
Figure 5.3

Figure 5.4

Cinematography One battery powered Photosonics 500 16mm camera, fitted with a 28mm lens and loaded with Kodak 16mm Ektachrome 7251 film, was positioned at a height of 1.6 m. The camera was positioned 10.2 m perpendicular to the centre of a force platform located in a proflex runway in order to film the right hand side of the javelin thrower. A frame rate of 200 frames per second was used to allow detailed analysis. Internal camera timing lights pulsed at 100 per second during filming and the image was used to check the film had reached the correct speed during movement analysis.

Markers were placed on each subject in the following nominal positions to facilitate joint centre determination to create a 14-segment model. (Figure 5.5) Four additional digitisation points were used during the investigation, they were as follows: tip of the javelin; metal 'front' of the javelin; front part of the 'grip' of the javelin; tail of the javelin.

Figure 5.5 : Digitisation Points



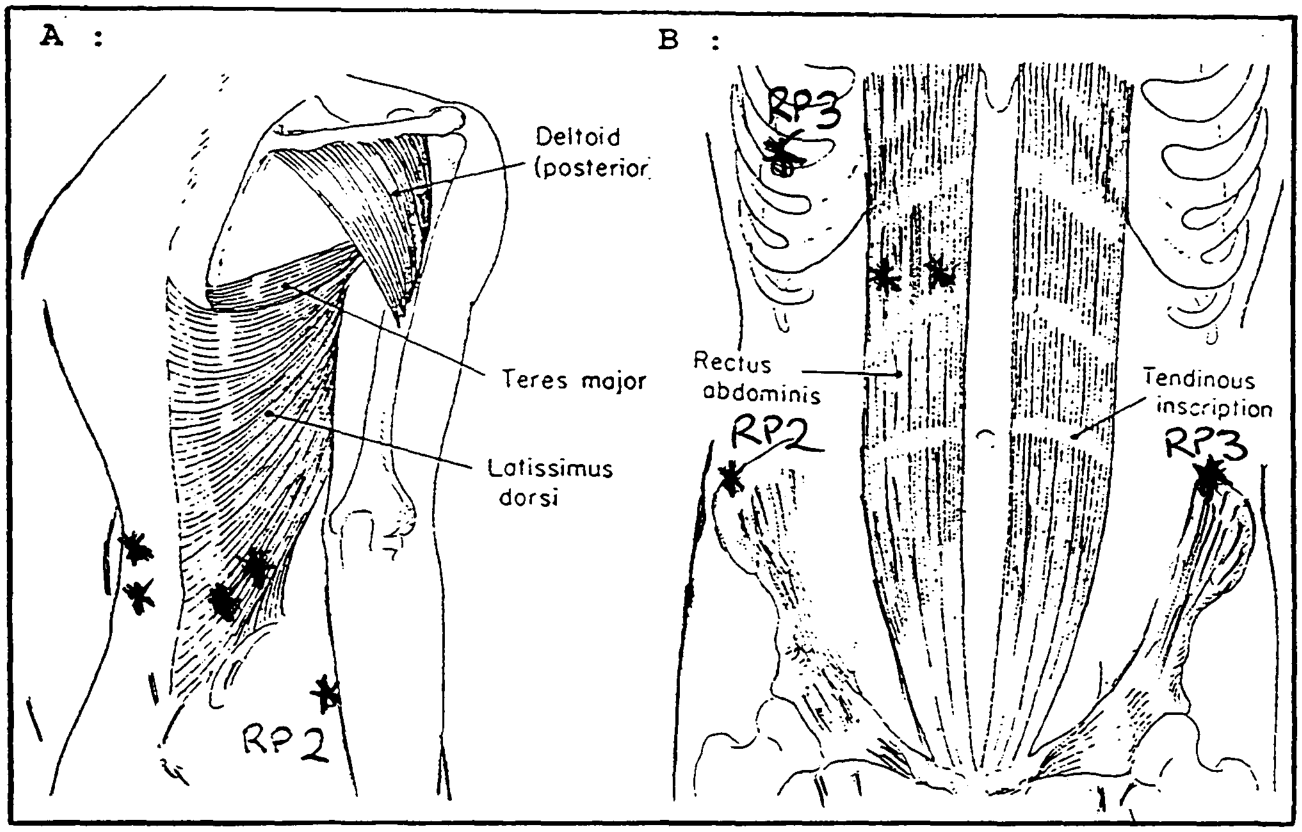
Electromyography The electromyographic activity of three torso muscles: Rectus Abdominis (RA), Right Lower Latissimus Dorsi (RL), Left Lower Latissimus Dorsi (LL), and three upper left leg muscles Biceps Femoris (BF), Rectus Femoris (RF) and Sartorius (SA) were recorded. Following skin preparation Medicotest N-50-E disposable electrodes were attached to the skin surface to record the electromyogram. Following skin preparation and application procedure detailed in Buchanan *et al.* (1996) skin impedance of typically less than 10 kΩ were routinely achieved. Pairs of electrodes were placed 0.05 m apart over the centre of each muscle with two muscles sharing a reference point. The reference point for the lower body was the patella. The reference points for the lumbar region was the right and left illiac crest (see Figure 5.6). The instrumentation set-up is the same as that outlined in the previous experiment (section 4.3.1). The electromyographic and ground reaction forces data acquisition programs were synchronised so that a single switch started simultaneous data collection on both systems.

Ground reaction forces The vertical (Fz), anterior-posterior (Fy) and medio-lateral (Fx) ground reaction forces occurring during the final delivery stride were measured using a 0.6 m by 0.4 m Kistler type 9851 piezoelectric force platform system. The force platform was situated within a section of a specially designed outdoor polyflex surface, 15 m by 1.5 m. The platform was positioned 0.017 m beneath the surface of the track, with a 0.017 m covering of polyflex on aluminium overlying the platform. Force platform data was converted to digital form and sampled at 500 Hz for a two second period using a 33 MHz 386 Viglen (IBM Compatible) personal computer running Orthodata Pro-vec data acquisition software.

Figure 5.6 : Positions of the electrodes on the six muscle groups measured for Electromyography activity during the final stages of the javelin throw.

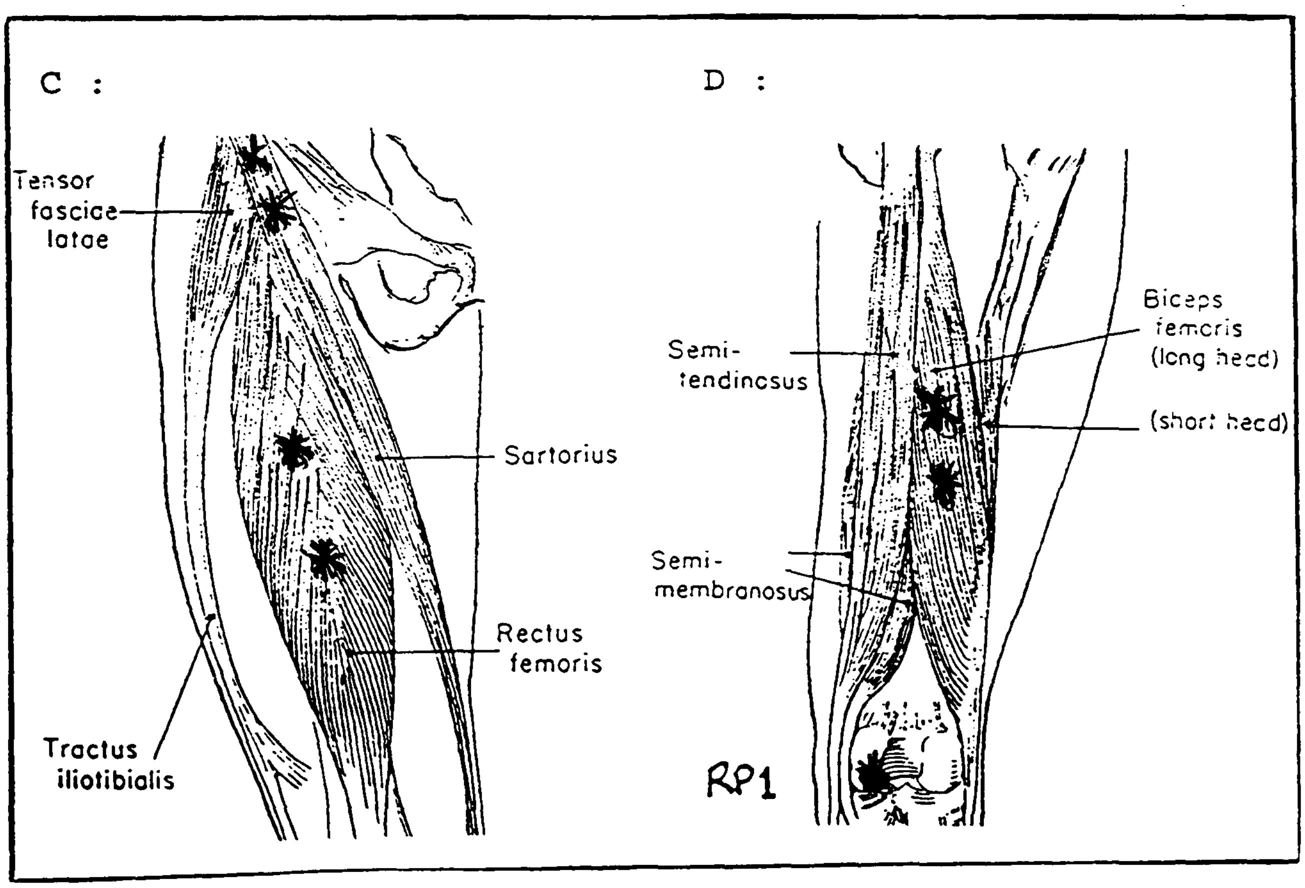
A : Right/Left lower
Latissimus Dorsi

B : Rectus Abdominis



C : Rectus Femoris
Sartorius

D : Biceps Femoris



Data Analysis

Cinematography The film image was projected using a Nac analysis projector onto a TDS High Resolution TP1067 digitiser tablet, connected to an Archimedes A440/1 microcomputer running two-dimensional cine analysis software (Bartlett and Bowen, 1993). The eighteen anatomical link system plus the four additional points on the javelin (tip, metal tip end, grip and tail) were digitised at every other frame (100 Hz) and then stored on floppy disc. Particular attention was made to the accurate digitisation of the right hand side body position markers, hip, shoulder, elbow, wrist and javelin grip for each test belt condition. Because of the advantages of the technique the cine data was smoothed and calculated velocities and accelerations using cross-validated quintic splines (Woltring, 1986).

Alternate serial film frames (five frames before left foot contact, through to ten frames after release) were digitised for each test condition. Peak linear speeds, prior to or at the point of release, were measured for five specific points. Attitude angle of the javelin (the angle between the long axis of the javelin and a right horizontal reference) was measured at the point of release of the javelin.

Accuracy of digitising procedure

Prior to any experimental analysis, it was necessary to test the equipment and two-dimensional digitisation procedure for accuracy. Firstly ten different balls were dropped and recorded using 100 Hz cinematography in order to calculate gravity. The mean and standard error obtained from the trials was 9.80 ± 0.18 m s^{-1}. One of the recorded javelin throws was digitised on three separate occasions, to check on the reliability of the procedure. Experimental error estimates for the variables analysed based on the standard deviations are as follows: (linear speed m s^{-1}) right hip ± 0.3, shoulder ± 0.5, elbow ± 0.4, wrist ± 0.5, finger ± 0.8 and grip of javelin ± 0.7: Javelin attitude angle at release $\pm 1.0°$.

Electromyography As data collection was initiated at the same time as the collection of ground reaction force data it was possible to transfer event times from the ground reaction force data to the electromyography data output, for example heel contact and toe off could be identified. The cinematographic data and ground reaction force data was synchronised manually, using heel strike as a key event, during data analysis enabling additional event times, for example the point of release to be established for the electromyogram recordings.

Ground reaction force The following variables were measured from the vertical and anterior-posterior ground reaction force data :

(1) Peak Vertical Ground Reaction Force.
(2) Time from the heel contact to peak Vertical Ground Reaction Force.
(3) Peak Anterior-Posterior Ground Reaction Force.
(4) Time from heel contact to peak Anterior-Posterior Ground Reaction Force.

The medio-lateral forces were not analysed in this study as it was considered that for this study the vertical and anterior-posterior forces were the most relevant.

Statistical Analysis

Descriptive statistics (mean and standard deviation) for each condition and for each subject were calculated. See Appendix D.

5.4 Results and Discussion

Each throw was analysed in depth. Parameters showing the most important differences between the belt test conditions are reported.

Cinematography For the three subjects the mean ± S.D. distances thrown were Subject 1 48.17 ± 4.45 m, Subject 2 52.95 ± 3.07 m and Subject 3 52.28 ± 2.98 m. The distances thrown for the three test conditions *A,B,C* were 52.69 ± 0.16 m, 54.07 ± 3.11 m and 46.63 ± 3.23 m respectively (mean ± S.D). Table 5.1 shows the peak linear speeds of the five joint centres, javelin grip release speed and distance thrown for three belt test conditions.

Table 5.1. Peak linear speeds (m s^{-1}) release speed (Javelin grip) / distance (m) during the three test conditions (n=3)

	Subject 1			**Subject 2**			**Subject 3**		
Test Condition	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Hip	**6.52**	**5.90**	**5.84**	**4.27**	**8.25**	**5.69**	**6.55**	**6.98**	**5.82**
Shoulder	**7.38**	**7.40**	**7.02**	**6.31**	**9.92**	**6.64**	**7.57**	**8.59**	**8.32**
Elbow	**13.41**	**11.79**	**11.63**	**10.20**	**14.67**	**14.14**	**14.24**	**15.60**	**13.18**
Wrist	**17.47**	**16.30**	**16.03**	**13.30**	**19.88**	**17.38**	**18.67**	**20.32**	**17.34**
Finger	**22.00**	**20.78**	**19.89**	**14.29**	**23.59**	**22.19**	**23.58**	**24.76**	**22.86**
Grip	**21.41**	**21.07**	**20.28**	**18.94**	**24.56**	**22.67**	**23.12**	**25.03**	**22.06**
Distance	**52.66**	**49.74**	**42.10**	**52.51**	**56.90**	**49.43**	**52.89**	**55.58**	**48.36**

The mean ± S.D. distance thrown (belt *B*) 54.07 ± 3.11 m was 7.44 m greater than the no belt condition 46.63 ± 3.23 m. Subject 1 threw furthest when wearing belt *A* while subjects 2 and 3 threw furthest while wearing belt *B*. It should be highlighted that subject 1 attained the fastest javelin release speed when wearing test condition *A*, whilst subjects 2 and 3 attained the faster release speeds when wearing test condition *B*. The linear speed for the shoulder joint centre was greater for all three subjects during test condition *B*. These results are encouraging, but must be treated with caution because of the limited sample size used in this preliminary study.

Table 5.2 reports the javelin attitude angles for each subject under the three test conditions. The release angles range between 31.4 and 40.4°. Subject 1 had a lower angle of release throughout all three test conditions than subjects 2 and 3.

Table 5.2 Javelin attitude angle (degrees) at release

Test Condition	A	B	C
Subject 1	34.0	31.4	32.6
Subject 2	35.6	37.4	38.9
Subject 3	40.4	38.9	38.6

Ground Reaction Force Table 5.3 summarises the vertical ground reaction forces and associated temporal data. The peak vertical ground reaction forces ranged from 4.12 to 6.83 expressed relative to body weight. There were no differences for test conditions *A,B* and *C* for peak vertical ground reaction forces expressed as BW, time to peak force and loading rates. The grand mean peak vertical ground reaction forces ± S.D. expressed relative to each subject's body weight was 4.95 ± 0.86 BW equivalent to 4.27 ± 0.72 kN. The time to peak vertical ground reaction forces was subject dependent with minor differences between belt test conditions. For all belt test conditions the mean ± S.D. time to peak vertical ground reaction forces was as follows: Subject 1: 44.67 ± 1.72 ms; Subject 2: 20.43 ± 14.01ms; Subject 3: 35.03 ± 2.52 ms.

Table 5.3 Peak Vertical Ground Reaction Forces expressed relative to body weight (BW) / Time to peak force (ms) / Loading Rates BW s^{-1} (mean ± S.D.)

Test Condition	Subject 1	Subject 2	Subject 3	Mean ± S.D.
A	5.38 42.5 127	4.12 40.2 102	6.83 33.1 206	5.44 ± 1.11 38.6 ± 4.00 145 ± 44.4
B	5.50 46.7 118	4.26 9.4 453	4.47 33.4 134	4.74 ± 0.54 29.8 ± 15.4 235 ± 154
C	4.83 44.8 108	4.94 11.7 422	4.24 38.6 110	4.67 ± 0.31 31.7 ± 14.4 213 ± 148

The time to peak vertical ground reaction force for subject 2 occurred at 9 and 12 ms after foot contact during test conditions *B* and *C*. The time to peak vertical ground reaction force during test condition *A* was 40 ms with an accuracy of 4 ms in the measurement. This highlights the variability of the javelin thrower's technique and timing during the delivery stride. Average loading rates calculated for each of the three belt conditions ranged from 145 ± 44.4 and 235 ± 154 BW s^{-1}. Subject 2 during test condition *B* reported the highest individual loading rate of 453 BW s^{-1} indicated the severity of the front foot impact during the delivery stride.

Table 5.4 Peak Anterior–Posterior Ground Reaction Forces expressed relative to body weight.

Test Condition	Subject 1	Subject 2	Subject 3	Mean ± S.D.
A	4.12	3.31	3.36	3.60 ± 0.37
B	3.54	3.60	2.25	3.13 ± 0.62
C	3.32	3.15	6.89	4.45 ± 1.72

Peak anterior–posterior ground reaction forces ranged from 2.25 to 6.89 BW (Table 5.4). No differences in anterior–posterior ground reaction forces measurement could be related to the test conditions. The grand mean ± S.D. for all belts worn by the three subjects was expressed relative to body weight was 3.73 ± 1.21 BW equivalent to 3.20 kN ± 0.96 kN. It is interesting to note the extremely high peak anterior–posterior ground reaction forces for subject 3 during belt condition C. It is higher than the peak vertical ground reaction force of 4.24 BW. The mean ± S.D. time to peak anterior–posterior ground reaction forces was: Subject 1: 40.0 ± 0.5 ms ; Subject 2 38.3 ± 2.1 ms; Subject 3: 35.6 ± 6.3 ms. Since the accuracy of the time to peak measurement was 4 ms no differences were evident between the test conditions.

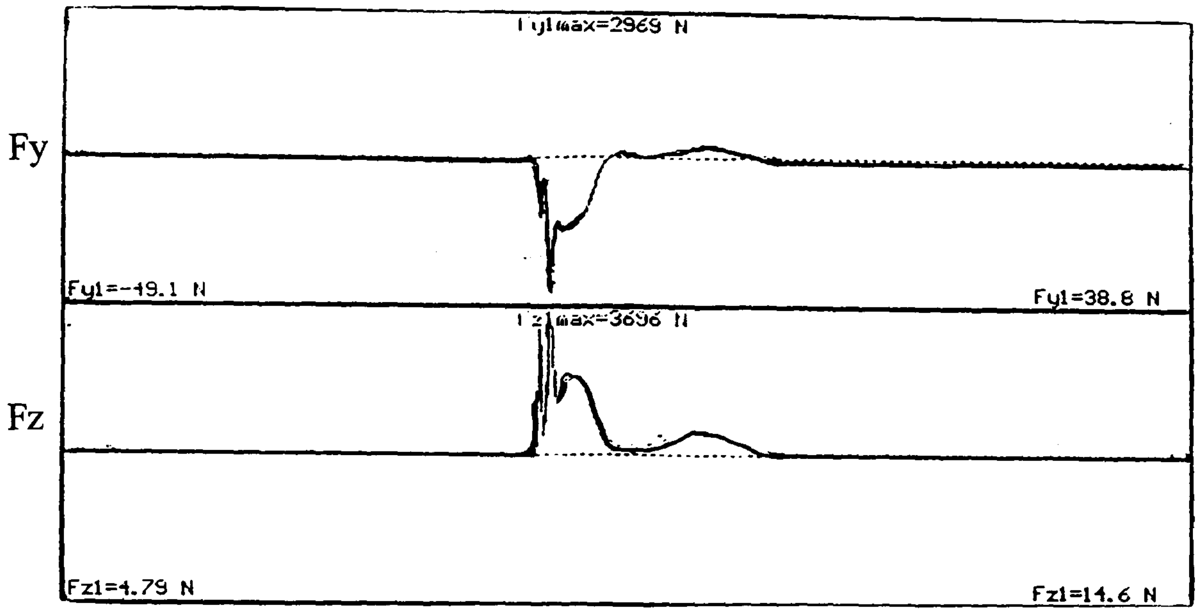
Figure 5.7 shows a synchronised ground reaction force trace and electromyogram obtained during the no belt condition.

Electromyography No differences between the muscle recruitment patterns and magnitude were evident between the three test conditions. During the interpretation of muscle activity patterns in multi-segmental movements the dependency of muscle activity upon the movement at all controlled joints needs to be considered. In this case the muscular activity of the Rectus Femoris may reflect both knee and hip movements. The following paragraphs describe an example electromyogram recording during the no belt condition. References are made to the duration and magnitude of muscle activity during the throwing phase.

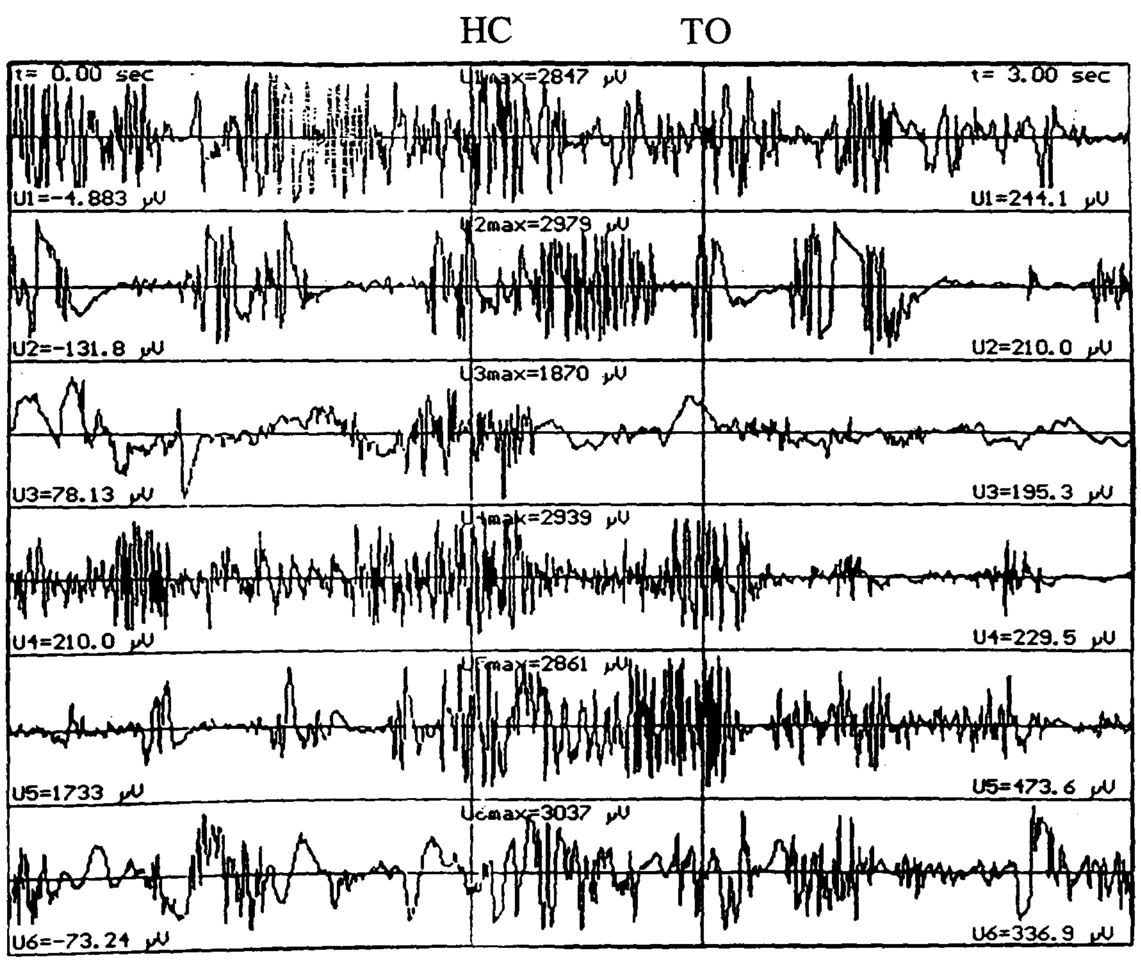
The Biceps Femoris is active before heel contact is made with the lead leg, due to the knee being slightly bent. Biceps Femoris activity reduces as the knee straightened with increased activity of Rectus Femoris prior to heel contact. Interestingly there was also maximal activity of the Sartorius; indicating hip flexion began before heel contact in preparation for the throw. Sartorius activity then continued, but at a reduced magnitude after heel contact through to just before the point of release. The Rectus Femoris muscle indicates maximally activity following heel contact and is maintained as the bracing lead leg straightens.

Figure 5.7 : Synchronised ground reaction force and electromyogram recording during the delivery stride of the javelin throw. (Belt A):
Subject 2 : Body Weight 897 Newtons

Ground Reaction Force : 3 second time base:
Fy: Anterior–Posterior   Fz: Vertical
Time to Peak Vertical Ground Reaction Force : 40.2 ms / 102.49 BW s^{-1}
Time to Peak Anterior–Posteior Ground Reaction Force : 36.0 ms
Total Time in Contact : 598 ms (Heel Strike – Toe off)



Electromyogram: 3 second time base: (HC = heel contact : TO = toe off)
1) Rectus Femoris (RF)   2) Biceps Femoris (BF)   3) Rectus Abdominis (RA)
4) Sartorius (SA)   5) Left Lower Latissimus Dorsi (LL)
6) Right Lower Latissimus Dorsi (RL)



However, reduced activity in the Rectus Femoris is evident prior to the release of the javelin. Maximal activity in the Biceps Femoris occurs as the left lead leg extends. The Left Lower Latissimus Dorsi is active over the longest duration. Following heel contact activity in the Right Lower Latissimus Dorsi increases as the right hand side of the body accelerates around the braced left side. Maximal activity in the Left Lower Latissimus Dorsi muscle occurs just prior to the point of release. The low-level activity following the point of release occurred as the body torso curled following the throw. After the point of release the Biceps Femoris was most active as the leg extended backwards, aided in the latter stages by action of the Sartorius and Rectus Femoris. Biceps Femoris was active as the knee bent to finally initiate the swing phase following toe off.

Limited differences between the electromyogram signals were evident between the belt test conditions for each of the three subjects. General patterns of muscle activity in terms of magnitude and phasic activity could be identified for subjects, individually or as a group. However, no differences were evident within subjects between belt test conditions, even when considering only conditions *B* and *C*.

5.5 Summary

A high release speed is considered to be of prime importance in the achievement of javelin throw distance (Komi and Mero, 1985; Bartlett and Best, 1988 and Whiting *et al.*, 1991). The speed of release of the javelin is the main focus of comparison between the different test conditions used in this study. Subject 1 attained the fastest javelin release speed when wearing test condition *A*, whilst subjects 2 and 3 attained the faster release speeds when wearing test condition *B*. The increased release speed of the javelin grip was associated with increased peak speeds of the body segments. The progressive increase in linear speed from the hip, shoulder, elbow, wrist and finger prior to the point of release was similar to that reported by Whiting *et al.* (1991). The javelin attitude angles occurring in this study were within the ranges reported by Bartlett and Best (1988) and Whiting *et al.* (1991) of $37 \pm 5°$. Changes were observed in throwing dynamics between the two belt conditions *A* and *B* and the no belt condition *C*. However, there was no systematic evidence from the electromyograms to establish the effect of belt conditions *A*, *B* and *C* on the sequential and temporal patterns of muscular activity. This may be because of a lack quantitative electroymographical data.

The values of peak vertical ground reaction forces obtained appear less (grand mean 4.2 kN $\pm$ S.D. 0.7 kN) than the 4.8 kN reported by Deporte and van Gheluwe (1988) for the front leg delivery stage of eight elite Belgian athletes and greater (mean 3.2 kN $\pm$ S.D. 1.0 kN) than the peak anterior–posterior ground reaction forces of 2.0 kN. No differences in ground reaction forces and associated temporal data during front foot contact of the javelin throw were reported for the three test conditions.

The results of this study indicate that the wearing of either a simple neoprene belt (test condition *A*) or a more complex neoprene belt (test condition *B*) aided an improvement in throwing distance or javelin release speed. Belt *B* was associated with a mean increase in throwing distance of 7.44 m. None of the three subjects had used Belt *B* prior to testing. This study has shown that there may be improved javelin throwing performance if a lumbar support is used. However, this study clearly can only be a preliminary investigation because of the limited number of successful throws obtained from each subject. Further investigation is required to analyse the effect of belt *B* during the final stages of the javelin throwing technique.

Chapter 6

EXPERIMENT 3

AN INVESTIGATION OF THROWING PERFORMANCE WHILST WEARING A LUMBAR SUPPORT BELT DURING AN OVERHEAD TWO-HANDED MEDICINE BALL THROWING TASK.

6.1 Introduction

6.2 Experiment 3 : The effect of a lumbar support belt on two-handed overhead throwing performance of novice subjects.

6.3 Method

6.4 Results and Discussion

6.5 Summary

6.6 Follow up Experiment 3A : The influence of subject experience of lumbar support belt use upon a two-handed overhead throwing task. Novice versus Experienced.

6.7 Method

6.8 Results and Discussion

6.9 Summary

6.1 Introduction

Many factors can influence the delivery action of the fast-medium bowler and javelin thrower such as wind speed, approach velocity, release angle, rotational affects of the trunk and even fatigue. These factors can influence the final release speed of both the cricket ball and javelin. Before any further biomechanical investigations are carried out to determine the effect of *Belt B* on bowling/throwing performance, it was considered necessary to design an experiment that allowed investigation of the changes induced by the lumbar support. The experiment described in this chapter was specifically designed to establish the effect that a lumbar support belt has on the hyperextension-flexion movement of the torso during an explosive throwing activity. The experiment involved throwing a medicine ball, using an overhead soccer style throw-in from a two-footed standing position. The subjects had to throw the medicine ball as far as possible with and without the lumbar support belt. The key variables throughout the experiment were distances thrown. The differences in distances thrown between the two test conditions were also calculated. By undertaking the experiment in an indoor situation, isolating the torso region and having only one dependent variable, distance thrown, it should be possible to determine what effect the lumbar support belt has during an explosive throwing activity.

The subjects taking part in the experiment were all novices with no prior experience of wearing a lumbar support belt or throwing a medicine ball. Each subject was familiar with the overhead soccer style throw-in. These novice subjects were chosen to contrast with the three highly trained javelin throwers analysed in the previous chapter. A condition of the javelin throw experiment (Experiment No. 2), was that all three subjects were familiar with the test condition *Belt A*. The athletes involved in the previous study were highly trained and experienced individuals who had participated in the javelin throw for many years. They would normally train and compete using support belt *A*.

Medicine Ball Throwing

Medicine ball throwing is an explosive action, where the athlete is required to throw the ball as far as possible. There are a number of recognised exercises used for explosive strength training involving the throwing of medicine balls. Such exercises are used by a wide variety of athletes from different sports. Medicine ball throwing exercises are used constantly during winter training by the British throwing squad as a way of improving explosive strength and also as a means of friendly competition. Most of the literature relating to medicine ball throwing describes the throwing technique. Tenke and Higgins (1992) and Miller (1987) give a description of how to perform the two-handed overhead throw correctly and indicate the muscles used in the exercise.

No kinematic studies of medicine ball throwing are reported in the literature, though two studies have analysed the overhead football throw-in, Kollatch and Schwirtz (1990) and Messier and Brody (1986). Both studies followed Federation Internationale Football Association (FIFA) regulations for the mass of the footballs (0.40 to 0.45 kg). Kollatch and Schwirtz (1990) reported upon the kinematics of the football throw-in. Thirteen experienced subjects completed a throw-in from a standing position and a throw-in following a run up. Video analysis (60 Hz) and force platform data were recorded. A number of release parameters were recorded, notably ball speed, angle of release and distance thrown. In addition trunk angle was analysed during the two styles of football throw. The amount of trunk extension, relative to the vertical showed figures ranging from 30 to 40° for the standing start throw to 40 to 45° for the run-up throw. Mean peak ball release velocity was 14.2 m s^{-1} for the standing throw and 15.3 m s^{-1} for the run-up throw. Mean distance thrown was 20.9 m and 24.1 m respectively for the two conditions. The throw-in from a standing position had a correlation of ($r = 0.93$) with speed of the ball and distance. A correlation of ($r = 0.56$) with hand joint speed at the moment of ball release and distance. A lower correlation of ($r = 0.46$) was found between the hip velocity when the ball was at its furthest point behind the athlete and throw-in length. Kollatch and Schwirtz (1990) stated that due to this the initial phase of the throw-in needed to be performed quickly. No significant differences between any body angles and throw-in length were reported.

Messier and Brody (1986) describe the mechanics of the conventional throw-in and make comparisons with the 'handspring' throw-in. Thirteen university level players performed the conventional throw-in and four performed the handspring throw-in (two university and two juniors). Each throw was filmed using two-dimensional cinematography analysis (100 Hz). Mean reported peak ball velocity was 18.05 m s^{-1} for the conventional throw in with an average distance of 29.26 m. The handspring style throw in had a mean peak ball velocity of 23 m s^{-1} with an average distance of 44.0 m. They showed that the conventional throw-in is characterised by a body, which is moving forwards and upwards and rotating upwards and there is a sequencing of segmental actions going from large to small. (from trunk to upper arm to lower arm).

Tanner (1982) investigated the electromyographical data of several specific training and throwing activities for one experienced javelin thrower. Electromyograms were obtained and analysed from a number of exercises and javelin throws. The triceps and the pectoralis major muscle groups during the two-handed medicine ball throw indicate very similar patterns to the javelin throw. The major difference between the two throws is the time scale, approximately 2 : 1. Tanner (1982) accounted for this difference by the greater range of movement in the javelin throw. However, the weight of the medicine ball used in the study was 25 lb (approximately 11 kg) is considerably heavier than that of an 800 g javelin. It is therefore, not surprising that the time scale was influenced. The weight of the medicine ball used by Tanner (1982) raise questions as to the relevance of throwing such a heavy object for javelin training.

6.2 Experiment 3 : The effect of a lumbar support belt on two-handed overhead throwing performance of novice subjects

The aim of this experiment was to determine the effect of a lumbar support belt on a two-handed overhead throwing task. Forty novice subjects, twenty-four male (Group 1) and sixteen female (Group 2), volunteered for the study. One research hypotheses was formulated: H1 and the following null hypotheses was tested: Ho during this experiment.

Ho : There will be no significant difference in distance thrown between the two test conditions.
H1 : There will be a significant difference in distance thrown between the two test conditions.

6.3 Method

Subjects Forty physically fit, active, undergraduate subjects volunteered to take part in the study. Group 1, twenty four male subjects; mean ± S.E. mass 75.2 ± 3.7 kg; height 1.78 ± 0.08 m and Group 2, sixteen female subjects; mean ± S.E. mass 67.8 ± 4.6 kg; height 1.69 ± 0.06 m. Each subject was also measured for leg length (hip joint centre to floor level) and for torso length (7th cervical vertebra to hip joint centre). The novice subjects had no prior experience of wearing a lumbar support belt or throwing a medicine ball. However, each subject was familiar with performing the overhead soccer style throw in. Each subject was shown the study location and the experimental procedures were explained. An opportunity to ask questions was provided. Each subject was told that withdrawal from the study was possible at any time. The subjects were each permitted a free warm-up period. Each subject was allowed five practice throws under each test conditions. During the study group 1 threw a 2 kg medicine ball and group 2, threw a 1.5 kg medicine ball. Each subject performed a total of twenty overhead throws. The order of throws was systematically rotated. Each group was sub-divided into two sections, referred to as Order A and Order B.

Order A : 5 Belt (1-5) / 5 No Belt (6-10) / 5 Belt (11-15) / 5 No Belt (16-20)
Order B : 5 No Belt (1-5) / 5 Belt (6-10) / 5 No Belt (11-15) / 5 Belt (16-20)

Belt Test Conditions

Test Condition 1 = No Belt

Test Condition 2 = Vulkan 3049 'neoprene lumbar belt' + 8 vertical plastic support bars + a horizontal nylon Velcro adjustable strap for additional support (5cm width). The additional horizontal velcro strap was to ensure that the back support (especially the plastic supporting strips) took on the shape of the subject's lower back. Each plastic strip (15cm x 1cm) was aligned vertically. (see figures 6.1, 6.2 and 6.3)

Data Acquisition

The experiment took place indoors in a gymnasium. Subjects were asked to throw the medicine ball using two hands in order to achieve maximum distance. They were instructed to position their feet behind the throwing line. No run-up step was allowed prior to release. Upon releasing the medicine ball they could, however, take one step forward over the line to prevent them overbalancing. The athletes threw the medicine ball into a chalk pit and a clear imprint of the ball was left on landing. The distance thrown was measured from the starting line to the point of the ball imprint nearest the subject.

Statistical Analysis

The mean and standard error of the distance thrown was calculated for Order A and Order B for all subjects. The difference in throwing performance, (Belt condition minus no belt condition) for each subject by order and by group was also calculated. A paired *t*-test (two-tailed) was used to find if there was any significant difference in throwing performance for each of the two groups under the two conditions. The mean and standard error for the physical characteristics of Order A and Order B subjects in both the male and female groups were also calculated (see Appendix E).

VULKAN 3049 Neoprene Lumbar Support Belt :

Dimensions (0.93 m x 0.26 m)

Figure 6.1 : Inside View

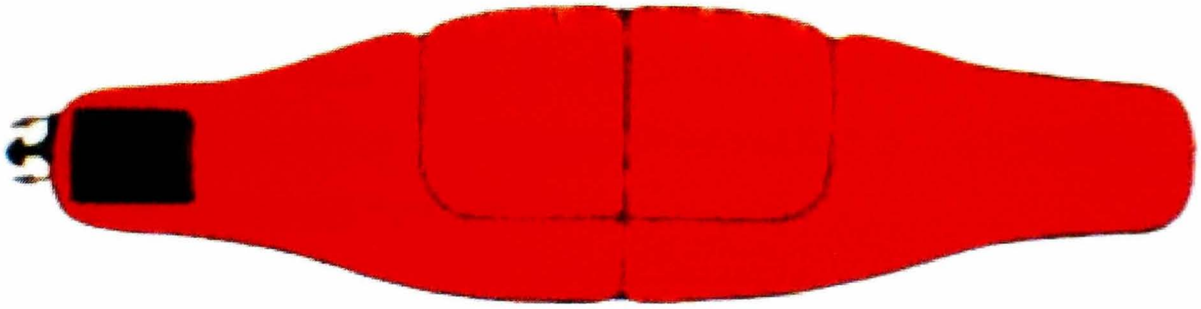


Figure 6.2 : Outside View showing the nylon velcro adjustable strap

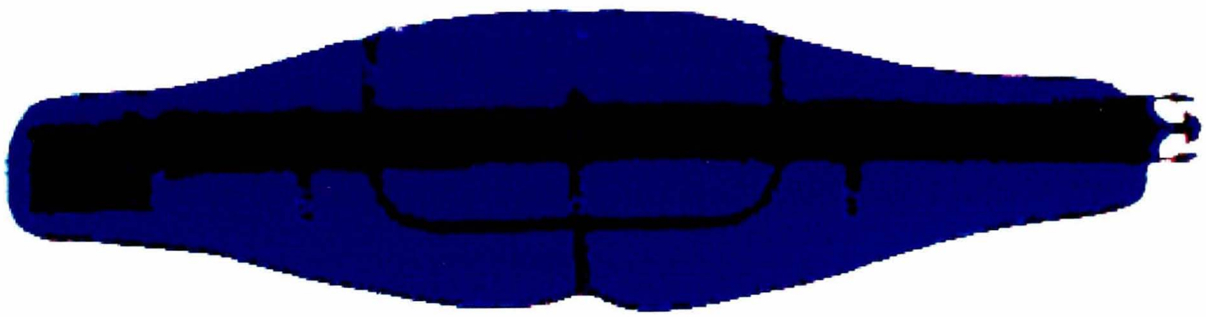
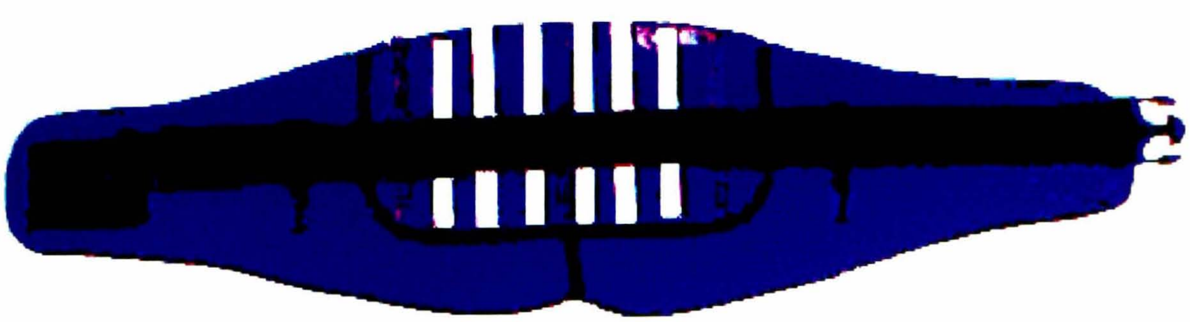


Figure 6.3 : Outside View showing the eight vertically aligned plastic support bars



6.4 Results and Discussion

Table 6.1 summarises the throwing performance for group 1 and group 2 using both test conditions (belt and no belt) and both order sequences (order A and order B). Group 1 shows an overall improvement when wearing the supporting belt of 0.33 m in throwing distance. This equates to a 2.8% improvement in performance. Similarly, Group 2 showed a 0.32 m improvement with the supporting belt (3.2% improvement). Overall for both the male and female subject groups the average improvement in distance thrown was 0.33 m. Data for this experiment are presented in Appendix E.

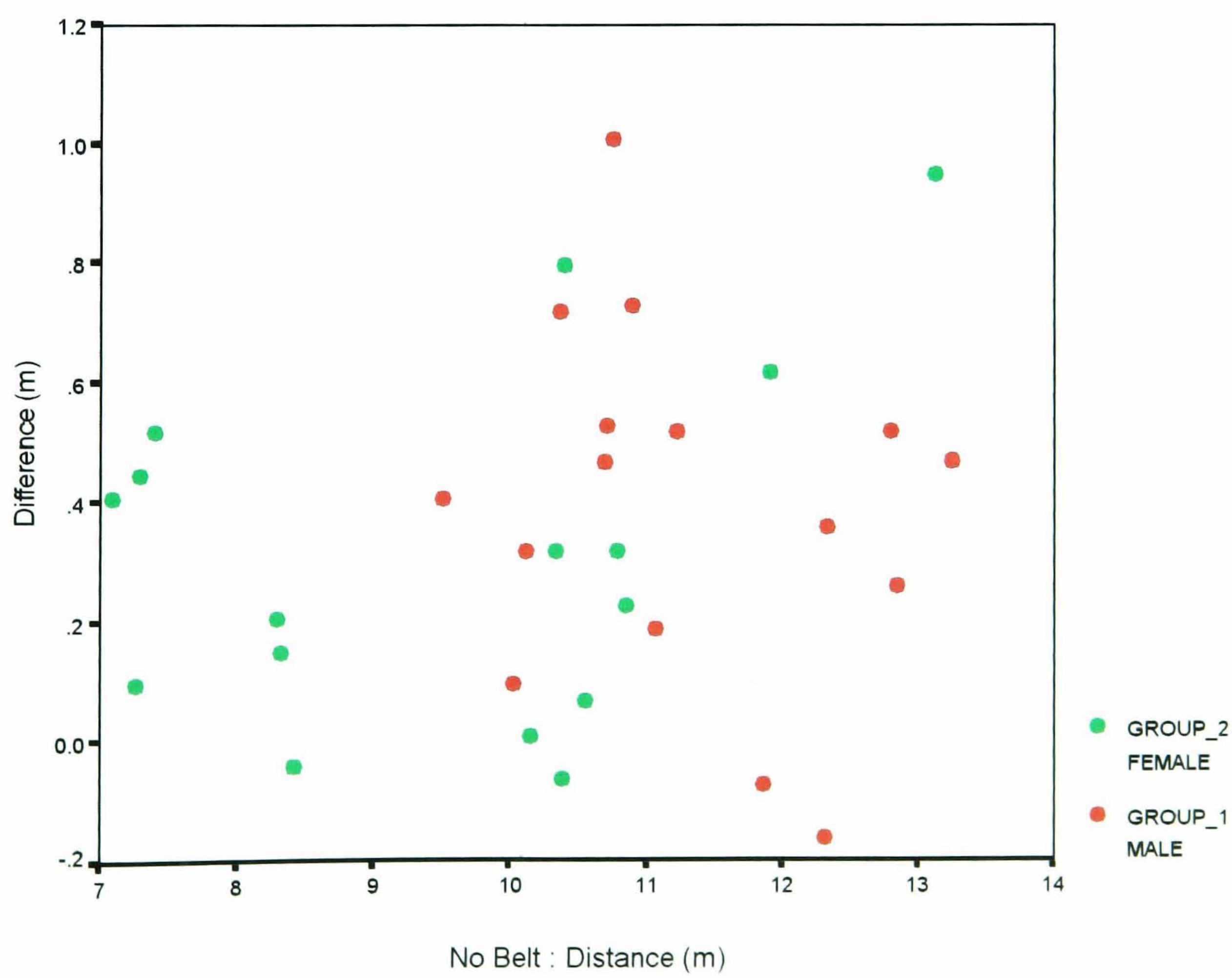
Table 6.1 : Medicine Ball : Summary of mean ± S.E. distance thrown (m) Group 1 / Group 2 : Order A / Order B: Difference in distance thrown (m).

	Belt	No Belt	Difference
GROUP 1 Order A	11.72 ± 0.33	11.25 ± 0.34	0.47 ± 0.09
GROUP 1 Order B	11.63 ± 0.39	11.44 ± 0.37	0.19 ± 0.08
TOTAL (n=24)	11.68 ± 0.25	11.34 ± 0.24	0.33 ± 0.06
GROUP 2 Order A	9.35 ± 0.65	9.11 ± 0.62	0.24 ± 0.08
GROUP 2 Order B	10.37 ± 0.72	9.97 ± 0.68	0.40 ± 0.13
TOTAL (n=16)	9.86 ± 0.49	9.54 ± 0.46	0.32 ± 0.07

The twelve order A subjects from group 1 had an average improvement of 0.47 ± 0.09 m. Only one subject from the twelve did not throw further with the lumbar support. Order B, however, had an average improvement of 0.19 ± 0.08 m. The eight female subjects in order A had an average improvement of 0.24 ± 0.08 m compared to order B, which had an improvement of 0.40 ± 0.13 m. The mean and standard error for the four sets of physical characteristics, height, leg length, length of spine and mass for both the male and female groups showed little differences. No differences in the physical characteristics were reported between order A and B subjects for both the male and female groups (see Appendix E).

The next stage of the study was to test the significance of the 0.33 m improvement in throwing performance using a paired *t*-test (two-tailed). A two-tailed test was used because at this stage of the experimental research it was not known if the belt would either help or hinder athletic performance. The difference in the average distance thrown (belt - no belt) for the ten throws (Group1 and 2) was calculated and is shown in graphical form on page 109. Figure 6.4 shows the difference in distance thrown between the two test conditions for each of the forty subjects against the no belt condition. Out of a total of forty subjects, thirty-four threw the medicine ball further whilst wearing the lumbar support. For group 1 (23 degrees of freedom (DF)) the critical *t* value at 0.01 level = 2.807. The calculated *t* value for group 1 was 5.27. For group 2 (15 DF) the critical *t* value at 0.01 level is 2.95 and the calculated *t* value for the group was 4.28. These tests indicate that there is a significant difference in throwing performance for both the novice male and novice female groups. Results are given in Appendix E.

Figure 6.4 : Average Difference (Belt – No Belt) for Groups 1 and 2



6.5 Summary

An average improvement of 0.33 m was recorded for the forty subjects when using the lumbar support belt. Out of a total of forty subjects, thirty-four threw the medicine ball further whilst wearing the lumbar support. Group 1 (novice males) had an average improvement when using the lumbar support condition of 0.33 m, which gives a 2.8% improvement in performance. Group 2 (novice females) had an average improvement of 0.32 m representing a 3.2% improvement in performance. For both groups no differences were evident between the physical characteristics in Order A and Order B.

From the data presented, it can be seen that the lumbar support significantly improved the performance of novice subjects. Further investigation is now required to determine why an improvement in distance thrown occurred. If this level of improvement can be found for the novice groups, then it is important that this research further investigates the effect of the lumbar support on the throwing performance of experienced subjects. The ability to train and become accustomed to the belt may be a significant factor in the improved performance of an athlete. The confidence gained by wearing a lumbar support belt during an explosive throwing activity may further influence the performance of the athlete. A follow up experiment was designed to investigate the effect of the lumbar support on throwing performance for both novice and experienced subjects.

6.6 Follow on Experiment 3A : The influence of subject experience of lumbar support belt use upon a two-handed overhead throwing task. Novice versus Experienced

The aim of this experiment was to establish why the lumbar support belt was associated with a mean improvement in distance of 3% for the forty novice subjects in experiment 3. This experiment aimed to determine the effect of the lumbar support belt on experienced subjects. The ability to train and become accustomed to the lumbar support may be a significant factor in the performance of an athlete. The additional confidence given to the athlete by wearing the lumbar support belt during the throw may further influence performance. As with experiment 3, the key dependent variables were the overall distance thrown and the difference in distance thrown by each subject with and without the belt. In addition, the kinematic parameters that are critical to throwing performance for both novice and experienced subjects were investigated.

Sixteen male subjects volunteered for the study and were divided into two groups based on experience. (Group 3 = novice : Group 4 = experienced) Experienced subjects were athletes who had used lumbar support belts in training and competition for a number of years. All subjects were familiar with the overhead medicine ball throw.

The aims of this experiment were to : -

(1) Establish why the lumbar support was associated with a mean improvement in distance thrown of 3% for the novice subjects in experiment 3.

(2) Determine the effect of the lumbar support belt on throwing performance for experienced subjects.

(3) Identify changes in kinematic parameters during throwing performance which occur as a result of wearing the lumbar support belt.

(4) Establish the kinematic parameters that are critical for throwing performance.

Four research hypotheses were formulated: H1(1) → H1(4) and the following four null hypotheses were tested: Ho(1) → Ho(4) during this experiment.

Ho : There will be no significant difference in the distance thrown between the two test conditions for the novice group.
H1 : There will be a significant difference in the distance thrown between the two test conditions for the novice group.

Ho : There will be no significant difference in the distance thrown between the two test conditions for the experienced group.
H1 : There will be a significant difference in the distance thrown between the two test conditions for the experienced group.

Ho : There will be no significant difference between the two test conditions in the peak linear speed of the ball, linear speed of the finger, wrist, elbow, shoulder and hip joint centres for the novice group.
H1 : There will be a significant difference between the two test conditions in the peak linear speed of the ball, linear speed of the finger, wrist, elbow, shoulder and hip joint centres for the novice group.

Ho : There will be no significant difference between the two test conditions in the peak linear speed of the ball, linear speed of the finger, wrist, elbow, shoulder and hip joint centres for the experienced group.
H1 : There will be a significant difference between the two test conditions in the peak linear speed of the ball, linear speed of the finger, wrist, elbow, shoulder and hip joint centres for the experienced group.

6.7 Method

Subjects Sixteen physically fit, active, subjects volunteered to take part in the study. Group 3, eight male novice subjects; mean ± S.E. mass 82.5 ± 2.63 kg and height 1.83 ± 0.03 m. Group 4, eight male experienced subjects, mean ± S.E. mass 83.9 ± 2.90 kg and height 1.82 ± 0.02 m. Each subject was also measured for leg length (hip joint centre to floor level) and for torso length (7th cervical vertebra to hip joint centre). Each subject was shown the study location and the experimental procedures were fully explained. An opportunity to ask questions was provided. Subjects were told that withdrawal from the study was possible at any time. Subjects were also permitted a free warm-up period. Each subject was allowed five practice throws under both test conditions. A 2 kg medicine ball was used. Each subject performed a total of twenty overhead throws. The order of throws was systematically rotated. Each group was divided into two sections:

Order A : 5 Belt (1-5) / 5 No Belt (6-10) / 5 Belt (11-15) / 5 No Belt (16-20)

Order B : 5 No Belt (1-5) / 5 Belt (6-10) / 5 No Belt (11-15) / 5 Belt (16-20)

Belt Test Conditions

Test Condition 1 = No Belt

Test Condition 2 = Vulkan 3049 '*Belt B*' (Identical belt to Exp3 Section 6.3)

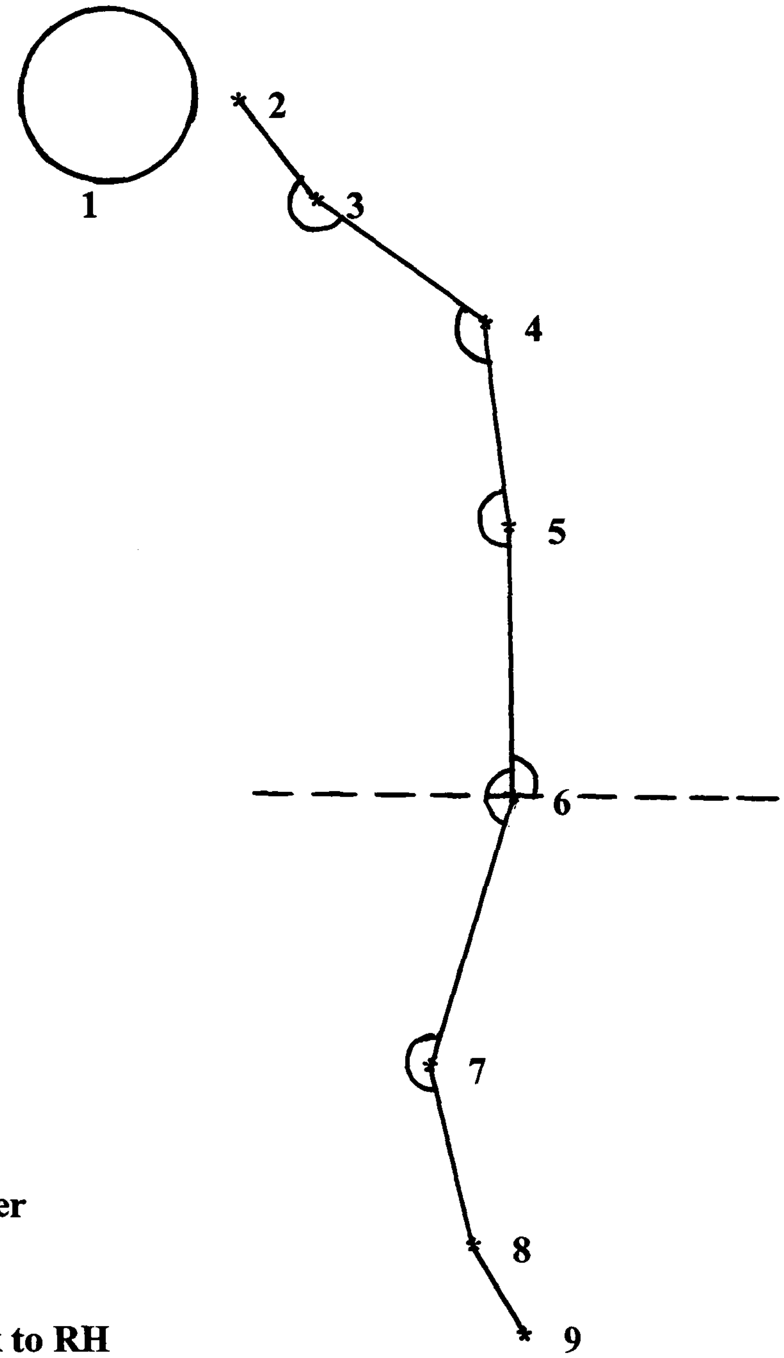
Data Acquisition

Identical to Experiment 3.

Cinematography Analysis

One battery powered Photosonics 500 16 mm camera, fitted with a 28 mm lens and loaded with Kodak 16 mm Ektachrome 7251 film, was mounted on a tripod at a height of 1.5 m. The camera was positioned 10 m perpendicular to the subject. A frame rate of 100 frames per second was used to allow detailed analysis. Internal camera timing lights pulsed at 100 per second during filming and the image was used to check the film had reached the correct speed during movement analysis. Camera shutter speed and aperture size was determined at the time of filming using a Gossen Six light meter. To ensure that there was sufficient lighting in the gymnasium, spot lights were used to provide extra illumination upon the focused area. Prior to testing, anatomical markers were placed on each subject to facilitate joint centre determination to create a nine-segment model. In addition, six angles were created from the model. (see Figure 6.5). Subjects wore minimal clothing during the testing procedure in order to minimise the movement of the joint centre markers during the throwing activity.

Figure 6.5: The nine-segment model



1 Ball

2 3rd Finger

3 Wrist

4 Elbow

5 Shoulder

6 Hip

7 Knee

8 Ankle

9 Toe

6 Angles
(1) 02 03 04 Wrist
(2) 03 04 05 Elbow
(3) 04 05 06 Shoulder
(4) 05 06 07 Hip
(5) 06 07 08 Knee
(6) 05 06 RH Trunk to RH

Analysis of Data

For each subject, two trials from each test condition were chosen for kinetic and kinematic analysis. Cinematography film was recorded for every 5th, 10th, 15th and 20th throw for each subject in both Order A & B groups. After processing, the film was projected, using a Nac analysis projector, onto a TDS High Resolution TP1067 digitiser tablet, connected to an Archimedes A440/1 microcomputer running Bartlett and Bowen (1993) two-dimensional analysis software. In order to project the image vertically, a prism-rotating lens was fixed to the projector. Two-dimensional (vertical and horizontal) scaling, prior to digitisation was then undertaken. Using the 'user define model' option, the nine-segment model was digitised for every frame (100 Hz) for each throw and then stored on disk. In each case, two control points were used. On average between 50 and 60 frames were digitised for each throw. Because of the advantages of the technique the cine data was smoothed and calculated velocities and accelerations using cross-validated quintic splines (Woltring, 1986).

Accuracy of digitising procedure

Prior to any experimental analysis, it was necessary to test the equipment and digitisation procedure for accuracy. Two tests were carried out. The first involved dropping different balls (12 trials) and using the digitisation (50 Hz) from these trials to calculate the constant g (gravity). The mean and standard error obtained from the trials was 9.82 ± 0.05 m s^{-1}. The second experiment involved testing for angular displacement of an industry standard electronic clock, which takes two seconds to complete 360°. This experiment was also carried out twelve times. After 2 seconds the average angular displacement calculated was $359 \pm 1.4°$. The mean and standard error results reported were very similar to the standardised readings. One of the recorded throws for the experienced group was digitised on five separate occasions, to assess the reliability of the two-dimensional procedure. Experimental error estimates for the variables analysed based on the standard deviations are as follows: (linear speed m s^{-1}): right hip ± 0.1, shoulder ± 0.2, elbow ± 0.2, wrist ± 0.3, finger ± 0.4 and ball ± 0.2 : Angle of release ± 1.2°, Angular displacement of the torso ± 2.3°.

Statistical Analysis

The mean and standard error of the distance thrown was calculated for Order A and Order B for all subjects in groups 3 and 4. The difference in throwing performance, (Belt condition - No Belt condition) for each subject by order and by group was calculated. A paired *t*-test (one-tailed) was used to investigate if there was any significant difference in throwing performance under the two conditions. A one-tailed test is now used because all earlier experiments have shown that athletic performance has not been hindered by the use of a belt. Given the fact that there were no violations of the major assumptions of ANOVA and the group sizes were equal, a two way analysis of variance was used to analyse the group effect of skill (novice and experience) and order (A and B) on the difference in throwing distances. The mean and standard error for the physical characteristics of Order A and Order B subjects were calculated for both the novice and experienced groups.

The cinematography trials consisted of recording the results of the 5th, 10th, 15th and 20th throws. Descriptive statistics for both the novice and experienced groups were calculated to examine the key kinematic parameters for both test conditions (see Appendix E). For both the novice and experienced groups, a set of comparisons were used to test for any significant difference between the five joint centre speeds and ball release speed for the two conditions. The Bonferrorni technique proposes a reduction in the significance level for each comparison to reduce the likelihood of type I and familywise errors in the set of comparisons. The level of significance for each independent comparison should be set to the nominal significance level divided by the number of comparisons (Howell 1992). The nominal significance level was set at (P=0.05), therefore each independent comparison was tested at $\alpha = .05/6 = 0.008$.

6.8 Results and Discussion

Table 6.2 summarises the throwing performance for group 3 and group 4 using both test conditions and both order sequences (Order A and Order B).

Table 6.2 : Medicine Ball : Summary of mean distance thrown ± S.E. (m)

	Belt	No Belt	Difference
GROUP 3 Order A	10.77 ± 0.73	10.57 ± 0.77	0.20 ± 0.05
GROUP 3 Order B	11.37 ± 0.28	11.09 ± 0.34	0.28 ± 0.08
TOTAL (n=8)	11.06 ± 0.38	10.83 ± 0.40	0.23 ± 0.04
GROUP 4 Order A	13.80 ± 1.14	13.31 ± 1.00	0.48 ± 0.14
GROUP 4 Order B	14.74 ± 0.29	14.16 ± 0.26	0.59 ± 0.03
TOTAL (n=8)	14.27 ± 0.57	13.73 ± 0.51	0.54 ± 0.07

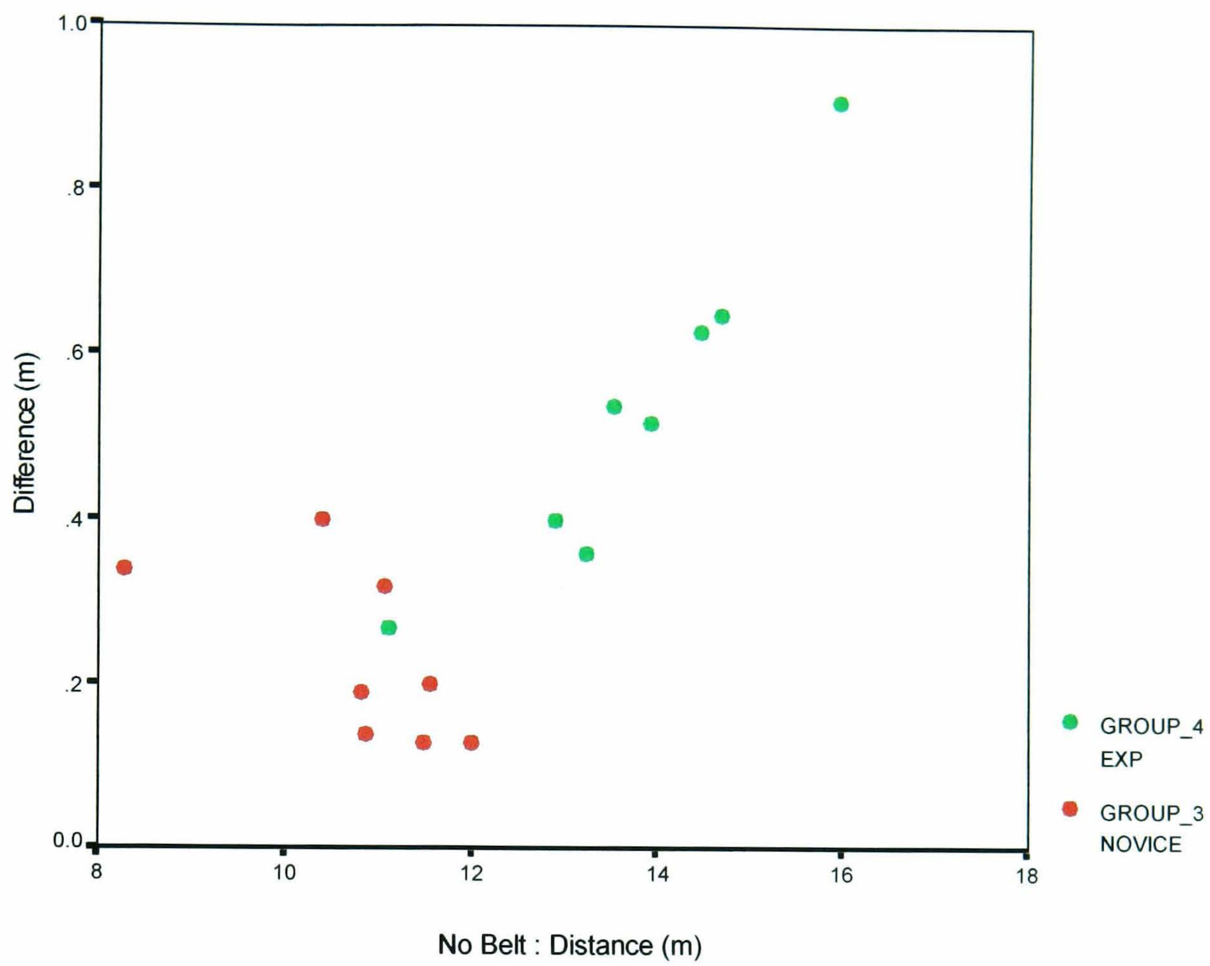
Group 3 increased by 2%, 10.83 ± 0.40 m to 11.06 ± 0.38 m when using the lumbar support. The mean distance improvement for the experienced group also increased but by a larger margin (4%) 13.73 ± 0.51 m to 14.27 ± 0.57 m. An increase in throwing performance was recorded for each of the subjects in groups 3 and 4 during the lumbar support condition. The mean and standard error for the four sets of physical characteristics, height, leg length, length of spine and mass for both the novice and experienced groups showed little differences. No differences in the physical characteristics were reported between order A and B subjects for both groups (see Appendix E).

The next stage of the investigation was to test the significance of the improvement in throwing performance for both group 3, (0.23 ± 0.04 m) and group 4, (0.54 ± 0.07 m). The difference in the average distance thrown (belt - no belt) for the ten throws (Group 3 and 4) was calculated and is shown in graphical form below. Figure 6.6 shows the average difference between the two test conditions against the no belt condition.

As in experiment 3 (section 6.2), a paired *t*-test was used which calculated the difference of the mean distance (belt - no belt) for the ten throws for each subject. For group 3 (7 DF) the critical *t* value at the 0.01 level is 2.998 (one-tailed). The calculated *t* value for the group is 6.13. The calculated *t* value for group 4 is 7.54. Both groups show a significant result at the 0.01 level in throwing performance when using the belt condition. See Appendix E.

A two-way analysis of variance was used to analyse the group effect of skill (novice and experience) and order (A and B) on the difference in throwing distances. No differences were found with regard to the order effect (P=0.327). As previously indicated, both groups 3 and 4 had an increase in throwing distance when using the lumbar support. The skill level was significant (P=0.005), which indicated that the experienced group threw significantly further than the novice group. No interaction was found with regard to skill and order (P=0.899). The results are shown in Appendix E.

Figure 6.6 : Average Difference (Belt – No Belt) for Groups 3 and 4



Group 3: Novice: Cinematography Analysis

Table 6.3 summarises the six key kinematic variables for group 3 under both test conditions.

Table 6.3: Novice: Mean Peak Linear Speeds m s^{-1}:
Time of occurrence with respect to ball release
Before + / After - (seconds) and Distance thrown (m)

	Distance	Hip	Shoulder	Elbow	Wrist	Finger	Ball
Average (n=32)	11.03	1.66 +0.06	2.19 +0.10	3.61 +0.09	8.62 -0.04	11.55 -0.04	10.21 -0.03
Belt (n=16)	11.11	1.66 +0.08	2.22 +0.10	3.57 +0.09	8.79 -0.04	11.69 -0.03	10.22 -0.03
No Belt (n=16)	10.94	1.66 +0.04	2.17 +0.10	3.64 +0.09	8.45 -0.05	11.40 -0.04	10.21 -0.03

An average improvement of 0.17 ± 0.09 m was reported for the belt condition for those trials measured by kinematic analysis. However, the two test conditions were not significantly different. The peak linear speeds for the five joint centres and release speed of the medicine ball were not significantly different: hip (P=0.94), shoulder (P=0.54), elbow (P=0.66), wrist (P=0.11), finger (P=0.06) and ball (P=0.91). The peak wrist and finger linear speeds were slightly higher during the belt condition, despite the ball release speed being almost identical. Results can be seen in Appendix E.

The time at which the peak linear speed of the five joint centres occurred were expressed in terms of time before and time after release of the medicine ball. The time at which the hip joint reached peak linear speed for the belt condition was 0.08 seconds prior to release. However, for the no belt condition this reduced to 0.04 seconds before release. The remainder of the anatomical joint centres had very similar, if not identical, times before/after release of the ball for the two test conditions. The difference in time between the hip and shoulder joints is the one area where you would expect the lumbar support to have the most influence in throwing technique. With only an average of 0.02 seconds between peak hip and shoulder speeds during the belt condition, the hip and lower limbs would have more opportunity to contribute to the throw. It therefore is suggested that the power generated by the lower body is less effective in contributing to the final release speed of the medicine ball for the no belt condition. This is reflected by the average time for the no belt condition being 0.06 seconds before release, indicating the overall lack of timing of the throws.

A smoother throwing technique was displayed when the subjects were wearing the lumbar support. This in turn enabled a more powerful throwing technique, which was reflected in the increased distance. However, in both conditions the novice subjects peak shoulder speed occurred before the peak hip speed. This demonstrated a generally poor throwing technique exhibited by the novice group as a whole. The contribution made by the lower segments of the body was ineffective in producing a maximal throw. The differences between the two conditions in terms of distance thrown cannot be explained by the angular displacement of the torso. The torso during the belt condition moves through a total of 50.19° (maximum hyperextension/flexion) and a total of 50.63° during the no belt condition during a period of 0.07 and 0.08 seconds respectively.

Table 6.4 summarises the average values for a number of release parameters for group 3 under the two test conditions. The difference in release parameters between the two test conditions was very minimal. An angle of 31° represented the throw with the highest angle of release.

Table 6.4: Novice: Release parameters: Mean ± S.E.

	Release speed (m s^{-1})	Height (m)	Angle of Release°	Distance (m)
Average (n=32)	10.21 ± 0.26	2.28 ± 0.02	23.7 ± 0.91	10.81 ± 0.23
Belt (n=16)	10.21 ± 0.39	2.28 ± 0.03	23.4 ± 1.28	10.90 ± 0.33
No Belt (n=16)	10.20 ± 0.36	2.29 ± 0.03	23.9 ± 1.33	10.73 ± 0.33

Group 4: Experienced: Cinematography Analysis

Table 6.5 summarises the key kinematic variables for group 4 under both test conditions.

Table 6.5: Experienced: Mean Peak Linear Speeds m s^{-1}: Time of occurrence with respect to ball release: Before + / After - (seconds) and Distance thrown (m)

	Distance (metres)	Hip	Shoulder	Elbow	Wrist	Finger	Ball
Average (n=32)	14.16	1.62 +0.11	3.32 +0.11	5.29 +0.08	10.82 -0.05	13.25 -0.04	12.59 -0.03
Belt (n=16)	14.42	1.64 +0.10	3.29 +0.10	5.30 +0.08	10.66 -0.05	13.22 -0.04	12.64 -0.03
No Belt (n=16)	13.90	1.61 +0.12	3.35 +0.12	5.28 +0.08	10.98 -0.05	13.28 -0.04	12.54 -0.03

A significant difference in mean distance thrown during the trials filmed by two-dimensional cinematography was found at the 0.01 level. A mean improvement in distance during the belt condition of 0.52 ± 0.15 m for those trials recorded by cinematography analysis. This is a similar improvement in distance thrown when compared to all when all twenty throws per subject were calculated (0.59 ± 0.03 m). However, no significant differences in peak linear joint centre speeds and release speed were found between the two conditions; hip (P=0.53), shoulder (P=0.48), elbow (P=0.82), wrist (P=0.32), finger (P=0.71) and ball (P=0.36). The release speed of the medicine ball was on average higher during the belt condition, this despite the wrist and finger joint centre speeds being lower.

It is interesting to note that the hip and shoulder joints reach peak speed at the same time 0.10 seconds before release in the belt condition and 0.12 seconds before in the no belt condition. Both conditions, nonetheless, are equal by the time peak linear speed for the elbow is reached. No significant differences in the linear peak speeds were reported. However, the difference in segmental timing during the belt condition may explain the additional distances thrown. The belt condition is characterised by a smoother throw. This is shown by the time difference between hip and elbow, 0.02 seconds for the belt condition and 0.04 seconds for the no belt condition. This initial difference in timing is not, however, carried forward to the lighter, faster moving segments of the body.

The differences between the two conditions in terms of distance thrown cannot be explained by the angular displacement of the torso. The torso moves through a total of 66.47° during the belt condition (maximum hyperextension/ flexion) and a total of 67.49° during the no belt condition. The range of movement occurred over a period of 0.13 and 0.11 seconds respectively. The experienced group on average had a 10° increase in angular displacement than the novice group and took an additional 0.04 seconds for the torso to move through the whole range.

Table 6.6 summarises the average values of a number of release parameters for the two conditions. Throughout all 32 trials, the highest calculated angle of release was 29°.

Table 6.6: Experienced: Release parameters: Mean ± S.E.

	Release speed $m\ s^{-1}$	Height (m)	Angle of Release°	Distance (m)
Average (n=32)	**12.59 ± 0.30**	**2.16 ± 0.02**	**24.38 ± 0.47**	**14.16 ± 0.25**
Belt (n=16)	**12.64 ± 0.46**	**2.15 ± 0.02**	**24.75 ± 0.74**	**14.42 ± 0.39**
No Belt (n=16)	**12.53 ± 0.41**	**2.16 ± 0.02**	**24.00 ± 0.60**	**13.90 ± 0.32**

6.9 Summary

The major finding from this experiment was that a significant improvement in distance thrown for both novice and experienced groups occurred as a result of wearing a lumbar support. The experienced subjects (Group 4) had a 4% improvement in throwing performance. They threw significantly further (P=0.005) than the novice group. The novice subjects (Group 3) had a 2% improvement in throwing distance.

No differences were evident in any of the four physical characteristics (height, leg length, length of spine and mass) for order A and order B for subject groups 3 and 4. This indicates that the subjects were all part of the same homogeneous population. The experiment could not identify any significant differences in peak linear speeds of the five key joint centres and medicine ball. However, it did indicate that the lumbar support might help with the overall timing of the throw, thus improving performance. The difference in timing was evident between the hip and shoulder joints. This difference was, however, not evident during the final part of the throw (elbow, wrist and finger joints).

If the curvature of an unloaded spine is taken as the true neutral position, erect standing requires about 15° of lumbar extension. Only a few degrees of further extension are possible before the physiological limit of the torso is reached. Therefore, standing up constitutes a backward bending movement and any action that increases the standing lordosis (backward bending) causes the limit of extension to be approached. This is not only applicable to the medicine ball throw but also to the final delivery phase of both the cricket bowler and javelin thrower. For a heavy object, such as a 2 kg medicine ball, the physiological stress and muscular characteristics to the lumbar region in particular, only allows a release angle of approximately 30°. The additional support, created by using the belt condition, resulted in a change in segmental timing during the overhead throw. This change in segmental timing may account for the difference in distance thrown between the two conditions. A javelin and cricket ball is considerably lighter than a 2 kg medicine ball. The relative timing and rate that the torso moves from a hyperextended position through to a flexed position during the delivery phase of javelin throwing and cricket bowling represents a key area of further research.

The medicine ball experiment aimed to eliminate as many of the external factors that influence the final speed of the cricket ball and distance of the javelin as possible. The medicine ball throw required a hyperextension, flexion movement of the trunk. However, no rotational forces acted on the trunk during the throw. Rotational effects need to be considered for the fast-medium bowler and javelin thrower. Assessment of the rotational effects of the trunk using both three-dimensional cinematography and electromyography of muscle recruitment patterns during the final delivery phase of the cricket bowl and javelin throw will help in the detailed analysis of relative timing of both actions. The two experiments described in this chapter showed that a lumbar support gave a significant improvement in throwing distance during an overhead throwing task for both novice subjects (Group 1: 2.8%, Group 2: 3.2 % and Group 3: 2%) and experienced subjects (Group 4: 4%). The next stage of this doctoral research is to consider the effect of wearing a lumbar support upon the final delivery phase of the fast-medium bowler and javelin thrower.

Chapter 7

EXPERIMENT 4 - FAST-MEDIUM BOWLING IN CRICKET

An investigation into the effect of a lumbar support belt on fast-medium bowling in cricket.

7.1 Introduction

7.2 Experiment 4 - An investigation into the effect of a lumbar support belt on fast-medium bowling in cricket

7.3 Method

7.4 Results and Discussion

7.5 Summary

7.1 Introduction

The technique of the final delivery stride of a fast-medium bowler in cricket has been discussed in the review of literature and is shown in Appendix A. This study analyses the athletic performance of the fast-medium bowler and aims to determine the effect of a lumbar support belt (Belt *B*) during the delivery stride. The emphasis throughout this experiment is performance improvement. The relative timing of the joint centres and rate that the torso moves from a hyperextended position through to a flexed position during the delivery phase represents a key area of interest. The assessment of any rotational movements of the trunk about the vertical axis through the use of three-dimensional cinematography and electromyograms will allow further analysis of the bowling action.

This study addresses the effect on athletic performance made by a lumbar support to an individual's bowling technique. The preceding chapter on medicine ball throwing reported that the use of a lumbar support belt resulted in a 3% (novice) and a 4% (experienced) improvement in distance thrown. Reasons for the improvement in throwing distance were attributed to the improved timing of the throw. A difference in segmental timing was evident between the shoulder and hip joints for both the novice and experienced groups. If a similar percentage improvement occurs as a result of wearing the lumbar support belt during the bowling action, it would most likely be observed in the final release speed of the cricket ball.

7.2 Experiment 4 - An investigation into the effect of a lumbar support belt on fast-medium bowling in cricket.

This investigation aimed to determine the effect of a lower lumbar support upon six male fast-medium bowlers during their delivery stride. All equipment used to record the action of a fast-medium bowler during the delivery stride was synchronised so that the techniques of three-dimensional cinematography, ground reaction forces and electromyography could be used in an integrated study. This experimental procedure has not been carried out previously in the sport of cricket.

This study is also unique in the fact that it utilised two force platforms that measured the ground reaction forces of the back foot and front foot during the same delivery stride. Previous research has used only one force platform, with subjects having to alter their starting position so as to hit the plate with either their back or front foot. Eight previous studies have investigated ground reaction forces generated by the bowler at front foot contact. Three of the eight studies have also investigated ground reaction forces of back foot contact. No previous study has examined synchronised ground reaction forces and electromyography analysis during the delivery stride of the fast-medium bowler. A previous electromyography study of fast or fast-medium bowling (Burden and Bartlett, 1990b) recorded electromyographic data from selected trunk, glenohumeral joint muscles, synchronised with cinematography data. Their objective was to determine the sequential and temporal patterns of muscular activity during the delivery stride.

This will be the first study to address the possible relationship between sports performance and athletic supports. The aims of this experiment were to :-

(1) Establish the effect of a lumbar support on important kinematic parameters during the delivery stride of the fast-medium bowler, notably the linear speeds of the joint centres and cricket ball. In addition, the segmental timing of the joints relevant to ball release will also be established.
(2) Determine the speed at which the torso moves from a hyperextended position through to a flexed position prior to the release of the cricket ball.
(3) Establish the effect of a lumbar support on ground reaction forces and associated temporal data during both back and front foot contact.
(4) Determine the effect of a lumbar support on selected trunk and lower limb muscles.
(5) Establish the sequential and temporal patterns of muscular activity during the delivery phase.

Five research hypotheses were formulated: H1(1) → H1(5) and the following five null hypotheses were tested: Ho(1) → Ho(5) during this experiment.

Ho: There will be no significant difference in peak linear speed (ball release speed, linear speed of mass centre, hip, shoulder, elbow, wrist and finger) between the two test conditions.
H1: There will be a significant difference in peak linear speed (ball release speed, linear speed of mass centre, hip, shoulder, elbow, wrist and finger) between the two test conditions.

Ho: There will be no significant difference in the timing and linear speed between the shoulder and hip joints in the two test conditions.
H1: There will be a significant difference in the timing and linear speed between the shoulder and hip joints in the two test conditions.

Ho: There will be no significant difference in ground reaction forces and associated temporal data experienced in either front or back foot contact between the two test conditions.
H1: There will be a significant difference in ground reaction forces and associated temporal data experienced in either front or back foot contact between the two test conditions.

Ho: There will be no significant difference in approach velocity between the two test conditions.
H1: There will be a significant difference in approach velocity between the two test conditions.

Ho: There will be no significant difference in the muscle recruitment patterns and magnitude between the two test conditions.
H1: There will be a significant difference in the muscle recruitment patterns and magnitude between the two test conditions.

7.3 Method

Belt Test Conditions

Test Condition 1 = No Belt

Test Condition 2 = Vulkan 3049 *'Belt B'* (Identical belt to Experiment 3A : Section 6.3)

Subjects

Six male cricket bowlers of collegiate or 1st team club standard (Sussex) bowlers (Mean ± S.E. age 23.5 ±1.3 yrs ; height 1.83 ± 0.04 m ; body weight 885 ± 42 N) performed their typical bowling action (full match run-up) under both test conditions during this study. None of the six bowlers participating in this study were familiar with a lumbar support belt. Each subject bowled at a set of stumps positioned at the standard pitch length (22 yards). Subjects wore their personal outdoor cricket shoes. The weather conditions during the testing period consisted of nil wind with temperatures of plus 20° C. The ground was extremely hard under foot. All trials were carried out over a period of one month during the competitive summer cricket season.

Data Acquisition

Three methods of data collection were used to enable an objective analysis to be made of the way in which lumbar support belts may influence the performance of the six bowlers. The delivery stride was filmed using two high-speed cinematographic cameras to allow a three-dimensional figure to be created. To improve the understanding of how the lower lumbar support belt may influence the bowling action, the electrical activity of a number of muscles on the torso and lead leg were recorded during each delivery. Ground reaction forces of both the front foot strike and back foot strike during the same delivery stride were measured. To aid in data interpretation a video recording (Sony Hi8 EVO 9100 P) of the experimental work was made. This provided a complete record of events. Figure 7.1 is a diagrammatic representation of the experimental setting.

Cinematography Two battery powered Photosonics 500 16 mm cameras, fitted with a 28 mm lens and loaded with Kodak 16 mm Ektachrome 7251 film, were mounted on a tripod at a height of 1.5 m. The two cameras were positioned at an angle of 90°, at a distance of 10 m from the bowling crease (Figure 7.1). A twenty-five point, three-dimensional calibration unit, Peak Performance, USA was filmed for each new reel of film at a rate of 50 Hz. A frame rate of 100 frames per second was used to allow detailed analysis of the bowling action. Internal camera timing lights pulsed at 100 per second during filming and the image was used to ensure that the film had reached the correct speed during movement analysis. Camera shutter speed and aperture size was determined at the time of filming by using a 'Gossen Six' light meter. Prior to testing, anatomical markers were placed on each subject to facilitate joint centre determination to create a 14-segment model (see figure 7.2). Subjects wore minimal clothing during the testing procedure in order to minimise the movement of the markers during the bowling action.

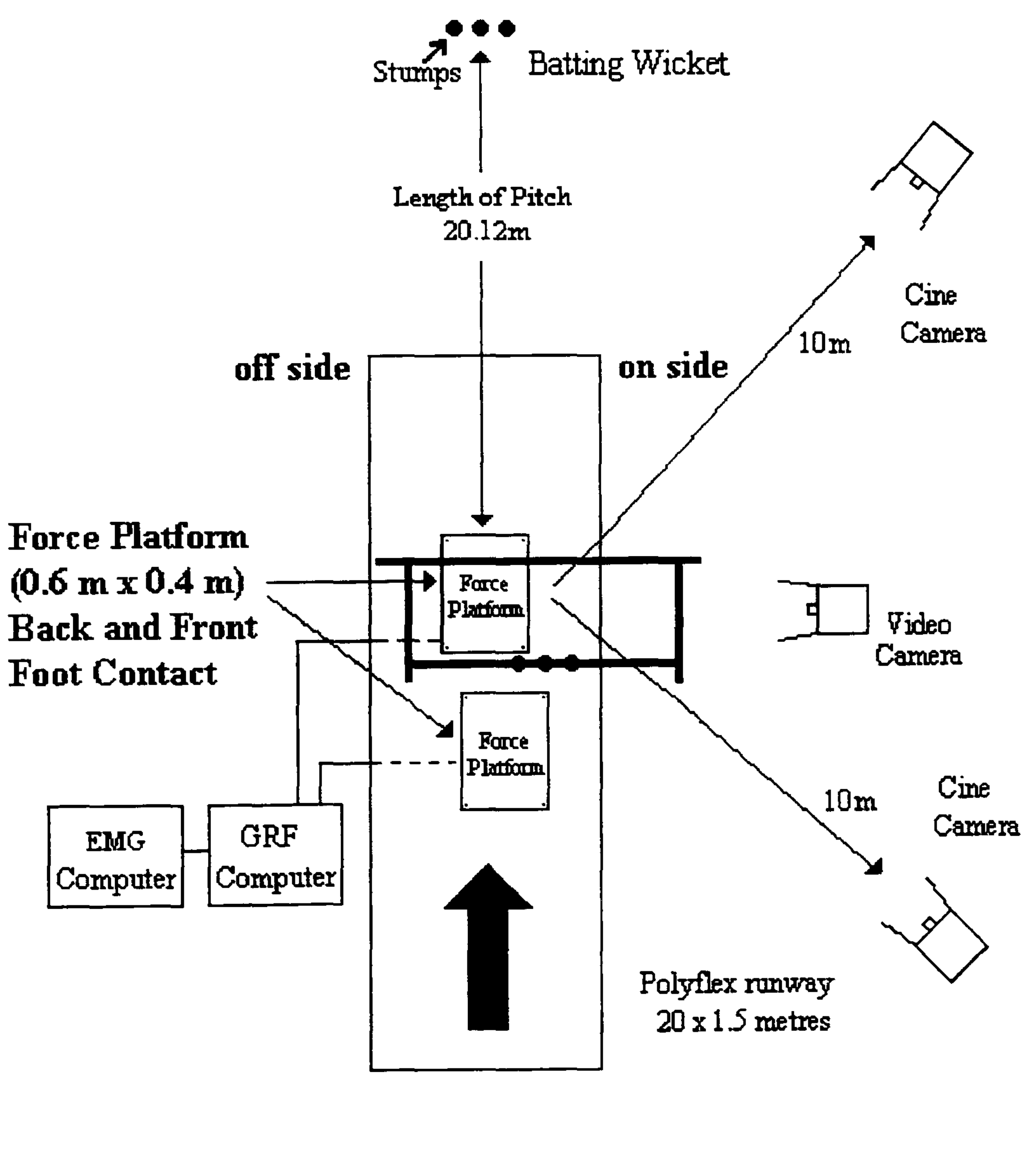
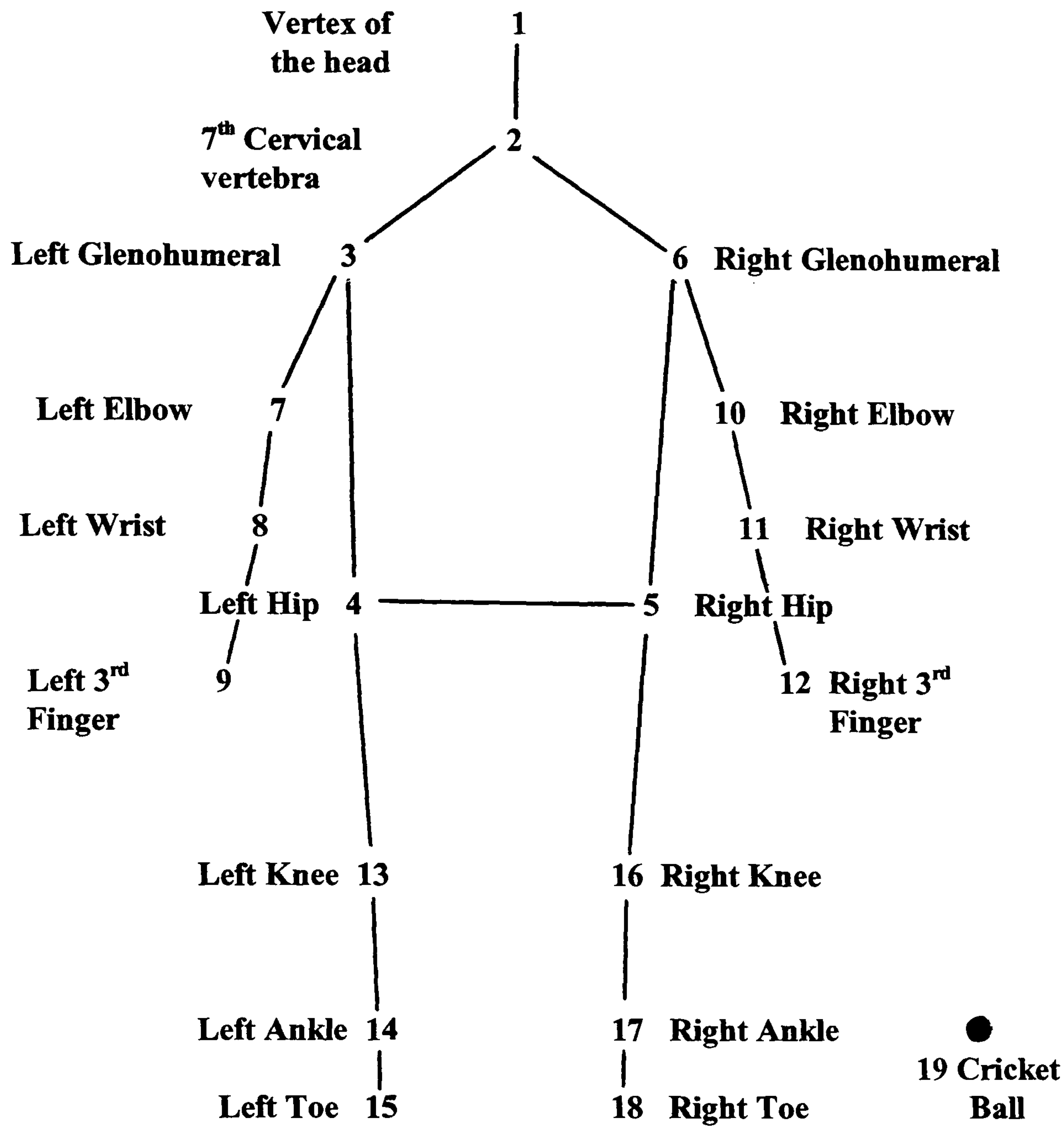


Figure 7.1: A diagrammatic representation of the experimental setting.

Figure 7.2: Digitisation Points



Ground reaction forces The vertical (Fz), anterior-posterior (Fy) and medio-lateral (Fx) ground reaction forces occurring during the final delivery stride for both feet were measured. Two 0.6 m by 0.4 m Kistler type 9851 piezoelectric force platforms were used. Each of the force platforms were situated within a section of a specially designed outdoor polyflex surface (IAAF Standard), 25 m by 1.5 m. Each platform was positioned beneath the surface of the track, with a 0.017 m covering of polyflex on an aluminium sheet mounted to the platform. Force platform data acquired was converted to digital form and sampled at 500 Hz for a three-second period. A 33 MHz 386 Viglen (IBM Compatible) personal computer running Orthodata Pro-vec data acquisition software was used. Each bowler performed their typical bowling action so that both their front and back feet landed on the two Kistler 9851 force platforms located beneath the outdoor polyflex runway (0.017 m depth). The position of the force platforms was adjustable to ensure that the bowler's feet landed in the centres for both the front and back foot force plates respectively. A specially designed force platform rig allowed the correct positioning of the plates to be achieved for each subjects delivery stride pattern (Chichester Institute of Higher Education).

Electromyographical Analysis Due to the importance of the bracing front leg throughout the delivery stride and the motion of the torso, the following muscles were chosen for analysis:

Rectus Abdominis (RA)
Right Lower Latissimus Dorsi (RL)
Left Lower Latissimus Dorsi (LL)
Biceps Femoris (BF)
Rectus Femoris (RF)
Gastrocnemius (medial) (GA)

Medicotest N-50-E disposable electrodes were attached to the skin surface in order to record the electromyogram. Following skin preparation and application procedure detailed in Buchanan *et al.* (1996) skin impedance of typically less than 10 kΩ were routinely achieved. Pairs of electrodes were placed 0.05 m apart over the centre of each muscle with three muscles sharing a reference point. The reference point for the lower body was the patella. The reference point for the lumbar region was the right illiac crest. Each muscle was located by asking the subject to perform appropriate actions against hand resistance (Daniels *et al.* 1956). Each muscle electrode pair was connected to a 4-kΩ pre-amplifier and the pre-amplifier referenced. Each pre-amplifier was connected to a biomedical radiotelemetry transmitter (MIE Medical Research Ltd, Leeds, UK). The transmitter was attached to a belt, worn around the waist of the subject. Pre-amplifiers and wires were secured to the subject with tape ensuring that no restriction was imposed on the subject's movement. The transmitted signals were received by a MTR8 bio-medical telemetry unit positioned beside the runway. The transmitted signals were converted to digital form by an Amplicon PC26AT analogue-to-digital converter. All electromyograms were sampled at 500 Hz. The information was visually scanned and stored on a 33 MHz 486 Viglen (IBM compatible) personal computer running Orthodata Myo-Dat 3.0 software. The computers running the electromyographic and force plate data acquisition programs were synchronised. A single switch started simultaneous data collection on both systems.

Analysis of Data

The analysis was performed for six fast-medium bowlers, two trials from each test condition using the most 'typical' (subject feedback and accuracy of delivery) bowling action for which good quality film was available. Cinematography film was recorded encapsulating the delivery sequence for each subject. After processing, the film was projected, using a Nac analysis projector, onto a TDS High Resolution TP1067 tablet. This was connected to an Archimedes A440/1 microcomputer running Bartlett and Bowen (1993) three-dimensional analysis software. In order to project the image vertically, a prism-rotating lens was fixed to the projector. Three-dimensional scaling, prior to digitisation was carried out using the three-dimensional calibration unit. All deliveries were digitised at a rate of 100 Hz and each delivery used two control points. On average between 60 and 75 frames were digitised per delivery. For all deliveries, digitisation began ten frames prior to back foot contact. Because of the advantages of the technique the cine data was smoothed and calculated velocities and accelerations using cross-validated quintic splines (Woltring, 1986).

A successful trial was characterised by the fact that both feet hit the force platforms during a typical bowling action. Six successful attempts were recorded for each test condition per subject. Electromyography data were recorded simultaneously.

Accuracy of digitising procedure

Prior to any experimental analysis, it was necessary to test the equipment and digitisation procedure for accuracy. One of the recorded cricket deliveries was digitised on three separate occasions, to assess the reliability of the three-dimensional procedure. Experimental error estimates for the variables analysed based on the standard deviations are as follows: (linear speed m s^{-1}): right hip ± 0.2, shoulder ± 0.2, elbow ± 0.3, wrist ± 0.6, finger ± 0.8 and ball ± 0.5: release height ± 0.02 m, delivery stride ± 0.03 m, torso angle at release ± 2.5° and max. torso angle ± 1.9°.

Statistical Analysis

Descriptive statistics were calculated for the key cinematographic variables, ground reaction forces and electromyographical data for both test conditions (see Appendix F). The difference in the mean values (Belt - No Belt) for each variable was calculated for each subject. A set of eight comparisons were used to test for any significant difference between the joint centre speeds and ball release speed for the two test conditions. The Bonferroni technique proposes a reduction in the significance level for each comparison to reduce the likelihood of type I and familywise errors in the set of comparisons. The nominal significance level was set at (P=0.05), hence each independent comparison was tested at $\alpha = .05/8 = 0.006$. The MANOVA technique was considered due to the dependent variables being mutually dependent however, due to the small sample size (n=6) paired t-test comparisons were used.

A further two paired *t*-tests (one-tailed) were used to investigate if there was any significance difference between the relative shoulder-to-hip joint speed and the relative timing of these speeds in the two conditions. A one-tailed test was used because all earlier experiments have shown that athletic performance was not hindered by the use of Belt *B*. Independent group analysis was also used to investigate the progressive linear speeds for both test conditions. See Appendix F.

7.4 Results and Discussion

Cinematography Analysis

Table 7.1 summarises the kinematic variables used for action classification of the six-fast-medium bowlers.

SIDE-ON: A shoulder alignment of 200° or less at back foot contact.

FRONT-ON: A shoulder alignment of greater than 200° at back foot contact. A bowler who has a Hip-to-Shoulder separation at back foot contact <20°.

MIXED: Any bowler who has a Hip-to-Shoulder separation of >20° at back foot contact.

Table 7.1: Kinematic variables used to classify the six medium-fast bowling actions.

		Shoulder Alignment°				Shoulder Separation°		
	Back Foot Angle	BFC	FFC	Ball Release	Change FFC to BR	BFC	FFC	BR
Subject 1 MIXED	319	221	205	286	82	31	-15	34
Subject 2 SIDE-ON	299	189	184	273	88	-11	-20	43
Subject 3 MIXED	324	239	189	281	92	37	-14	42
Subject 4 MIXED	308	216	218	307	89	26	-16	39
Subject 5 FRONT-ON	316	206	206	283	77	13	-19	24
Subject 6 MIXED	317	213	259	299	40	24	-34	40
Mean ±S.E.	314 ±2	214 ±3	210 ±5	288 ±3	77.9 ±4	20.0 ±3	-19.6 ±2	38.5 ±2

BFC : Back Foot Contact FFC : Front Foot Contact BR : Ball Release

Mean ± S.E. of the shoulder alignment for the six fast-medium bowlers were 214 ± 3° and 210 ± 5° at back foot and front foot contacts respectively. Stockill and Bartlett (1992) suggested that the analysis of hip to shoulder separation angles might provide more conclusive and informative results than simply viewing the shoulder angle alone. The Hip-to-Shoulder separation angle at back foot contact was 20.0 ± 3°. Four of the six bowlers reported Hip-to-Shoulder separation angles of greater than 20° at back foot contact. These four bowlers were categorised as having a mixed bowling technique. Subject 3 reported a Hip-to-Shoulder separation angle of 37° at back foot contact. The six fast-medium bowlers can be divided into sub-groups by technique. However, the size of these sub-groups would not be sufficient to analyse the effect of the lumbar support belt on the three bowling techniques observed. For the purpose of this study the six bowlers are investigated as one group.

All six subjects participating in this study, according to Abernethy (1981), are characterised as fast-medium bowlers due to a release speed of between 27 and 36 m s^{-1}. The average peak release speed of the cricket ball was 32.2 m s^{-1} for the belt condition and 31.6 m s^{-1} for the no belt condition. The peak release speed occurred on average 0.01 seconds after release (see table 7.2). The progressive linear increase in peak speed from the mass centre through to the cricket ball for both test conditions was significant at the P=0.001 level. Table 7.2 summarises the peak joint centre speeds during the two test conditions and the results of the paired t-test comparisons. No significant differences were found between the two test conditions.

Table 7.2: Mean Peak Joint Centre Linear Speeds: Approach Velocity (m s^{-1}): Differences (Belt-No Belt): Mean ± S.E.

	Approach Velocity	Mass Centre	Hip	Shoulder	Elbow	Wrist	3rd Finger	Cricket Ball
Belt	5.43 ± 0.30	6.09 ± 0.34	6.47 ± 0.55	8.71 ± 0.39	13.73 ± 0.25	21.80 ± 0.48	25.23 ± 0.62	32.16 ± 0.63
No Belt	5.67 ± 0.27	6.32 ± 0.48	6.79 ± 0.56	8.64 ± 0.36	13.53 ± 0.34	21.71 ± 0.64	25.11 ± 0.68	31.56 ± 0.78
Average Difference	-0.23 ± 0.13	-0.23 ± 0.18	-0.32 ± 0.13	0.07 ± 0.16	0.21 ± 0.30	0.09 ± 0.41	0.13 ± 0.54	0.60 ± 0.63
P value	0.09	0.25	0.06	0.68	0.53	0.83	0.82	0.38

The average mass and hip joint centre speeds were slower (-0.32 m s^{-1}) during the belt condition. However, the average ball release speed was higher during the belt condition (0.60 m s^{-1}). Because of the importance of timing, found during the medicine ball experiment, the relative difference between the shoulder and hip speed for each subject was calculated (see table 7.3). If the belt were going to have an effect on performance then one would expect the most likely difference to occur between the hip and shoulder joints. The peak linear speed of the shoulder joint was 8.71 ± 0.39 m s^{-1} for the belt condition and 8.64 ± 0.36 m s^{-1} for the no belt condition.

Table 7.3: Difference in linear speeds (m s^{-1}) between shoulder-to-hip joints.

	Shoulder-to-Hip Mean ± S.E.
Belt	2.23 ± 0.26
No Belt	1.85 ± 0.25
Difference	0.38 ± 0.12
P value	0.012

Despite no significant differences in the peak linear joint centre speeds, a significant difference ($P<0.05$) is evident between the difference in relative shoulder-to-hip joint speeds during the two test conditions. No differences were found, however, when the time between the peak linear (shoulder-to-hip) were tested ($P=0.13$). Table 7.4 summarises the temporal data associated with the peak linear speeds between the two test conditions.

Table 7.4: Time to peak linear speed (seconds): + Before / - After Point of Ball Release

	Mass Centre	Hip	Shoulder	Elbow	Wrist	3rd Finger	Ball Release	(Shoulder -Hip)
Average (n=24)	+0.26	+0.22	+0.08	+0.04	+0.01	+0.00	-0.01	0.13
Belt (n=12)	+0.27	+0.20	+0.08	+0.05	+0.01	+0.00	-0.01	0.12
No Belt (n=12)	+0.26	+0. 23	+0.09	+0.04	+0.02	+0.01	-0.01	0.15

For the majority of the joint centres performance was very similar, if not identical, in both conditions. It can be seen from the table that for the belt condition, the peak hip linear speed is reached 0.20 seconds before release compared to no belt condition 0.23 seconds. It should also be stated that the peak ball speed cannot occur 0.01 s after release, this is due to the cross-validated quintic smoothing procedure performed on the data. Table 7.5 further summarises important release parameter values that are commonly reported in scientific literature.

Table 7.5: Important kinematic features (Mean ± S.E) of the fast/medium bowling technique: Total = Belt + No Belt : Difference (Belt - No Belt)

	TOTAL	BELT	NO BELT	DIFFERENCE
Back Foot Angle°	314 ± 2.19	313 ± 3.31	314 ± 3.02	-1.50 ± 1.77
Shoulder Alignment°				
BFC	214 ± 3.20	214 ± 4.77	214 ± 3.85	0.08 ± 1.19
FFC	210 ± 5.23	213 ± 8.31	207 ± 6.64	5.33 ± 2.53
Ball Release	288 ± 2.72	290 ± 3.95	286 ± 3.84	3.58 ± 1.64
Change FFC to BR	77.9 ± 4.11	77.2 ± 6.33	78.6 ± 5.52	-1.42 ± 2.30
3D Hip-to-Shoulder° [1]				
BFC	20.0 ± 3.35	18.8 ± 3.68	21.2 ± 4.03	-2.42 ± 2.13
FFC	-19.6 ± 1.57	-20.2 ± 2.48	-18.9 ± 2.86	-1.31 ± 1.69
BR	38.5 ± 1.74	38.7 ± 1.89	38.3 ± 2.07	0.46 ± 1.49
Hip joint speed at BFC ($m\ s^{-1}$)	5.55 ± 0.20	5.43 ± 0.30	5.66 ± 0.27	-0.23 ± 0.11
Contribution (%) to Ball Release	17.4 ± 0.62	16.9 ± 0.86	18.0 ± 0.89	-1.10 ± 0.68
Torso angle at release°	1.00 ± 2.42	0.49 ± 3.47	1.50 ± 3.53	-1.01 ± 0.82
Max. torso angle°	7.69 ± 1.47	7.08 ± 2.22	8.29 ± 1.99	-1.21 ± 0.86
Range of torso [2]	6.69 ± 1.25	6.59 ± 1.51	6.79 ± 2.07	-0.20 ± 1.09
Time (second) :	0.08 ± 0.01	0.09 ± 0.01	0.08 ± 0.01	0.01 ± 0.01
Front Knee Angle°				
FFC	167 ± 1.11	166 ± 1.74	168 ± 1.42	-1.26 ± 1.76
BR	142 ± 4.00	142 ± 5.94	142 ± 5.64	0.23 ± 1.71
(BR-FFC)	-25.1 ± 3.88	-22.4 ± 5.17	-25.7 ± 6.01	3.25 ± 2.24
Back Knee Angle°				
BFC	147 ± 1.41	147 ± 2.07	148 ± 1.97	-1.49 ± 2.27
FFC	137 ± 1.29	137 ± 1.88	138 ± 1.83	-0.65 ± 1.53
BR	102 ± 2.57	103 ± 3.48	102 ± 3.94	0.68 ± 2.78
Release Height (m)	2.00 ± 0.02	2.01 ± 0.03	2.00 ± 0.03	0.01 ± 0.02
% Height	110 ± 0.82	111 ± 1.24	110 ± 1.13	0.50 ± 1.15
Delivery Stride (m)	1.19 ± 0.03	1.18 ± 0.04	1.20 ± 0.04	-0.02 ± 0.02
% Height	65.6 ± 1.33	64.9 ± 1.95	66.3 ± 1.87	-1.33 ± 1.03

[1] 3D Hip-to-Shoulder separation angle° [2] Total angle of torso movement°
BFC: Back Foot contact FFC: Front Foot contact BR: Ball Release

Ground Reaction Forces

Table 7.6 summarises the ground reaction forces of both the back and foot contact during the same delivery stride exhibited by the six fast-medium bowlers.

Table 7.6: Comparison of front / back foot mean peak ground reaction forces ± S.E. and with respect to body weight (BW) of six fast-medium bowlers. (2 conditions)

	No Belt Condition				Belt Condition			
	Back Foot		Front Foot		Back Foot		Front Foot	
	newtons	B.W.	newtons	B.W.	newtons	B.W.	newtons	B.W.
Vertical Fz	1953 ± 89.5	2.38 ± 0.14	4809 ± 920	5.75 ± 0.98	2022 ± 117	2.46 ± 0.18	4873 ± 911	5.82 ± 0.98
Braking Fy –ve	770 ± 122	0.95 ± 0.16	2933 ± 565	3.54 ± 0.67	806 ± 94.6	0.99 ± 0.13	2949 ± 577	3.55 ± 0.69
Propulsive Fy +ve	142 ± 44	0.17 ± 0.05	257 ± 39.2	0.31 ± 0.05	142 ± 44.2	0.17 ± 0.05	263 ± 48	0.32 ± 0.06
Medial Fy –ve	404 ± 66.1	0.49 ± 0.05	548 ± 136	0.65 ± 0.05	484 ± 72.4	0.59 ± 0.05	517 ± 122	0.62 ± 0.06
Lateral Fy +ve	356 ± 78.8	0.45 ± 0.10	380 ± 124	0.46 ± 0.15	337 ± 72.2	0.42 ± 0.10	358 ± 120	0.43 ± 0.14

Back Foot

The peak mean ± S.E. vertical ground reaction forces during the no belt condition was 2.38 ± 0.14 BW with a range of 1.76 to 2.68 BW. Mean peak braking force ranged from 0.20 to 1.23 BW with a mean ± S.E. of 0.95 ± 0.16 BW. The results obtained during the belt condition are very similar to the no belt condition. The peak mean vertical ground reaction forces was 2.46 ± 0.18 BW with a range of 1.64 to 2.88 BW. Mean peak braking force ranged from 0.39 to 1.23 BW with a mean of 0.99 ± 0.13 BW.

Front Foot

The peak mean vertical ground reaction forces during the no belt condition was 5.75 ± 0.98 BW with a range of 2.08 to 9.51 BW. Mean peak braking force ranged from 0.43 to 4.51 BW with a mean of 3.54 ± 0.67 BW. The data obtained during the belt condition are very similar to results for the no belt condition. The peak mean vertical ground reaction force was 5.82 ± 0.98 BW with a range of 2.02 to 9.45 BW. Mean peak braking force ranged from 0.38 to 4.92 BW with a mean of 3.55 ± 0.69 BW.

Peak vertical ground reaction forces obtained during this study are reached on average within 0.02 seconds of front foot contact. The mean peak vertical loading rate for front foot contact was 249 ± 63.8 for the no belt condition and 268 ± 64.8 BW s^{-1} with a range of 551 to 88.2 BW s^{-1}. These mean results are similar to the peak loading rates recorded during Chapter 1 (section 4.4): 277 ± 39.3 BW s^{-1}. Table 7.7 summarises loading rates experienced by the six cricket bowlers.

Table 7.7: Loading Rates for Front and Back Foot contact during the final delivery action of fast-medium bowling in cricket: BW s^{-1} (Two conditions)

	No Belt Condition		Belt Condition	
	Back Foot	Front Foot	Back Foot	Front Foot
Subject 1	85.0 ± 5.7	176 ± 16.6	71.9 ± 16.2	214 ± 15.0
Subject 2	36.2 ± 3.9	154 ± 15.1	41.3 ± 3.4	171 ± 6.9
Subject 3	66.3 ± 6.7	269 ± 16.0	61.7 ± 5.5	297 ± 22.0
Subject 4	30.1 ± 1.0	540 ± 21.9	25.7 ± 1.4	551 ± 18.3
Subject 5	37.1 ± 2.9	255 ± 27.5	51.3 ± 11.6	289 ± 22.7
Subject 6	48.7 ± 2.4	98.0 ± 5.5	54.7 ± 1.8	88.2 ± 5.5
Mean ± S.E.	**50.6 ± 8.6**	**249 ± 63.8**	**51.1 ± 6.6**	**268 ± 64.8**

Approach speed (linear speed of hip joint centre at back foot contact) for the two conditions (Belt 5.43 ± 0.30 m s^{-1}; No Belt 5.67 ± 0.27 m s^{-1}) were not significantly different (P=0.09). The mean peak vertical loading rate for back foot contact was 50.6 ± 8.6 for the no belt condition and 51.1 ± 6.6 BW s^{-1} with a range of 85.0 to 25.7 BW s^{-1}. The range of the results from the back foot contact is very small. This is not the case for the front foot. Subject 6 had a peak mean vertical ground reaction force of 2.73 BW for back foot contact. This compared with a mean vertical ground reaction force of 2.05 BW for front foot contact. However, overall there were no significant differences between the two belt conditions experienced by the same group of six bowlers.

Table 7.8 summarises the average time in contact, time to peak vertical force exhibited during back and front foot contact for the six subjects.

Table 7.8: Time in Contact: Time to Peak vertical force (second)

	No Belt Condition		Belt Condition	
	Back Foot	Front Foot	Back Foot	Front Foot
Time in Contact	0.233 ± 0.02	0.349 ± 0.020	0.230 ± 0.018	0.358 ± 0.016
Time to Peak Vertical Force	0.053 ± 0.006	0.026 ± 0.002	0.054 ± 0.004	0.024 ± 0.002

The major difference between this study and those previously reported is that the ground reaction forces recorded occurred during the same delivery. An example trace of the combined front and back foot ground reaction forces (self scaled) is shown in figure 7.3. It is interesting to note that there is either none or very little overlap (toe off of the back foot to heel strike of the front foot) in the timing of the forces between the front and back foot. Table 7.9 summarises the mean values for the total time in contact with both platforms (back foot contact – toe off front foot) and the overlap time.

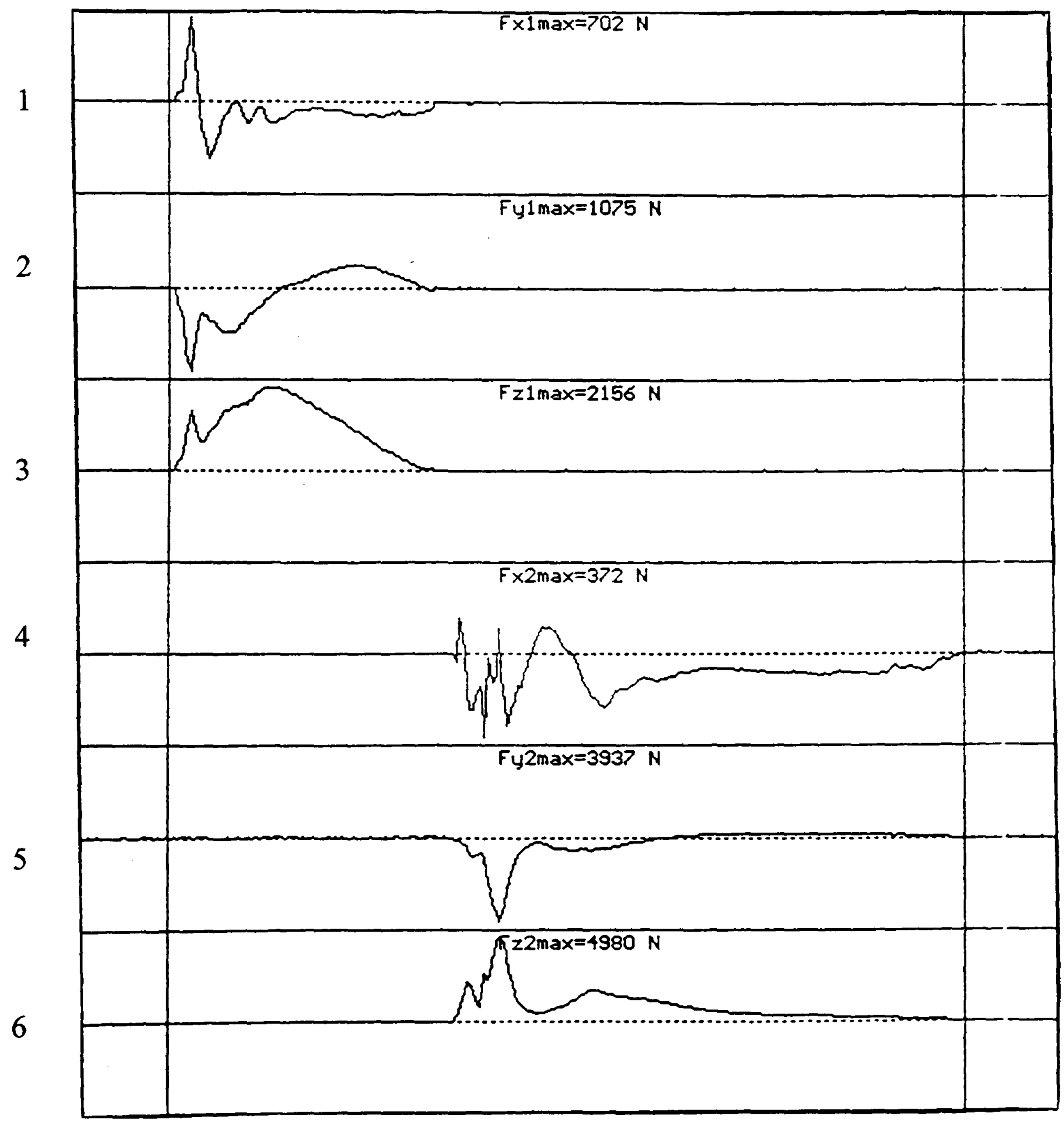
Table 7.9: Total time in Contact (second): Overlap Time (+Overlap -Gap)

	No Belt Condition	Belt Condition
Total Time in Contact (seconds)	0.587 ± 0.037	0.596 ± 0.029
Overlap Time + Overlap -Gap	-0.003 ± 0.012	0.007 ± 0.009

Figure 7.3: Fast-medium bowling: Example trace: Time base = 0.70 second (1-3 Back Right Foot) (4-6 Front Left Foot)

1 : Fx1 Medial / Lateral
2 : Fy1 Braking / Propulsive
3 : Fz1 Vertical
4 : Fx2 Medial / Lateral
5 : Fy2 Braking / Propulsive
6 : Fz2 Vertical

Total time in contact: 0.570seconds / Overlap time : +0.012seconds
Time in contact for back foot: 0.192
Time to peak vertical force for back foot: 0.076
Vertical Loading Rate for back foot: 36.6 BW s^{-1}
Time in contact for front foot: 0.366
Time to peak vertical force for front foot: 0.034
Vertical Loading Rate for front foot: 189 BW s^{-1}



Electromyographical Analysis

The electromyogram traces showed clear sequential and temporal patterns for each individual bowler allowing identification of the muscle recurrent patterns during the bowling action. Differences can be related to the bowling technique of the individual. Maximal electromyographic activity in the belt condition indicated no significant changes to that of the no belt condition. Electromyogram recordings for latissimus dorsi and rectus abdominis are similar to those given by Burden and Bartlett (1990b). It was clear from subject feedback that the lumbar support 'felt different' during the delivery phase of the bowling action. Certain individuals showed differences in maximal electromyographic activity during the support conditions. However, across all six subjects, the average difference between the two conditions was nominal (Table 7.10). During the testing procedures it was not possible to collect a complete set of data for all six subjects. Some athletes sweated more than others due to the environmental conditions resulting in some of the surface electrodes becoming detached. It was not realistic to stop after each delivery and re-attach the electrodes since this would have seriously interrupted the bowling rhythm of the subject. A further difficulty occurred because several of the bowlers had a high level of body fat around the waist. It was therefore not possible to have data from all of the six muscles analysed, for all six subjects.

Table 7.10: Maximal amplitude electromyogram readings during the delivery stride of the fast-medium bowler.

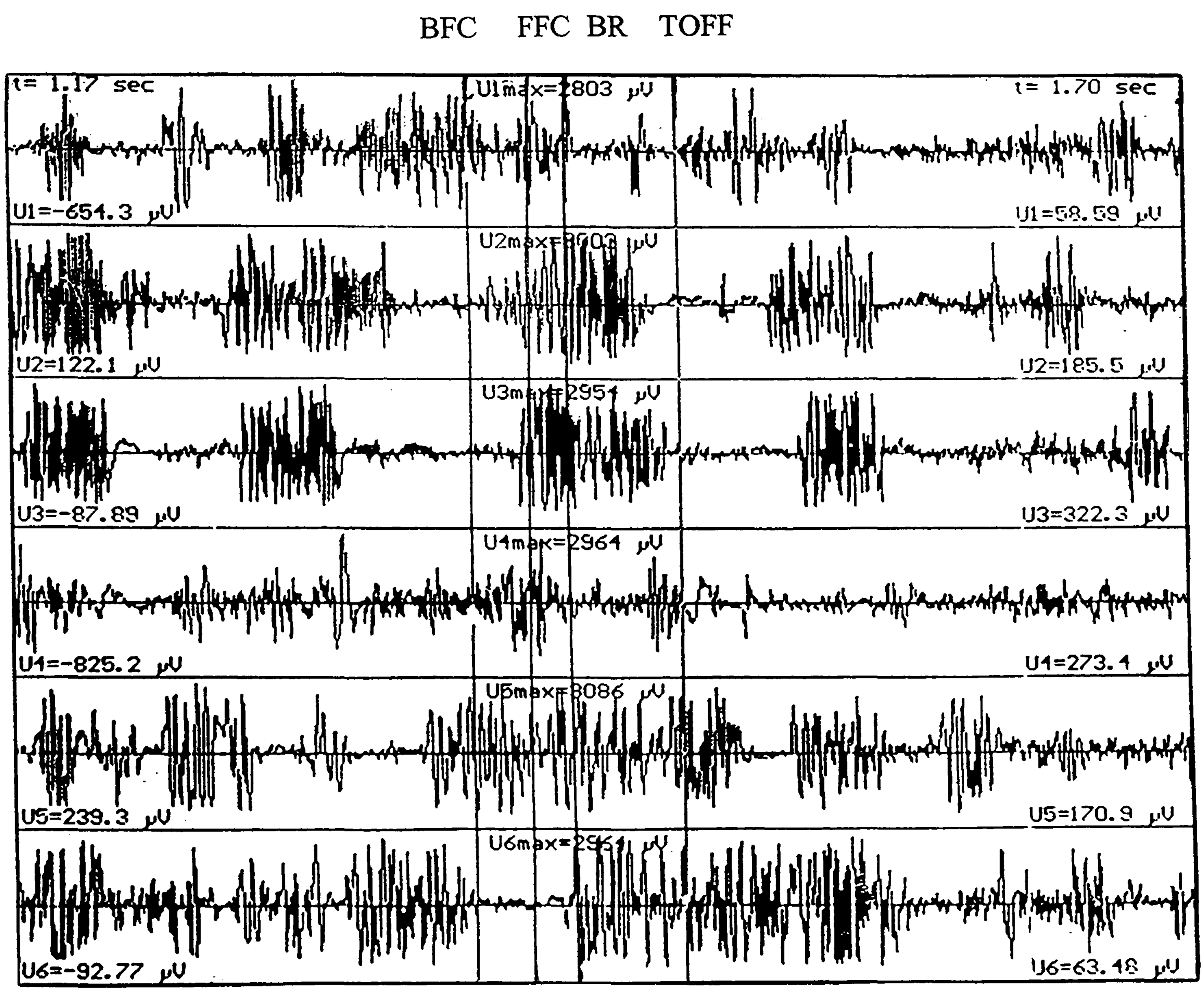
	Rectus Femoris (RF)	Biceps Femoris (BF)	Gastrocnemius (GA)	Rectus Abdominis (RA)	Right Latissimus Dorsi (RL)	Left Latissimus Dorsi (LL)
Belt	2942 ± 75.4	3065 ± 33.2	2956 ± 112	2676 -	3140 ± 95.5	2877 ± 198
No Belt	3060 ± 77.4	3045 ± 32.9	2938 ± 120	3055 ± 169	3034 ± 110	2894 ± 138
Average Difference	-55.1 ± 36.4	19.9 ± 23.3	17.4 ± 43.6	-61.7 -	11.2 ± 109	26.9 ± 31.7

Figure 7.4 is an example electromyogram during the delivery stride of a fast-medium bowler (no belt condition).

Figure 7.4: Fast-medium cricket bowling: Example electromyogram : (1-3 muscle groups are measured on the front (bracing) leg. Time base (3 seconds)

U1 : Rectus Femoris
U2 : Biceps Femoris
U3 : Gastrocnemius
U4 : Rectus Abdominis
U5 : Right Latissimus Dorsi
U6 : Left Latissimus Dorsi

BFC : Back Foot Contact
FFC : Front Foot Contact
BR : Ball Release
TOFF : Toe-off Front Foot



The three leg muscles analysed during the fast-medium bowling action are recorded on the front (bracing) leg. Rectus Femoris is active prior to heel contact with the back foot. Right Latissimus Dorsi is also active during this phase of the throw and remains active during back foot contact, coil position, delivery and follow through. Right Latissimus Dorsi (bowling arm side) was active over the longest duration. Biceps Femoris activity increases after back foot contact, continues to increase in magnitude after front foot contact to near maximal contraction during the release of the cricket ball. Gastrocnemius activity is also maximal during front foot contact and ball release. Both Biceps Femoris and Gastrocnemius activity continues, but at a reduced magnitude after release prior to toe-off with the lead leg. The Rectus Femoris shows minimal activity following front foot contact and remains so throughout the delivery phase. Following front foot contact there was considerable activity in Left Latissimus Dorsi, as the right hand side of the bowler rotates around the braced left side. Left Latissimus Dorsi activity remains constant well into the follow through of the bowler.

7.5 Summary

No significant differences were found in the mass centre, hip, shoulder, elbow, wrist, third finger and final release speed of the cricket ball. However, this study did find a significant difference in the relative speed of shoulder-to-hip joint for the belt condition compared with the no belt condition. This indicates that for a similar run-up speed a bowler using the lumbar support belt can move the torso from a hyperextensive position through to a flexed position at a greater speed. This additional speed caused by the wearing of the lumbar support to the shoulder joint is not, however, carried forward to the remaining parts of the delivery action (elbow, wrist, finger and ball). The lumbar support belt has altered the overall timing and rhythm of the delivery action.

None of the six bowlers participating in this study was familiar with a lumbar support belt of any description. This study suggests that improved bowling performance, notably an increase in shoulder joint speed, would result with the use of *Belt B*. If a bowler were to use the lumbar support belt repeatedly over an extended period of time this may well lead to an increase in ball release speed. Further research into the use of a lumbar support belt needs to consider the effect of training with the support belt on bowling performance. Pre and post biomechanical testing, using an integrated approach, would enable further comparisons to be made.

Chapter 8

EXPERIMENT 5 - JAVELIN THROWING

An investigation into the effect of a lumbar support belt in javelin throwing.

8.1 Introduction

8.2 Experiment 5 : An investigation into the effect of a lumbar support belt in javelin throwing.

8.3 Method

8.4 Results and Discussion

8.5 Summary

8.1 Introduction

The technique of the javelin thrower during the delivery phase of the implement has been discussed in the review of literature and is shown in Appendix A. The kinesiological movements needed by an athlete to throw maximal distances are very strenuous. They require fast, explosive movements, which occur from extensive stretching and pre-tension of the muscles. The physical requirements placed upon the body are a major concern to the athlete. This study will investigate the athletic throwing performance of the javelin thrower. The aim of the experiment is to establish the effect of a re-designed lumbar support (Belt *B*) during the final delivery phase of the throw. Key factors, which influences throwing performance, are the speed and distance in which the torso moves from hyperextension to flexion. If the athlete can increase the speed of the torso through this phase of the throw, it will allow a further increase in the speed of the arm. The emphasis throughout this experiment, as with chapter seven, is the assessment of performance improvement.

8.2 Experiment 5: An investigation into the effect of a lumbar support belt in javelin throwing.

This biomechanical investigation analysed the effect of a lower lumbar support upon six male javelin throwers during their delivery stride. The integrated study utilised the three major biomechanical tools of three-dimensional cinematography, ground reaction forces and electromyography. All three biomechanical tools were synchronised to record the throwing action. The majority of the biomechanical studies investigating the javelin throw have utilised cinematography in reporting upon the critical release parameters for throwing performance. The majority of the research has reported upon the technique of the thrower during elite competition. This study is also unique in the fact that it utilised two force platforms that measured the ground reaction forces of the back foot and front foot during the same delivery stride. Deporte and van Gheluwe (1988) used only one force platform at a time with each subject having to alter their starting position so as to make contact with the platform with either back or front foot.

Two previous studies have investigated muscle activity during the javelin throw. Salchenko and Smirnov (1992) compared muscle activity of skilled and beginner javelin throwers. They recorded electromyographic data from selected glenohumeral joint muscles and lower leg muscles. Tanner (1982) investigated muscular activity of selected torso and upper limb muscles. Tanner reported electromyographic activity during the javelin throw and in addition also analysed a number of recognised javelin training exercises. No previous study has examined synchronised ground reaction forces and electromyographic analysis during the delivery stride of the javelin thrower.

Many international and national athletes wear support belts during training and competition. This study aims to establish the effect on athletic performance made by the lumbar support during an individual's throwing technique. The preceding chapter on fast-medium bowling in cricket showed a significant difference in the relative speed of shoulder-to-hip joint for the belt condition compared with the no belt condition. However, no differences were found in peak linear joint centre speeds and the release speed of the cricket ball.

This will be the first study to address the possible relationship between javelin throwing performance and athletic supports. This aims of this experiment were to:-

(1) Establish the effect of a lumbar support on important kinematic parameters during the delivery phase of the javelin throw, notably the linear speeds of the joint centres and javelin. In addition, the segmental timing of the joints relevant to release of the javelin will also be established.
(2) Determine the speed at which the torso moves from a hyperextended position through to a flexed position prior to the release of the javelin.
(3) Establish the effect of a lumbar support on ground reaction forces and associated temporal data during both back and front foot contact.
(4) Determine the effect of a lumbar support on selected trunk and lower limb muscles.
(5) Establish the sequential and temporal patterns of muscular activity during the delivery phase of the throw.

Six research hypotheses were formulated: H1(1) $\rightarrow$ H1(6) and the following six null hypotheses were tested: Ho(1) $\rightarrow$ Ho(6) during this experiment.

Ho: There will be no significant difference in distance thrown between the two test conditions.
H1: There will be a significant difference in distance thrown between the two test conditions.

Ho: There will be no significant difference in peak linear speeds (javelin release speed (grip), linear speed of mass centre, and linear joint centre speed of the hip, shoulder, elbow, wrist and finger) between the two test conditions.
H1: There will be a significant difference in peak linear speeds (javelin release speed (grip), linear speed of mass centre, and linear joint centre speed of the hip, shoulder, elbow, wrist and finger) between the two test conditions.

Ho: There will be no significant difference in the timing and linear speed between the shoulder and hip joints in the two test conditions.
H1: There will be a significant difference in the timing and linear speed between the shoulder and hip joints in the two test conditions.

Ho: There will be no significant difference in ground reaction forces and associated temporal data experience in either front or back foot contact between the two test conditions.
H1: There will be a significant difference in ground reaction forces and associated temporal data experience in either front or back foot contact between the two test conditions.

Ho: There will be no significant difference in approach velocity between the two test conditions.
H1: There will be a significant difference in approach velocity between the two test conditions.

Ho: There will be no significant difference in the muscle recruitment patterns and magnitude between the two test conditions.
H1: There will be a significant difference in the muscle recruitment patterns and magnitude between the two test conditions.

8.3 Method

Belt Test Conditions

Test Condition 1 = No Belt

Test Condition 2 = Vulkan 3049 *'Belt B'* (Identical belt to Experiment 3A : Section 6.3)

Subjects

Six male javelin throwers (two of club, two of county and two of national standard) Mean ± S.E. 25.6 ± 1.5 yrs; height 1.85 ± 0.05 m; body weight 890 ± 47.1 N) performed their typical throwing action under both test conditions during this study. Each of the six athletes participating in this study had worn, or does wear a lumbar support belt of some description during training or competition.

Experimental Conditions

Athletes performed their typical throwing performance, throwing the 800g javelin into the 40° throwing sector. Every effort was made to ensure each athlete was throwing to his typical competition performance. Subjects wore their personal javelin throwing shoes and clothing. The weather conditions during the testing period consisted of nil wind, with temperatures in the range of 22-27° C (Chichester Institute of Higher Education). All trials were carried out over the period of a month, during the competitive athletic season. Due to the nature of the javelin throw, with its explosive activity, each throw, according to subject feedback was deemed a successful throw, irrespective of whether or not the subject made contact with the force platforms. Typically, between ten and fifteen successful throws were performed by each subject, equally split between the two test conditions.

A successful trial for three-dimensional analysis was determined by feedback from each subject regarding that particular throw. Ground reaction forces and electromyograms were recorded for every attempt. A successful trial, in terms of ground reaction forces, was characterised by either one or both feet making contact with the correct force platform. Subject's feedback regarding the throw was again taken into account. Due to the nature of the javelin event, in that it is so explosive, each subject completed as many throws as possible under both conditions. This typically comprised of between ten and fifteen attempts. Every effort was made to ensure that out of these ten to fifteen attempts, the subject achieved the highest number of contacts as possible with either or both force platforms.

Data Acquisition

Three methods of data collection were used to enable an objective analysis to be made of the way in which lumbar support belts may influence performance. The final delivery stride was filmed using two high-speed cinematographic cameras to allow a three dimensional figure to be created. To improve the understanding of how the lower lumbar support belt may influence the throwing action, the electrical activity of a number of muscles on the torso and lead (bracing) leg were recorded during each throw. Ground reaction forces of both the front foot strike and back foot strike during the same delivery stride were measured. A video recording (Sony Hi8 EVO 9100 P) of the experimental work was also produced. Figure 8.1 is a diagrammatic representation of the experimental setting.

Cinematography Two battery powered Photosonics 500 16 mm cameras, fitted with a 28 mm lens and loaded with Kodak 16 mm Ektachrome 7251 film, were mounted on a tripod at a height of 1.5 m. The two cameras were positioned at an angle of 90°, each at a distance of 10 m to the subject. A twenty-five point, three-dimensional calibration unit, Peak Performance, USA was recorded for each new film at a rate of 50 Hz. A frame rate of 150 frames per second was used to allow detailed analysis of the throwing action. Internal camera timing lights pulsed at 100 per second during filming of the activity. Camera shutter speed and aperture size was determined at the time of filming by using a 'Gossen Six' light meter. The 18 points, defining a 14-segment performer model, plus the 4 additional points on the javelin can be seen in figure 5.5; section 5.3.

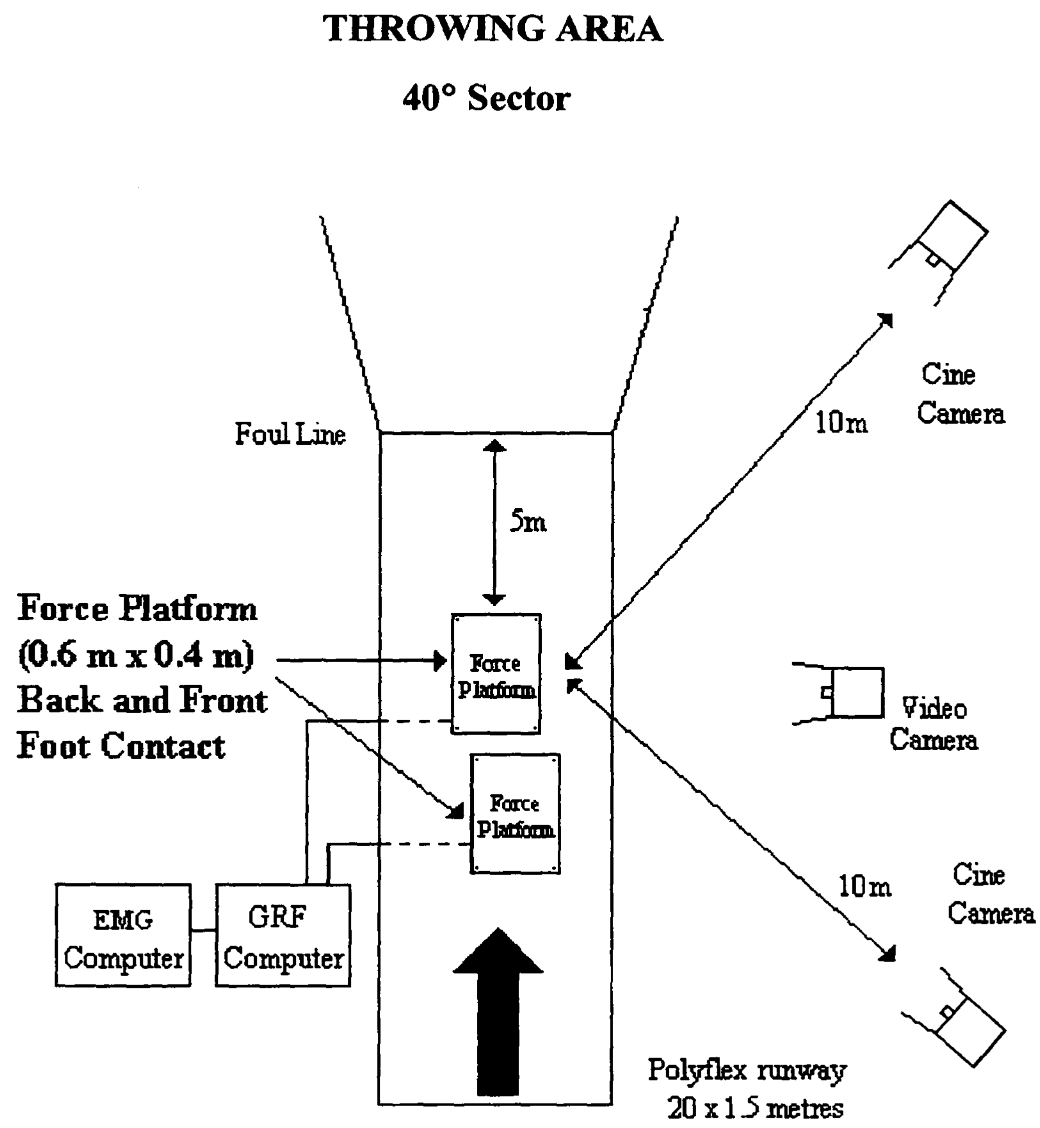


Figure 8.1 : Diagrammatic representation of experimental setting.

Ground reaction forces The vertical (Fz), anterior-posterior (Fy) and medio-lateral (Fx) ground reaction forces occurring during the final delivery stride, for both feet, were recorded. Two 0.6 m by 0.4 m Kistler type 9851 piezoelectric force platforms measured the ground reaction forces of the front and back foot simultaneously using a force platform position mounting system (Chichester Institute of Higher Education). The two force platforms were situated within a section of a specially designed outdoor polyflex surface (International Amateur

Athletic Federation standard). The position of the force platforms were adjustable so to ensure that the feet of each thrower landed in the centres of both the back and the front foot force plates respectively. Each platform was positioned beneath the surface of the track, with a 0.017 m covering of polyflex on an aluminium sheet mounted to the platform. Force platform data acquired was converted to digital form and sampled at 500 Hz for a three-second period. A 33 MHz 386 Viglen (IBM Compatible) personal computer running Orthodata Pro-vec data acquisition software was used.

Electromyographical Analysis Due to the importance of the bracing front leg throughout the delivery stride and the motion of the torso, the following muscles were chosen for analysis: Rectus Abdominis (RA), Right Lower Latissimus Dorsi (RL), Left Lower Latissimus Dorsi (LL), Biceps Femoris (BF), Rectus Femoris (RF) and Gastrocnemius (medial) (GA).

Medicotest N-50-E disposable electrodes were attached to the skin surface in order to record the electromyogram. Following skin preparation and application procedure detailed in Buchanan *et al.* (1996) skin impedance of typically less than 10 kΩ were routinely achieved. Pairs of electrodes were placed 0.05 m apart over the centre of each muscle with three muscles sharing a reference point. The reference point for the lower body was the patella. The reference point for the lumbar region was the right illiac crest. Each muscle was located by asking the subject to perform appropriate actions against hand resistance (Daniels *et al.* 1956). Each muscle electrode pair was connected to a 4-kΩ pre-amplifier and the pre-amplifier referenced. Each pre-amplifier was connected to a biomedical radiotelemetry transmitter (MIE Medical Research Ltd, Leeds, UK). The transmitter was attached to a belt, worn around the waist of the subject. Pre-amplifiers and wires were secured to the subject with tape ensuring that no restriction was imposed on the subject's movement. The transmitted signals were received by a MTR8 bio-medical telemetry unit positioned beside the runway. The transmitted signals were converted to digital form by an Amplicon PC26AT analogue-to-digital converter. All electromyograms were sampled at 500 Hz. The information was visually scanned and stored on a 33 MHz 486 Viglen (IBM compatible) personal computer running Orthodata Myo-Dat 3.0 software. The computers running the electromyographic and force plate data acquisition programs were synchronised. A single switch started simultaneous data collection on both systems.

Analysis of Data

Two trials from each test condition were chosen for kinetic and kinematic analysis for each subject. Cinematography film was recorded encapsulating the delivery sequence for each subject. After processing, the film was projected, using a Nac analysis projector, onto a TDS High Resolution TP1067 tablet. This tablet was connected to an Archimedes A440/1 microcomputer running Bartlett and Bowen (1993) analysis software. In order to project the image vertically, a prism-rotating lens was fixed to the projector. Three-dimensional scaling, prior to digitisation was carried out using the three-dimensional calibration unit. All throws were digitised at a rate of 150 Hz and each throw used two control points to compensate for film movement in the projector. On average between 60 and 75 frames were digitised per throw. For all throws digitisation began ten frames prior to back foot contact. Because of the advantages of the technique the cine data was smoothed and calculated velocities and accelerations using cross-validated quintic splines (Woltring, 1986).

Accuracy of digitising procedure

Prior to any experimental analysis, it was necessary to test the equipment and digitisation procedure for accuracy. One of the recorded throws from a county javelin thrower was digitised on three separate occasions, to assess the reliability of the three-dimensional procedure. Experimental error estimates for the variables analysed based on the standard deviations are as follows: (linear speed m s^{-1}): right hip ± 0.2, shoulder ± 0.3, elbow ± 0.4, wrist ± 0.5, finger ± 0.9 and javelin (grip) ± 0.7: release height ± 0.04 m, delivery stride ± 0.04 m, torso angle at release ± 1.7°, max. torso angle ± 1.3°: Attitude angle at release ± 1°: Front knee angle at front foot contact ± 2.2°.

Statistical Analysis

Descriptive statistics were calculated for the key cinematographic variables, ground reaction forces and electromyographical data for both test conditions (see Appendix G). The difference in the mean values (Belt - No Belt) for each variable was calculated for each subject. A set of nine comparisons were used to test for any significant difference between the distance thrown, (those analysed by three-dimensional cinematography) joint centre speeds and javelin release speed for the two test conditions. The Bonferroni technique proposes a reduction in the significance level for each comparison to reduce the likelihood of type I and familywise errors in the set of comparisons. The nominal significance level was set at (P=0.05), hence each independent comparison was tested at $\alpha = .05/9 = 0.006$. The MANOVA technique was considered due to the dependent variables being mutually dependent, however, due to the small sample size (n=6) paired t-test comparisons were used.

A further two paired t-tests (one-tailed) were used to investigate if there was any significance difference between the relative shoulder-to-hip joint speed and the relative timing of these speeds in the two conditions. A one-tailed test was used because all earlier experiments have shown that athletic performance was not hindered by the use of Belt *B*. Independent group analysis was also used to investigate the progressive linear speeds for both test conditions. See Appendix G.

8.4 Results and Discussion

The average distance thrown for the no belt condition was 58.03 ± 4.00 m. The average distance thrown for the belt condition was 59.75 ± 4.11 m. This resulted in an average difference (Belt - No Belt) of 1.73 ± 0.79 m. This equates to 3% improvement in distance thrown. A paired t-test was used to test the significance of the difference in distance thrown under the two conditions. Table 8.1 shows the distances for the two test conditions for each of the six throwers.

*Table 8.1: Distance (m) *Three-dimensional Cinematography Analysis*

	No Belt	Belt		No Belt	Belt
Subject 1	50.35	51.74	Subject 4	70.23	*77.57
	52.04	*50.98		*76.03	*81.85
	*49.71	49.89		*74.53	74.62
	48.93	52.25		67.50	73.49
	*48.32	*50.63		68.80	72.14
	50.26	53.87			
Average	**49.94**	**51.56**	Average	**71.42**	**75.93**
S.E.	**± 0.53**	**± 0.57**	S.E.	**± 1.65**	**± 1.73**
Average Difference	**+1.63**			**+4.52**	
Subject 2	47.97	52.80	Subject 5	73.54	74.46
	50.92	51.60		*74.88	*77.52
	48.70	57.10		*76.02	*69.20
	*50.46	*54.70		68.53	68.40
	50.83	55.90		67.54	67.92
	52.71	*55.67			
	*49.78	51.35			
		49.45			
Average	**50.20**	**53.57**	Average	**72.10**	**71.50**
S.E.	**± 0.59**	**± 0.94**	S.E.	**± 1.71**	**± 1.91**
Average Difference	**+0.38**			**-0.60**	
Subject 3	48.90	49.56	Subject 6	49.86	51.35
	52.74	50.35		50.44	54.78
	50.88	52.84		52.96	54.50
	51.76	49.76		55.62	*53.68
	50.83	*49.84		*55.28	*59.20
	*50.60	*51.29		*59.53	58.64
	*49.53	50.46			
	49.04				
Average	**50.54**	**50.59**	Average	**53.95**	**55.36**
S.E	**± 0.47**	**± 0.43**	S.E.	**± 1.48**	**± 1.23**
Average Differences	**+0.05**			**+1.41**	

Belt Average	**59.75**	**No Belt Average**	**58.03**
S.E.	**± 4.11**	**S.E.**	**± 4.00**

Average Difference between Belt-No Belt Condition

Average + 1.73 m

± S.E. 0.79 m

t = 2.182

The critical *t* value at the 5% level for 5 DF = 2.015 (one-sided)

Five out of the six throwers recorded greater distances when using the lumbar support. The difference between the belt condition minus the no belt condition for each subject was tested to see if this difference was significantly different from zero. A significant difference in distance thrown between the belt and no belt conditions was found at the $P<0.05$ level. All the results of the experiment, cinematography, ground reaction forces and electromyograms are presented in Appendix G. Individual results, ground reaction forces and electromyograms are also presented in Appendix G.

Cinematography Analysis

Table 8.2 summarises the peak linear joint centre speeds for the six throwers during the two test conditions and the results of the paired t-test comparisons. No significant differences were found in the peak linear speeds of the leading right side of the body joint centres or distance thrown between the two conditions.

Table 8.2: Mean ± S.E Peak Linear Joint Centre Speeds (m s^{-1}): Differences (Belt - No Belt): p value

	Distance (m)	Mass Centre	Hip	Shoulder	Elbow	Wrist	3rd Finger	Javelin (Grip)
Belt	61.01 ± 5.07	6.24 ± 0.13	6.73 ± 0.11	8.79 ± 0.25	14.29 ± 0.66	21.30 ± 0.97	24.63 ± 1.13	25.76 ± 1.33
No Belt	59.56 ± 5.15	6.39 ± 0.25	6.82 ± 0.19	8.59 ± 0.35	14.17 ± 0.58	21.10 ± 0.85	24.52 ± 1.09	25.31 ± 1.51
Average Difference	1.45 ± 1.17	-0.15 ± 0.18	-0.09 ± 0.13	0.20 ± 0.17	0.11 ± 0.38	0.21 ± 0.28	0.12 ± 0.35	0.45 ± 0.38
P value	0.27	0.44	0.53	0.28	0.78	0.49	0.75	0.29

The average peak release speed of the javelin was 25.76 ± 1.33 m s^{-1} for the belt condition, ranging between 30.25 and 22.91 m s^{-1}. The no belt condition had a range of 30.83 and 22.69 m s^{-1} with an average peak release speed of 25.31 ± 1.51 m s^{-1}. Because of the importance of timing, found firstly in the medicine ball experiment (chapter 6) and secondly in cricket bowling (chapter 7), the relative difference between the shoulder-to-hip speed for each subject was calculated (see table 8.3). The average peak linear speed of the shoulder joint equals 8.79 ± 0.25 m s^{-1} and 8.59 ± 0.35 m s^{-1} for the belt and no belt condition respectively.

Due to a slower average approach speed during the belt condition, the difference between the shoulder and hip joints during the belt condition equals 2.06 m s^{-1} compared with only 1.77 m s^{-1} for the no belt condition. Despite no significant differences in the peak linear joint centre speeds, a significant difference (P<0.05) is evident between the relative shoulder-to-hip joint peak linear speeds during the two test conditions (Table 8.3).

Table 8.3: Difference in linear speed (m s^{-1}) between shoulder and hip joints.

	(Shoulder-to-Hip) Mean ±S.E.
Belt	2.06 ± 0.21
No Belt	1.77 ± 0.18
Difference	0.29 ± 0.14
P value	0.046

Table 8.4 summarises the temporal data associated with the peak linear speeds between the two test conditions.

Table 8.4: Time to peak linear speed (seconds): Before / After Point of Release

	Mass Centre	Hip	Shoulder	Elbow	Wrist	3rd Finger	Javelin (Grip)	Shoulder - Hip
Average (n=24)	+0.28	+0.20	+0.09	+0.07	+0.01	+0.00	-0.01	0.11
Belt (n=12)	+0.28	+0.20	+0.09	+0.05	+0.01	+0.00	-0.01	0.12
No Belt (n=12)	+0.28	+0.20	+0.09	+0.09	+0.01	+0.00	-0.01	0.11

No significant difference (P=0.34) in the time to peak linear speeds between the two test conditions is evident between the hip and shoulder joints relative to the release of the javelin, despite the difference in linear speeds (see Appendix G). However, an average difference of 0.04 seconds is evident at the elbow joint. During the no belt condition, on average the shoulder and elbow reach peak linear speed at the same time. In both conditions, the peak linear speed of the wrist, finger and javelin are the same during each throw. It should also be stated that the peak speed of the javelin cannot occur 0.01 s after release, this is due to the cross-validated quintic smoothing procedure performed on the data. Table 8.5 further summarises important release parameter values that are commonly reported in scientific literature.

Table 8.5 : Some important release parameter values during the javelin throw. (Mean ± S.E) : Total = Belt + No Belt : Differences (Belt - No Belt)

	TOTAL	BELT	NO BELT	DIFFERENCE
Attitude Angle at Release [1]	31.2 ± 1.04	30.7 ± 1.90	32.01 ±2.33	-1.61 ±1.16
Shoulder Alignment°				
BFC	174 ± 1.34	174 ± 2.67	174 ± 2.86	-0.50 ± 0.72
FFC	191 ± 1.64	192 ± 3.63	191 ± 2.58	1.25 ± 3.10
Release	280 ± 1.25	280 ± 2.72	281 ± 1.87	-0.58 ± 1.84
Change FFC to R	88.8 ± 1.94	87.9 ± 3.04	89.8 ± 4.06	-1.83 ± 2.60
3D Hip-to-Shoulder° [2]				
BFC	-33.0 ± 2.62	-33.1 ± 5.49	-32.8 ± 5.48	-0.31 ± 1.50
FFC	-31.9 ± 1.68	-31.4 ± 2.88	-32.3 ± 3.37	0.87 ± 2.56
Release	4.70 ± 5.73	4.77 ± 12.6	4.64 ± 11.9	0.13 ± 0.91
Hip joint speed at BFC ($m\ s^{-1}$)	5.95 ± 0.09	6.00 ± 0.18	5.91 ± 0.15	0.09 ± 0.06
Torso angle at Release°	10.3 ± 3.16	9.91 ± 6.82	10.6 ± 6.66	-0.69 ± 0.47
Max. torso angle°	4.93 ± 4.93	5.32 ± 4.26	4.54 ± 4.49	0.77 ± 1.02
Range of torso [3]	19.2 ± 2.25	19.5 ± 4.38	19.0 ± 5.17	0.54 ± 1.03
Time (second) :	0.23 ± 0.01	0.23 ± 0.02	0.23 ± 0.02	-0.00 ± 0.00
Front Knee Angle°				
FFC	167 ± 0.94	167 ± 1.35	166 ± 1.29	0.68 ± 1.64
Release	157 ± 2.42	155 ± 3.88	160 ± 4.40	-5.75 ± 1.45
(R-FFC)	-9.38 ± 2.33	-12.6 ± 3.90	-6.17 ± 3.94	-6.43 ± 1.06
Back Knee Angle°				
BFC	139 ± 2.22	140 ± 4.96	138 ± 4.26	1.55 ± 1.44
FFC	139 ± 1.36	140 ± 2.59	138 ± 2.83	1.62 ± 1.91
Release	123 ± 3.19	121 ± 6.59	124 ± 6.41	-3.17 ± 1.36
Release Height (m)	1.96 ± 0.02	1.95 ± 0.03	1.96 ± 0.04	-0.01 ± 0.02
% Height	107 ± 0.65	107 ± 1.05	108 ± 1.35	-0.42 ± 0.88
Delivery Stride (m)	1.36 ± 0.04	1.37 ± 0.10	1.36 ± 0.09	0.01 ± 0.01
% Height	74.0 ± 2.05	73.8 ± 4.54	74.3 ± 4.06	-0.50 ± 1.10

[1] Javelin attitude angle at the point of release°
[2] 3D Hip/Shoulder Separation angle°
[3] Total angle of torso movement°
BFC : Back Foot contact FFC : Front Foot contact R : Release

Ground Reaction Forces

Table 8.6 summarises the ground reaction forces of both the back and foot contact during the same delivery stride exhibited by the six javelin throwers.

Table 8.6: Javelin Throwing: Comparison of front / back foot mean peak ground reaction forces (B.W.) ± S.E. of six javelin throwers. (2 conditions)

	No Belt Condition				Belt Condition			
	Back newtons	Foot B.W.	Front Newtons	Foot B.W.	Back newtons	Foot B.W.	Front Nnwtons	Foot B.W.
Vertical Fz	2035 ± 179	2.28 ± 0.18	5069 ± 420	5.69 ±0.43	2084 ± 149	2.35 ± 0.19	5015 ± 340	5.65 ± 0.42
Braking Fy –ve	947 ± 154	1.05 ± 0.15	4065 ± 300	4.58 ±0.34	958 ± 172	1.07 ± 0.18	4011 ± 227	4.53 ± 0.31
Propulsive Fy +ve	321 ± 64.0	0.31 ± 0.08	253 ± 40.1	0.26 ±0.03	346 ± 61.7	0.33 ± 0.08	307 ± 84.1	0.32 ± 0.08
Medial Fx –ve	258 ± 51.2	0.30 ± 0.08	624 ± 90.7	0.71 ±0.03	277 ± 65.6	0.32 ± 0.08	603 ± 57.3	0.67 ± 0.08
Lateral Fx +ve	431 ± 108	0.43 ± 0.10	553 ± 51.1	0.68 ±0.09	475 ± 109	0.46 ± 0.09	587 ± 60.2	0.70 ± 0.07

Back Foot Contact

The peak mean ± S.E vertical ground reaction forces during the no belt condition were 2.28 ± 0.18 BW with a range of 1.80 to 2.89 BW. Mean peak braking force ranged from 0.51 to 1.43 BW with a mean ± S.E of 1.05 ± 0.15 BW. The results obtained during the belt condition were very similar to those recorded during the no belt condition. The peak mean ± S.E vertical ground reaction forces were 2.35 ± 0.19 BW with a range of 1.84 to 3.16 BW. Mean peak braking force ranged from 0.33 to 1.52 BW with a mean ± S.E of 1.07 ± 0.18 BW. Peak vertical ground reaction forces obtained during this study are reached on average within 0.04 seconds of back foot contact. The mean peak vertical loading rate for back foot contact was 51.5 ± 8.8 for the no belt condition and 56.1 ± 7.4 BW s^{-1} with a range of 22.2 to 80.5 BW s^{-1}. Table 8.7 summarises the loading rates experienced by the six athletes.

Table 8.7: Loading Rates for Front and Back Foot contact during the final delivery action of javelin thrower: BW s^{-1} (Two conditions)

	No Belt Condition		Belt Condition	
	Back Foot	Front Foot	Back Foot	Front Foot
Subject 1	30.3 ± 2.6	215 ± 10.3	32.9 ± 2.8	220 ± 9.7
Subject 2	22.2 ± 0.5	314 ± 26.8	68.6 ± 27.7	295 -
Subject 3	65.8 ± 5.0	97.3 ± 2.6	80.5 ± 10.2	112 ± 4.8
Subject 4	38.8 -	198 ± 0.9	53.9 -	141 -
Subject 5	75.2 ± 35.6	297 -	32.8 -	273 ± 11.1
Subject 6	76.0 ± 4.91	132 ± 7.6	68.1 ± 6.0	134 ± 11.3
Mean ± S.E.	**51.5 ± 8.8**	**209 ± 32.2**	**56.1 ± 7.4**	**196 ± 28.9**

Front Foot Contact

The peak mean ± S.E. vertical ground reaction forces during the no belt condition were 5.69 ± 0.43 BW with a range of 4.16 to 7.00 BW. Mean peak braking force ranged from 3.55 to 5.74 BW with a mean ± S.E. of 4.58 ± 0.34 BW. The data obtained during the belt condition, as with the back foot, were very similar to results of the belt condition. At a mean approach velocity of 5.96 m s^{-1} the peak mean ± S.E. vertical ground reaction forces were 5.65 ± 0.42 BW with a range of 4.47 to 7.08 BW. Mean peak braking force ranged from 3.61 to 5.67 BW with a mean ± S.E. of 4.53 ± 0.31 BW.

Peak vertical ground reaction forces obtained during this study are reached on average within 0.02 seconds of front foot contact. The mean peak vertical loading rate for front foot contact was 209 ± 32.2 for the no belt condition with a range of 314 to 97.3 BW s^{-1}. The mean peak vertical loading rate for the belt condition was 196 ± 28.9 BW s^{-1} with a range of 273 to 112 BW s^{-1}. The wide range of loading rates reflects the individual nature the javelin throwing technique of each athlete. Due to the nature of the javelin event, every effort was made to ensure that out of the ten to fifteen attempts each subject typically made, the subject achieved the highest number of contacts as possible with either or both force platforms. Each athlete made at least one successful (with either back or front foot) contact for each condition (see Appendix G).

Approach speed (linear speed of hip joint centre at back foot contact) for the two conditions (Belt 6.00 ± 0.43 m s^{-1}; No Belt 5.91 ± 0.37 m s^{-1}) were not significantly different (P=0.20) (see Appendix G). Overall, the two belt conditions showed very little differences in ground reaction forces, loading rates and associated temporal data during both back and front foot contact.

Table 8.8 : Time in Contact : Time to peak vertical ground reaction force (s)

	No Belt Condition		Belt Condition	
	Back Foot	**Front Foot**	**Back Foot**	**Front Foot**
Time in Contact	0.268 ± 0.017	0.428 ± 0.016	0.280 ± 0.015	0.448 ± 0.040
Time to Peak Vertical Force	0.055 ± 0.006	0.032 ± 0.003	0.048 ± 0.006	0.034 ± 0.003

An example trace of the combined front and back ground reaction forces (self scaled) is shown in Figure 8.2. It is interesting to note that there is considerably more overlap (toe off for the back foot to heel strike for the front foot) in the timing of the forces than there was evident during Experiment 4 (fast-medium bowlers in cricket: section 7.4). Table 8.9 summarises the total time in contact (back foot contact to toe off front foot) and the overlap time (toe off back foot to heel contact front foot).

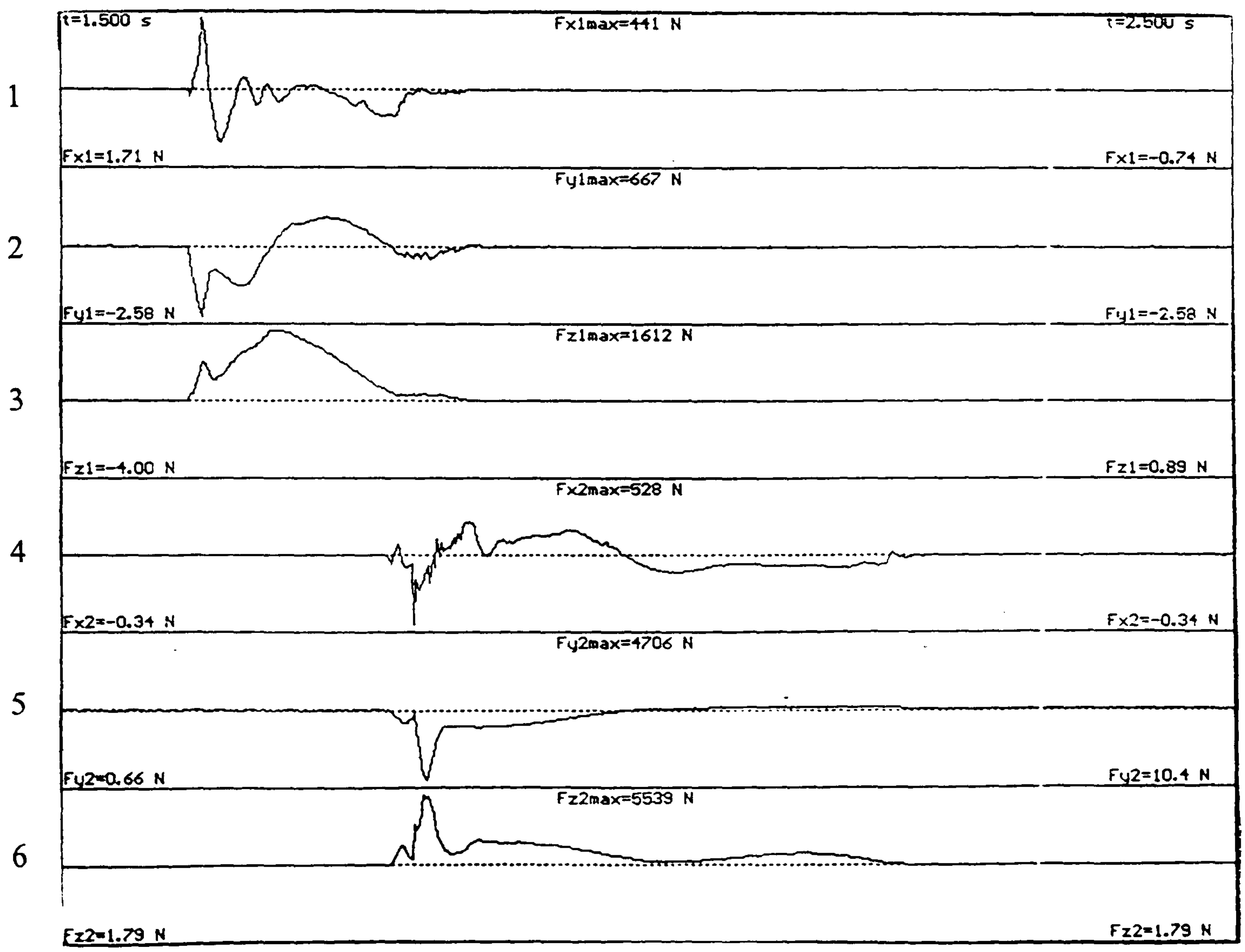
Table 8.9: Total time in Contact (s): Overlap Time (s) (+Overlap -Gap)

	No Belt Condition	**Belt Condition**
Total Time in Contact	0.625 ± 0.021	0.672 ± 0.043
Overlap Time + Overlap -Gap	+0.078 ± 0.015	+0.073 ± 0.021

Figure 8.2: Javelin Throwing: Example Trace : Time base = 1 second
(1-3 Back Right Foot) (4-6 Front Left Foot)

1 : Fx1 Medial / Lateral
2 : Fy1 Braking / Propulsive
3 : Fz1 Vertical
4 : Fx2 Medial / Lateral
5 : Fy2 Braking / Propulsive
6 : Fz2 Vertical

Total time in contact : 0.626seconds / **Overlap** time : +0.074seconds
Time in contact for back foot : 0.242
Time to peak vertical force for back foot : 0.076
Vertical Loading Rate for back foot : 27.1 BW s^{-1}
Time in contact for front foot : 0.458
Time to peak vertical force for front foot : 0.032
Vertical Loading Rate for front foot : 221 BW s^{-1}



Electromyographical Analysis

The electromyograms show clear sequential and temporal patterns for each individual thrower allowing identification of the muscle recurrent patterns during the throwing action. Differences can be related to the individual's technique. It was clear from subject feedback that the lumbar support 'felt different' during the delivery phase of the throwing action. Certain individuals showed differences in maximal electromyographic activity during the support conditions. However, across all six subjects, no differences were evident.

During the testing procedures it was not possible to collect a complete set of data for all six subjects. Some athletes sweated more than others due to the environmental conditions, which resulted in some of the surface electrodes becoming detached. It was not realistic to stop after each throw and re-attach the electrodes since this would have seriously interrupted the subject's rhythm. A further difficulty occurred because several of the athletes had a high level of body fat around the waist. These are two problems, which are very difficult to overcome in the practical testing situation. It was therefore not possible to have data form all of the six muscles analysed, for all six subjects. See Appendix G for data for each individual subject.

Table 8.10 summarises the maximal amplitude peak to peak electromyographic activity during the final delivery stride. (N.B. No data was available for subject No.5)

Table 8.10: Maximal amplitude of electromyographic activity during the final delivery stride of the javelin throw (Mean ± S.E.)

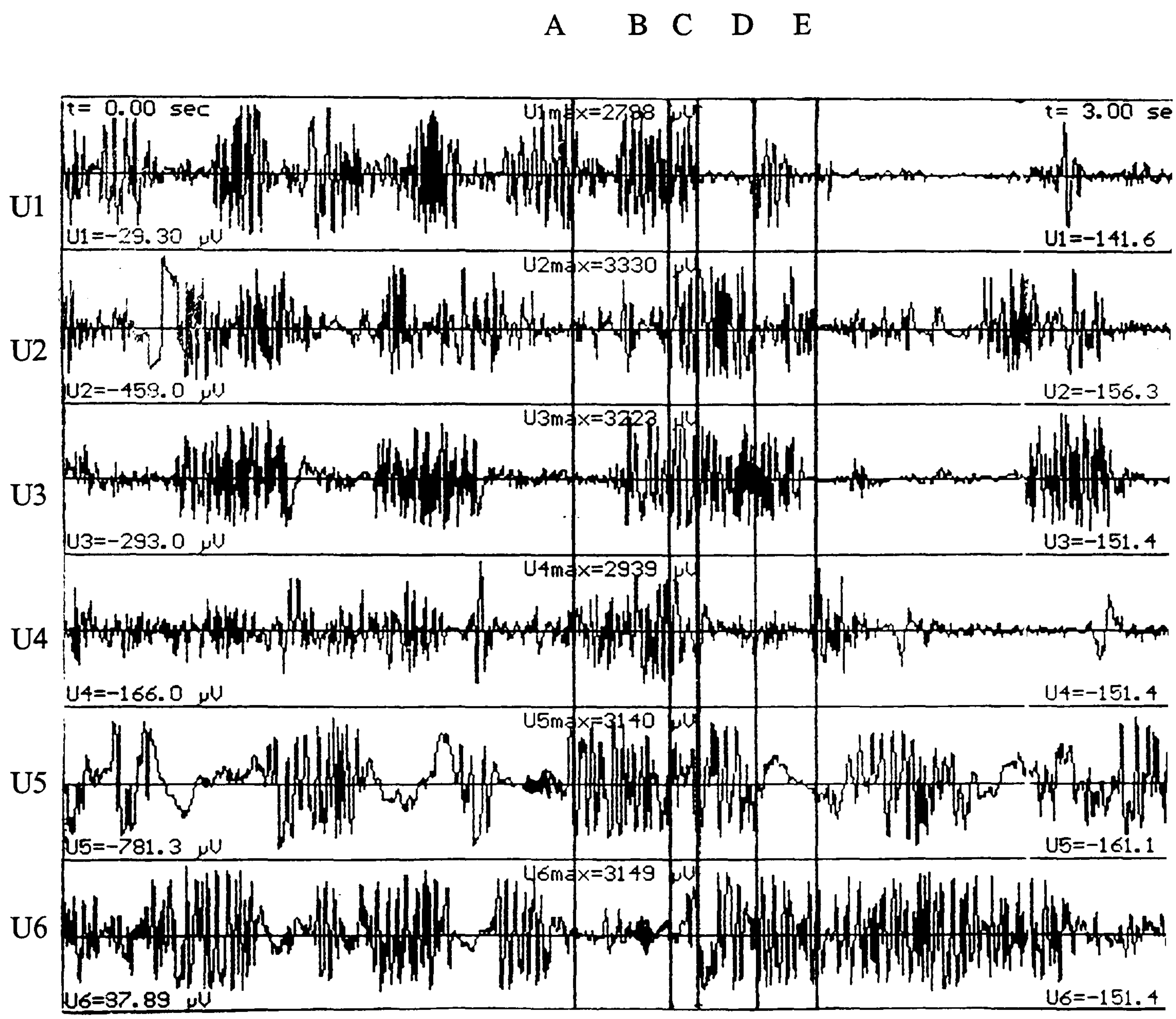
	Rectus Femoris (RF)	Biceps Femoris (BF)	Gastrocnemius (GA)	Rectus Abdominis (RA)	Right Latissimus Dorsi (RL)	Left Latissimus Dorsi (LL)
No Belt	2953 ± 71.5	3114 ± 70.5	2902 ± 79.2	2988 ± 113	3143 ± 31.5	3184 -
Belt	3037 ± 84.1	3102 ± 59.1	2955 ± 69.7	2970 ± 55.5	3101 ± 58.8	3087 -
Average Difference	83.9 ± 38.6	-6.17 ± 35.6	52.6 ± 33.9	-18.7 ± 42.7	-42.7 ± 27.3	-96.2 -

Figure 8.3 is an example electromyogram recorded during the final delivery stride of the javelin throw.

Figure 8.3: Javelin Throwing: Example electromyogram: Time base = 3 seconds (1-3 muscle groups are measured on the left front (bracing) leg.

U1 : Rectus Femoris
U2 : Biceps Femoris
U3 : Gastrocnemius
U4 : Rectus Abdominis
U5 : Right Latissimus Dorsi
U6 : Left Latissimus Dorsi

A) 'Back' Foot Contact
B) 'Front' Foot Contact
C) Toe off 'Back' Foot
D) Release of Javelin
E) Toe off 'Front' Foot



The three leg muscles analysed during the javelin throw are recorded on the front left (bracing) leg. Rectus Femoris is active during the crossover phase, prior to heel contact with the back foot. Immediately after back foot contact, Rectus Femoris activity on the bracing front leg reduces marginally before peak activity in the muscle prior to front foot contact. During this phase of the throw maximal activity occurs in the Right Latissimus Dorsi and remains so throughout back foot contact, the power position and release of the javelin. Gastrocnemius is active before and during front foot contact. Biceps Femoris is active during flexion of the knee following front leg heel contact until javelin release. Maximal contraction of the Biceps Femoris occurs during toe of back foot through to the release of the javelin. Both the Biceps Femoris and Gastrocnemius muscles are active after the release of the javelin, prior to toe-off with the front foot but at a considerably reduced magnitude. The Rectus Femoris is active as the front left leg extends prior to heel contact. The Right Latissimus Dorsi is active until the javelin is released. Left Latissimus Dorsi activity remains constant during release as the right hand side rotates around the braced left side of the athlete and well into the recovery phase of the throw. Rectus Abdominis is most active as the trunk flexes forwards prior to back foot toe-off.

8.5 Summary

The wearing of the lumbar support belt resulted in a significant increase ($P<0.05$) in distance thrown (see table 8.1). The trials analysed by three-dimensional cinematography (as indicated by *) although not significant ($P=0.27$) did, however, show a similar improvement in distance of 1.45 m during the belt condition. Subject 4 had the greatest average improvement (4.43 m) in throwing distance during the belt condition, with an average increase in release speed of 1.17 m s^{-1}. Subjects 4 and 5 have noticeably higher release speeds than the remaining four athletes.

The vertical ground reaction forces reported during back foot contact in this study are considerably lower, (2.32 BW) than those reported by Deporte and van Gheluwe (1988). They reported maximal vertical ground reaction forces of up to

9.1 times body weight at back foot contact, with a mean value of 6.65 kN. The mean peak braking force reported was 4.07 kN. The vertical ground reaction forces reported during front foot contact obtained during this study (5.7 BW) are, however, lower than those reported by Deporte and van Gheluwe (1988) (6.6 BW) but considerably higher those reported by Bartlett *et al.* (1995) at 2.8 BW. Peak anterior-posterior forces reported in this thesis were double to those reported by Deporte and van Gheluwe (1988), 4.03 kN compared to 2.0 kN. This study would suggest that due to the importance of both feet during the delivery phase of the javelin throw, plus the wide range of results reported in the literature, that the ground reaction forces and associated temporal data be further investigated. The major difference between this study and that of Deporte and van Gheluwe (1988) and Bartlett *et al.* (1995) is that the ground reaction forces were recorded during the same delivery. This may account for some of the variations in the ground reaction forces. However, the surface on top of the force platform should be standardised to enable all the biomechanical literature to be compared.

Differences in electromyographic patterns can be related to the technique of the individual. It was clear from subject feedback that the lumbar support 'felt different' during the delivery phase of the throwing action. Nonetheless, across all six subjects no differences were evident in magnitude. Certain individual differences were evident in maximal muscle activity during the lumbar support belt condition.

Lumbar support belts have gained in popularity because of their attributed benefits of injury prevention. However, it appears from subjective comments by the athletes that they provide support which aids throwing performance. In this javelin experiment there is evidence that the wearing of a lumbar support belt alters body movements. No significant differences were found in the mass centre, hip, shoulder, elbow, wrist, third finger and final release speed of the javelin. Nevertheless, a significant difference was reported in the relative speed of shoulder-to-hip joint between the two test conditions. For a similar approach speed, the athlete using the belt is able to move from a hyperextended position through to a flexed position at a greater rate. This movement creates the initial stage of acceleration for the throw. The additional speed attributed by the lumbar support through to the shoulder joint is, however, not transferred to the remaining lighter segments of the body (elbow, wrist, finger and javelin). The lumbar support has altered the overall timing and rhythm of the throwing action.

The relative timing of the segmental movements is important to determine the effect of the lumbar support on athletic performance. For each of the joint centres of segment end-points only the time and magnitude are analysed. Future research in this area should use methods that preserve the richness of the time series data, such as conjugate cross-correlations. For example, by overlaying the linear speed of the right wrist joint (belt / no belt) direct comparisons throughout the time series of the throw could be addressed, rather than just the peak figures of the two conditions.

This study suggests that athletic performance, notably an increase in the throwing distance would result with repeated use and experience of wearing the lumbar support. Training and competing in the lumbar support could lead to the change in timing required. This would enable the increase in shoulder speed to be transferred to the lighter faster moving parts of the body.

Chapter 9

CONCLUSIONS AND FURTHER RECOMMENDATIONS

Conclusions

In the introduction to this study, two specific aims were outlined for research and experiment. The results are set out in the following paragraphs.

Biomechanical analysis of the technique of the individual in order to assess injury potential was the first aim of this doctoral thesis. A series of experiments considered the use of neoprene supports and how they may effect the delivery phase of the fast-medium cricket bowler and javelin thrower. Biomechanical investigations into fast-medium bowling and javelin throwing highlighted the high ground reactions forces and loading rates exhibited during front foot contact for both activities. No significant differences in peak ground reaction forces, associated temporal data and loading rates were evident as a result of wearing athletic supports for both fast-medium bowling and javelin throwing. Loading rates measured during the neoprene support conditions, were typically lower than for the no support condition, but were not significant. If loading rates could be reduced as a result of wearing a neoprene support, it may assist those bowlers prone to repeated injury.

No significant differences in maximal electromyographic activity were evident as a result of wearing athletic supports for both fast-medium bowling and javelin throwing. It was clear from subject feedback that during the delivery phase of the bowling and throwing movement, certain support conditions felt different. A number of individuals showed differences in maximal electromyographic activity during the athletic support conditions. Although no significant differences were found for any of the muscles analysed, there was an indication that the back support altered muscle activity in the lumbar region.

The results from chapter 5 showed an average increase in javelin throwing distance of 7.44 m as a result of wearing a lumbar support belt (*Belt B*). An increase in release speed and an increase in peak speeds of the body segments were also achieved. A possible change in throwing dynamics caused by the wearing of *Belt B* is indicated by the identification of a significantly different linear trend of the peak speeds from the hip to the javelin grip. Although changes were observed in throwing dynamics between the two belt conditions (*A* and *B*) and the no belt condition (*C*), there was no systematic evidence from the studies of electromyographic activity to suggest that muscle activity was altered between test conditions *A*, *B* and *C*.

These two preliminary investigations highlighted the high ground reaction forces and loading rates exhibited during front foot contact for both sporting activities. It also became clear, after these two experiments that research into the assessment of injury potential and prevention, involving the use of athletic supports, required a longitudinal approach. A survey incorporating a training and competition diary would be required to be able to state whether or not athletic supports reduced injury occurrence in the long-term. This assessment of long-term injury risk due to use of athletic supports was beyond the scope of this thesis and is an area for future research. However, results obtained during this thesis did not give any reason to indicate that athletic supports increased the risk of injury to either the fast-medium bowler or javelin thrower.

The remaining experiments of this doctoral research focused on the second aim of the thesis, the performance of the individual and focused on the reason for the improved performance measured when a lumbar support belt was worn.

Due to the large number of external variables that influence the final distance thrown of the javelin and release speed of the cricket ball, a simplified experiment was designed to specifically investigate the lumbar support (Belt *B*). The object was to measure the performance (distances thrown) under two conditions, belt and no belt. An average improvement of 0.33 m was found during the belt condition. The ability to train and become accustomed to the belt may also be a significant factor in the performance of an athlete. The confidence given to an experienced subject, whilst wearing a support belt may further influence their performance. Further investigation was undertaken to measure the effect of the lumbar support belt on the medicine ball throwing performance of experienced subjects. In addition to the distance thrown, two-dimensional cinematography was used in order to analyse the kinematic variables associated with performance. The lumbar support considerably improved throwing distance for both the novice (3%) and experienced (4%) groups. No significant differences in the peak joint centre speeds and release speed of the medicine ball were found between the belt and the no belt conditions for both the novice and experienced groups. This study did suggest, however, that the lumbar support might help with the overall timing of the medicine ball throw. A difference in the segmental timing was evident between the hip and shoulder joints. However, this difference was not evident during the final part of the throw at the elbow, wrist and finger joints. The next stage entailed two similar experiments that focused on the effect of the re-designed lumbar support belt *(Belt B)* during the final delivery phase of the fast-medium bowler and the javelin thrower.

Six fast-medium bowlers (chapter 7) showed no significant differences between the two test conditions in the peak linear speeds of the mass centre, hip, shoulder, elbow, wrist, third finger and the final release speed of the cricket ball. However, this study found a significant difference in the relative speed of shoulder to hip joint for the belt condition compared with the no belt condition. This indicates that for the same run up speed a bowler using the belt is likely to get a higher relative rate of hyperextension-flexion of the torso. The additional speed attributed by the lumbar support belt through to the shoulder joint could not be carried forward to the remaining lighter segments of the body. This, one would suspect is due to the lack of timing in the bowling action and the lack of familiarity with wearing a lumbar support belt. The performance of the fast-medium bowlers may possibly improve with additional familiarity of the lumbar support belt. This is an area of future research. Repeated bowling using the lumbar support belt may lead to the change in timing needed, to be able to transfer the increased shoulder speed, to lighter faster moving parts of the body and cricket ball. Each of the six fast-medium bowlers participating in the study indicated their preference to the use of the lumbar support belt with comments such as;

“it felt as if there was more protection to the back, particularly the lower right hand side”;
“it kept the bowling position upright and able to transfer forward momentum to the release of the ball”;
“it makes you feel taller, more upright, deliver from a higher position”;
“it stops you falling away prior to delivery.”

A significant difference in the distance thrown in the javelin experiment (chapter 8) was found at the 5% level when all throws were used for the analysis. Those trials analysed by cinematography, although not significant (P=0.20) did, however, show a similar improvement in distance (1.45 m) during the belt condition. No significant differences were found in the mass centre, hip, shoulder, elbow, wrist, third finger and final release speed of the javelin. However, this study indicated a significant difference in the relative speed of shoulder to hip joint between the two test conditions. If the athlete approached with the same speed, the athlete using the lumbar support belt may be likely to achieve a greater hyperextension – flexion movement of the torso. The additional speed attributed by the lumbar support through to the shoulder joint was however, unable to be carried forward to the remaining lighter segments of the body. This is feasible due to the change in timing during the throwing action as a result of wearing the lumbar support belt. Training and competing in the lumbar support belt may lead to the change in timing required, to be able to transfer the increased shoulder speed, to lighter faster moving parts of the body and javelin. All six subjects who participated in the javelin study stated they preferred to wear the lumbar support belt and added;

“it kept the throwing position more upright, enabling the javelin to be released over the top”;
“it makes me feel taller, more upright. I am able to deliver the javelin from a higher position, it stops you falling away prior to release”;
“it put me in a better upright throwing position and gave me a better general posture”.

A lumbar support belt may allow trunk muscles to perform in a more optimal way by restricting relative lateral movements of the upper and lower trunk. Research undertaken during this thesis has shown that wearing a lumbar support belt did not adversely influence bowling and throwing performance. The results, however, showed a significant difference in the relative speed of shoulder to hip joints during the belt condition. Subjective comments made by the athletes, suggesting improved confidence in the use of the belt, could lead, with regular training, to a further improvement in athletic performance. This sentiment is echoed by one of the javelin throwers participating in this study who stated that,

> 'You would have to have a good winter's training to benefit from the belt, purely to get used to it'

If the subjects are comfortable with the lumbar support belt, if it feels good psychologically and above all, they perform better in it, then the support must be construed in a positive way. If significant increases in peak vertical ground reaction forces, loading rates and muscle activity had been associated with the wearing of a lumbar support belt, then it could be argued that the use of such a support during athletic performance might be detrimental in the long term. It may also be argued that the support does the work of the paravertebral muscles and has an effect on respiration, due to the increased intra-abdominal pressure. However, no significant differences in the peak vertical ground reaction forces, loading rates and muscle activity were found during the thesis whilst wearing the lumbar support condition.

The precise long-term consequences of using athletic supports, in particular the lumbar support belt, are not yet known. During the course of the research described in this thesis, approximately one hundred sportsmen and women, coaches and sports therapists have been consulted. One common theme has emerged: each year more and more athletes are using athletic supports, particularly the lumbar belt, in the belief that by doing so they can improve their personal performance, reduce the possibility of injury and old injuries can be cushioned against further stress.

Recommendations for Future Research

Belt B was of one design with the shape, size and length of the eight supporting bars constant. The only variable in the wearing of the lumbar support was how tight each subject fastened the belt around their waist. It is clearly evident that the design of such lumbar supports needs to be addressed. A more in-depth study, incorporating gender, physical characteristics, right and left handed athletes and even sporting activity would enable the lumbar support belt to be designed specifically for the individual. The technical properties of the supporting bars used in Belt *B*, in terms of strength and flexibility may also be improved. This would enable the design of the belt to suit the individuals physical characteristics and athletic movements. A lumbar support belt designed for a fast-medium bowler should provide maximum support for the individual when their torso is hyperextended and rotated coupled with a high vertical ground reaction force during front foot contact.

This thesis has demonstrated that the use of a support belt is beneficial to performance. It could be argued that the lumbar support belt should become standard equipment for the bowler and athlete. This then raises the issue of individuals becoming dependent on the athletic support. This may be more relevant to the weekend (club/social) athlete who is less likely to undertake any degree of physical training except weekend sport. Future research should address this problem of possible dependency on athletic supports.

The cricket and athletic equipment industry must research into optimum footwear in order to reduce ground reaction forces and loading rates experienced during the delivery stride of both activities. Research into the loads imposed on the biological structures of the body, especially the lower back, are required in order to assess the risk of injury.

Because of the high ground reaction forces and loading rates exhibited during front foot contact for both the fast-medium bowler and javelin thrower, plus the wide range of results reported in the literature, this thesis suggests that further biomechanical studies should investigate the simultaneous measurement of back and front foot ground reaction forces.

Further research into the use of a lumbar support belt needs to consider not only the more long-term effects with respect to injury occurrence, but also the effect of training with the support belt on performance. This would incorporate the use of a training study over a minimum period of three months. Pre and post biomechanical testing using an integrated approach would enable comparisons to be made as to the effect of the lumbar support belt on injury potential and performance. The final judgement on the effectiveness of Belt *B* is the focus of future research.

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APPENDIX A

Technical Movement Description of the Cricket Fast-Medium Bowling action : (a) Andrew (1986) with reference to the MCC's Guidelines and (b) the Javelin Throw : Payne, H. (1985) with reference to I.A.A.F guidelines.

Technical movement description of the cricket fast-medium bowling action : (a) Andrew (1986) with reference to the MCC's Guidelines and (b) the Javelin Throw : Payne, H. (1985) with reference to I.A.A.F guidelines.

Possibly the most fundamental asset of a fast-medium bowler in cricket and a javelin thrower is that of being able to perform a specialist activity with a high degree of skilled motor behaviour. Fast bowling in cricket and javelin throwing are complex actions which require the athlete to recruit muscles in an effective order so as to produce the optimal release speed. This initiates the bowl/throw at an optimum angle and provides the correct physical alignment and trajectory of the projectile. All motions of the human body and the projectile during the activity are ultimately governed by the laws of mechanics.

The cricket action also adopts a style that is most comfortable to perform, although in general the motion is typical of that outline by Andrew (1986) who with references to MCC's guidelines, describes the motion in five stages. The five stages of the action as described as follows with additional notes to physical attributes and kinematics, ground reaction forces during the stages of the action. Note the similarity to that of the javelin throw. As with the javelin throw the technical execution of the action is one continuous smooth movement from the run-up, through to the delivery stride and into the follow through. The bowler has to perform a combination of co-ordinated body movements in order to deliver the ball at a maximum but '*controlled*' speed. These are general guidelines reported by the M.C.C. The bowling action can be divided into three distinct categories, these are addressed in detail in the review of literature (chapter 2). This biomechanical investigation is primarily interested in the later positions of the 'delivery stride/ launch phase'. The acceleration of the ball/javelin is created primarily from the "Bow Position" - it is from this position that the trunk uncoils creating a 'whipping' action. This stage is described in great detail as it is the main focus of the doctoral study.

Andrew (1986) MCC's Guidelines - Fast Bowling in Cricket

Run-up and Production of Momentum

Throughout the approach to the delivery of the cricket ball, the athlete aims to gain optimum momentum which will enable the athlete to attain the most favourable delivery position. The run-up commences when the bowler walks, jogs over his marker gradually increasing speed on their approach to the wicket, achieving sufficient momentum to allow the athlete to achieve a optimal delivery stride.

The Bound

Stage 2, which is termed the bound, begins as the bowler jumps from the left foot (Figure 1a) and turns sideways in the air. The left arm abducts and the right arm abducts and the right arm flexes at the elbow.

The Coil

The 'Coil' (Figure 1b), as characterised in bowling terminology, constitutes stage 2. The trunk of the body leans back with lateral flexion and slight hyper-extension. The left arm fully abducts, with the bowler viewing the target from behind this arm. The right arm remains flexed at the elbow and the left leg is flexed at both the hip and the knee. the right leg (back foot) is extended at both the hip and knee and supports the bowlers weight. The bowler then begins to 'uncoil', which is stage 3 (figure 1c). The trunk straightens with lateral extension but there is still hyper-extension occurring. The left leg extends at the knee and a compound movement of flexion and outward rotation occurs at the hip. Abduction begins to occur with the right leg as the bowler's body mass transfers to the left side. The left arm adducts, slightly leading abduction of the right arm which also extends at the elbow.

Release of the Ball

The fourth stage, is when the bowler releases the ball (figure 1d). The body pivots to the left side and the bowlers weight is rapidly shifted to the left foot. Lateral flexion of the trunk also increases momentum. The right arm fully abducts and circumduction occurs as the ball is released. the left arm fully adducts. There is slight flexion of the left leg at the hip with the knee being fully extended or slightly flexed (to absorb impact forces). The right leg outwardly rotates and the knee flexes.

Follow Through

During the final stage, which is termed as the 'follow- through' (figure 1e), the body pivots round to face the direction of the delivery. The left arm hyperextends and the right arm experiences a compound movement of adduction, extension and horizontal flexion at the shoulder. Finally, the left leg flexes at both the hip and knee.

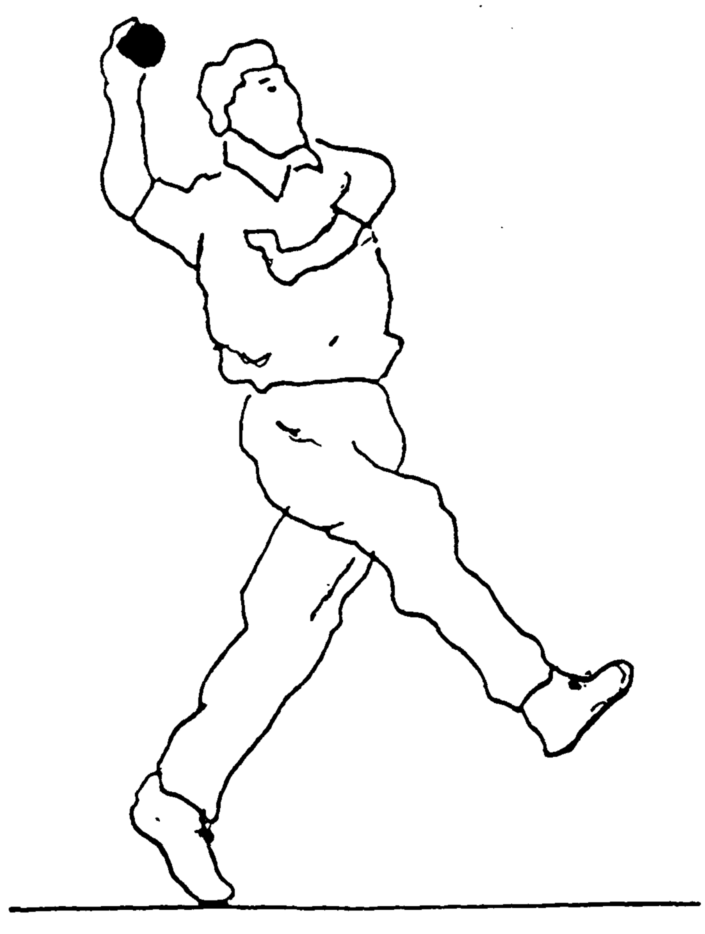


Figure 1(a) : Stage 1 - the 'Bound' Left Foot Take off

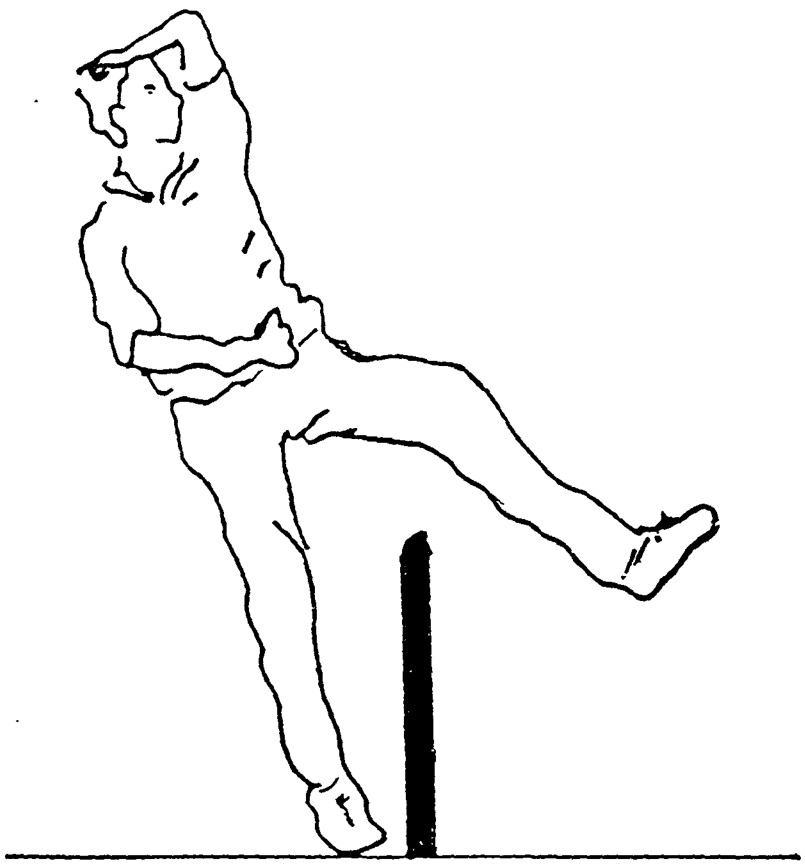


Figure 1(b) : Stage 2 - the 'Coil' position Back Foot Contact

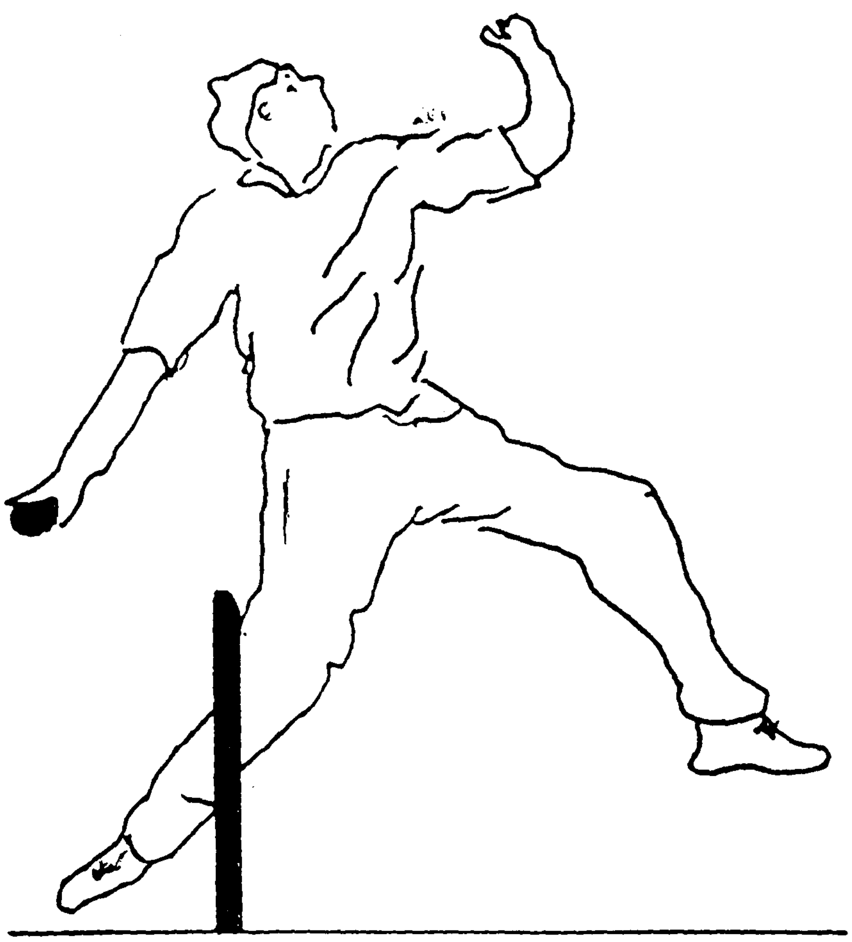


Figure 1(c) : Stage 3 - the Bowler 'Uncoiling' immediately prior to Front Foot Contact

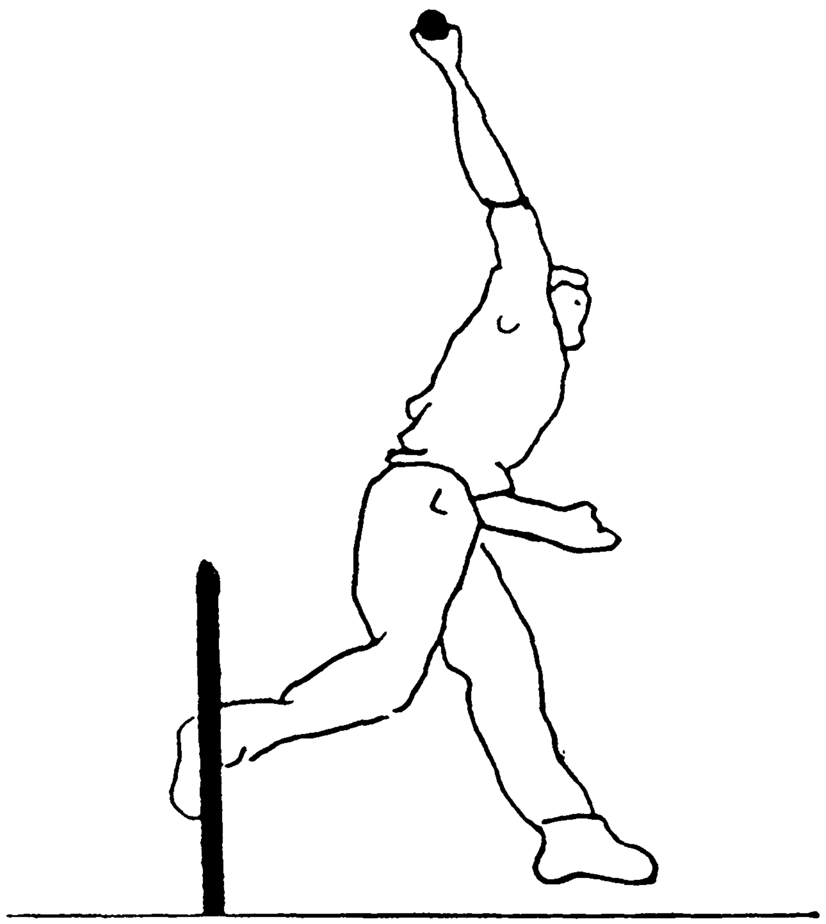


Figure 1(d) : Stage 4 - Ball Release During Front Foot Contact

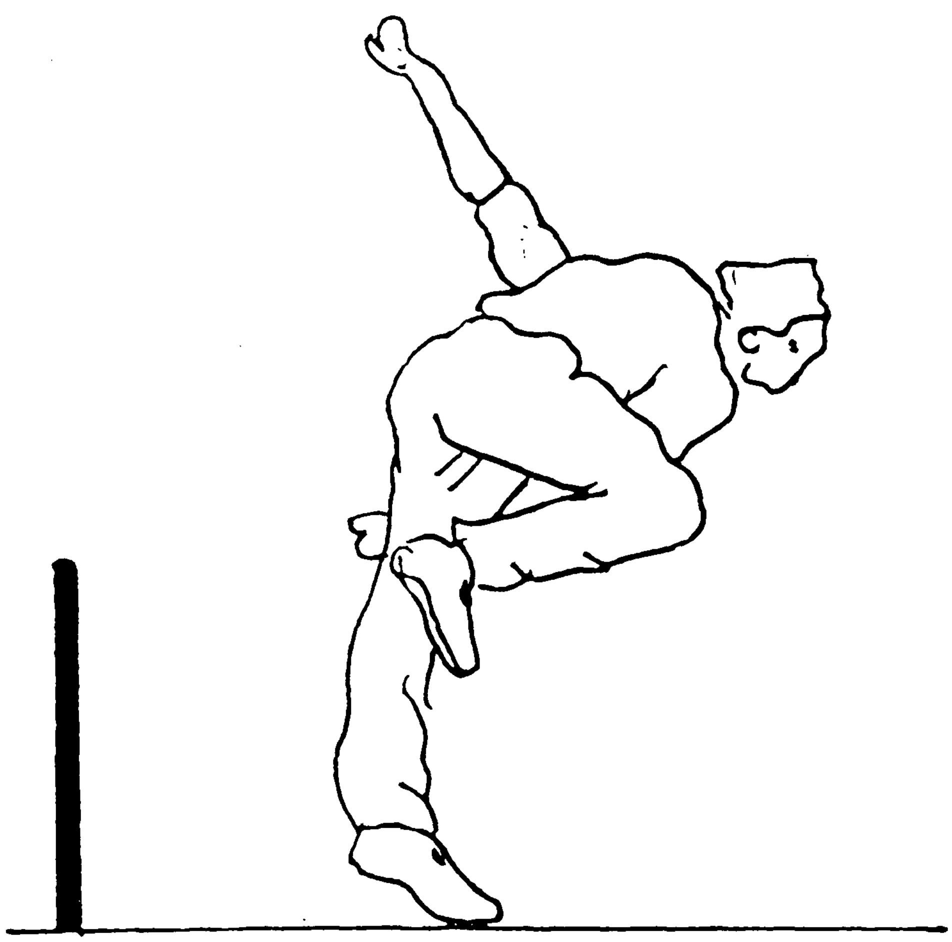


Figure 1(e) : Stage 5 - 'Follow-Through'

Payne (1985) I.A.A.F Guidelines - Javelin Throw.

The motion of the Javelin throw is typical of that outlined by Payne (1985), with reference to I.A.A.F guide-lines, describes the manoeuvre in six stages. The performance of the individual can be compared to such a model, with modifications made for physique and mechanical attributes. The six stages of the javelin throw, are described as follows. (Note for a right handed athlete). Technical execution of the javelin throw is a smooth movement from the first strides of the run-up to the final positions after release. Only for the purpose of kinesiological analysis is the continuous movement broken down into the fundamental parts.

Run-up and Production of Momentum

Throughout the approach to the throw, the athlete aims to gain optimum momentum which will enable the athlete to attain the most favourable throwing position. The run-up is divided into two phases, from the start of the run-up to the withdrawal of the javelin and from the start of the withdrawal to the moment the thrower arrives in the throwing position.

The First Part of the Run-Up

The athlete begins with some easy strides, gradually increasing the speed of running. The total length on average for international throwers is about 30 m, the run-up however should be suited to the individual so as to attain the optimum velocity required for the greatest possible throwing effort. The first part of the run-up starts at the first check mark and finishes at the second where the implement is withdrawn. This leads into the second part of the run up.

The Withdrawal of the Javelin

During this phase two basic requirements should be carried out: Firstly the use of the momentum gained during the first part of the run-up should properly pre-stretch the muscles contributing to the release in order to increase the force available for the acceleration of the javelin. The approach speed must not decrease as the javelin is withdrawn, the shoulders gradually rotate to the right, the hips should still face the direction of the throw. Secondly, a favourable position should be assumed by the throwing arm to create the 'arch of the body'. The pre-cross over stride is a driving stride, driving strongly from the right leg, as the athlete is rolling over the left leg, the pelvic axis turns to the right as much as the torsion from the shoulder region demands. The right knee is picked up fast and high as the left arm is wrapped around the body. The legs lead the throwing arm into the "Power Position". see Photograph No. 1

Connection of the Run-up to the Throw

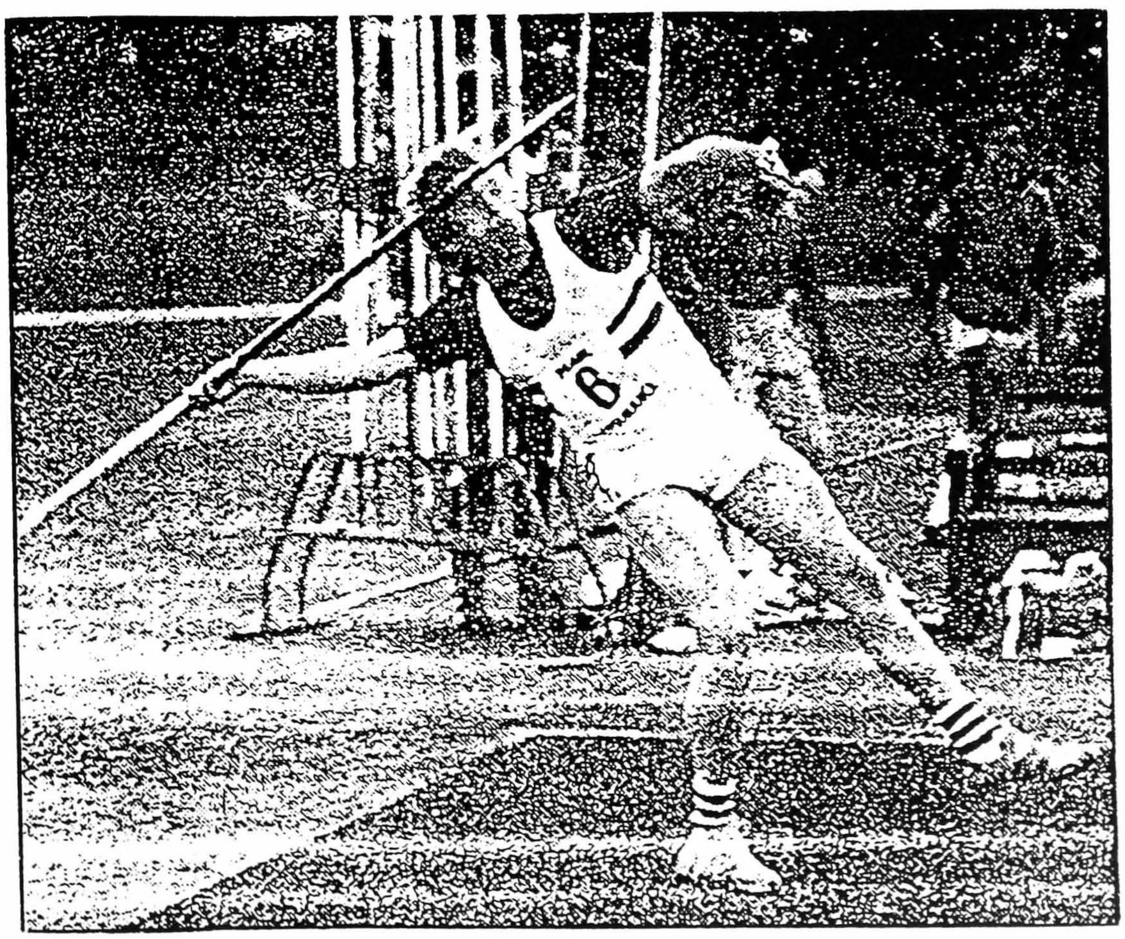
Upon landing on the right foot, the athlete despite the need to cover the ground quickly, produces a essentially static position. The power position places the thrower in the most effective position ready to throw. The trunk remains relatively upright and inert, the shoulders and the javelin lie in parallel, and the throwing hand is held high. As the right leg lands, it first yields arresting the movement before creating force. During this settling movement on the right leg the thrower begins to drive forward with the right leg and rotate it in the direction of the throw. The momentum of the athlete continues forward, until once passed the vertical the right leg thrusts upwards and forwards. The heel of the right foot lifts up and rotates outwards, pushing forward and at the same time rotating the right knee to the front causes the pelvis to begin its rotation to the left. The action of the right leg is one of the most important factors during the throw. It as this moment the **left** leg makes contact with the ground, creating the 'Bow Position'. see Photograph No. 2

Acceleration of the Javelin and its release

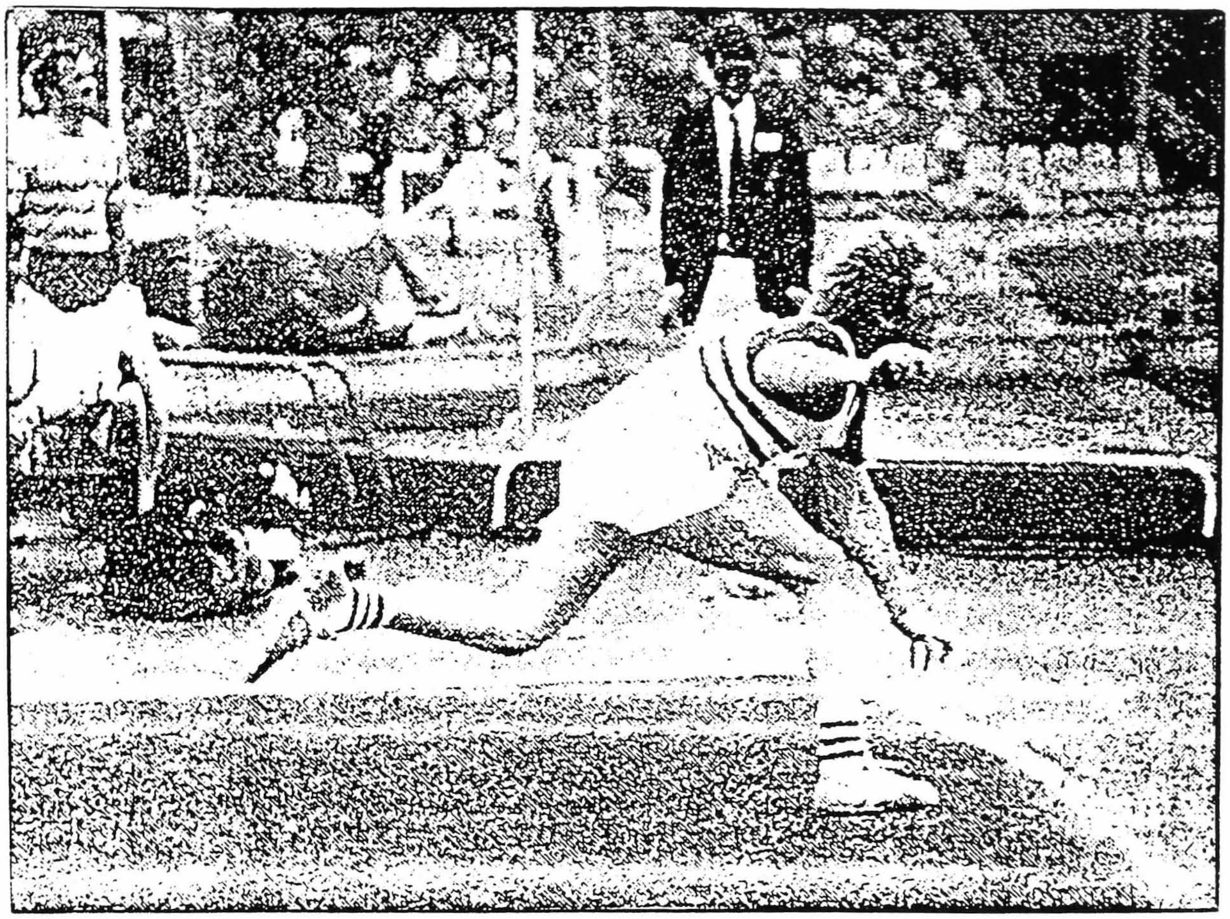
The left foot should be placed approximately thirty centimetres to the left of the line of the throw. The foot plant is executed in such a way that the heel and full sole of the shoe are pressed firmly into the ground and immediately start the breaking action. Due to the momentum, there will be a slight bend in the left knee and the muscles in the thigh contract eccentrically owing to the intense load. Proper execution of the left foot plant is very important since during the release it is the only factor contributing to the vertical component of the throw. Having absorbed the initial shock of landing, both the left leg and the left side must brace against the thrusting right leg action. This movement is focused through the left shoulder focal point, as a result the thrower assumes the characteristic "Bow Position" when viewed from the side. The "Bow" ought to occur in the higher region of the thorisac section, rather than the lower lumbar region. During the final stage of this phase, it is important for the right leg to drive forwards and upwards in order to maintain the position of the hips, and to help the left leg drive forward. The left leg should lift as the thrower rides over it, (the quadriceps femoris and the extensors of the ankle, recoil with enormous quantity of potential energy resulting from the stretch given to them from absorbing the run-up momentum) it is at this point the throwing arm is brought into play. This progression over the left leg is regulated by the hip musculature. It can be speeded up by the hip flexors and the abdominal muscles, while by contracting the hip extensors and the lower back muscles it can be decelerated. The release is initiated from the point when the "arching position" of the body is at its greatest so that all the muscles can act effectively (abdominal, chest, shoulder, upper-arm muscles). The left leg during release plays one final role lifting the body with its final extension. The muscles around the waist, hips and the lower back muscles brake the forward movement of the waist and the hips. The momentum of these parts is transferred through the right arm to accelerate the javelin. The arm must strike lightening fast, with the elbow high and close to the mid-line. The acceleration of the javelin is carried out by the throwing arm, it will produce a braking force in the shoulder joint, and around the shoulder and chest region so that the effective function of the hip flexors plus abdominals is required.

Recovery Position - Post release position.

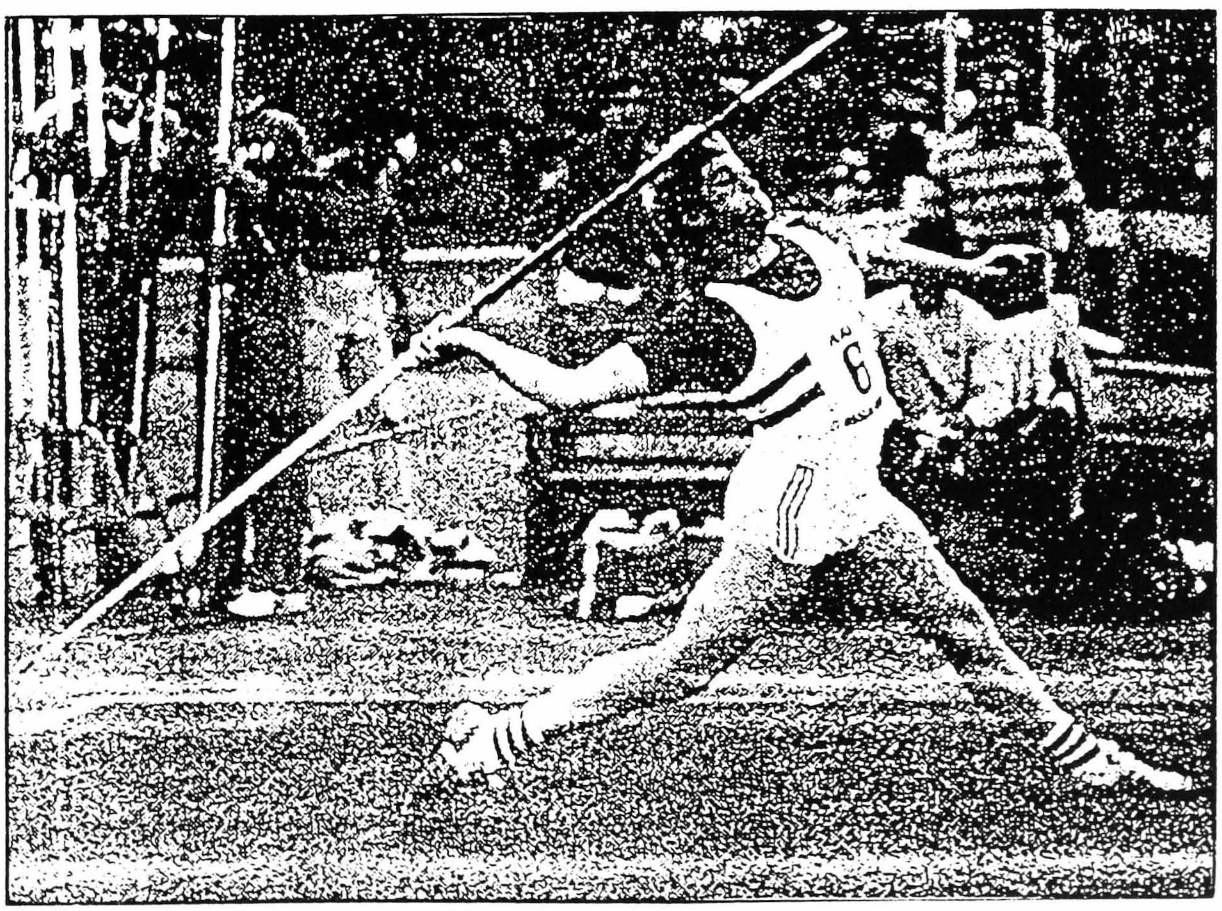
Space has to be left in which to check residual forward momentum before the scratch-line is reached. It is usual for this to be accomplished with one long stride. The thrower rides up over the leg in the final act of throwing. It remains grounded as the right leg is brought past it to cushion the action. In this way the thrower steps past the left leg and halts. The amount of space needed to stop before the scratch-line is reached depends upon the amount of horizontal momentum remaining after delivery. If there is too much momentum remaining after the throw it means that the throw was not efficient. In theory it can be shown and verified that optimum conversion of the energy gained during the run-up to the javelin's speed is made if the body after release has no more momentum. In practice, 1.5-2.5 m gives an average distance needed from planting the leg to the throwing line to avoid fouling the throw. see Photograph No. 3



The Power Position: Photograph 1
Back Foot Contact



The Bow Position: Photograph 2
Left Side Brace



Recovery Position: Photograph 3
The feet are reversed to save the throw

APPENDIX B

Sporting Injuries in male fast-medium cricket bowlers and javelin throwers. A retrospective survey of injury.

Injury Questionnaire: Designed by Paul D. Hurrion / April 1996

Fast-Medium Cricket Bowlers (n=52)

Recreational (n=10)
Club (n=24)
County (n=12)
National (n=6)

Javelin Throwers (n=34)

Club (n=16)
County (n=12)
National (n=6)

Q1. Gender Male / Female

Q2. Age. .... years

Q3. Approximate Weight .... Kg
Height .... Metres / Feet : Inches

Q4. Level of Competition

Recreational / Club / County / National
(indicate as appropriate)

Q5. Have you experienced any 'Cricket Bowling / Training' sports related injuries that have prevented training for a period of ***'one week'*** or greater?

Yes / No (If **No** go to Q11)

Q6. **If Yes** then how many such injuries have you incurred ?

1 2-3 4-5 6-10 10+
(indicate as appropriate)

Q7. How many of these injuries were recurrent episodes of an original injury ?

None 1 2-3 4-5 6-7 8+
(indicate as appropriate)

Q8. How many of these *'Cricket Bowling'* injuries you experienced have necessitated medical attention of some description ?

None 1 2-3 4-5 6-10 10+
(indicate as appropriate)

Please indicate (by the means of a tick) which form of medical attention was required for each injury :

	1	2	3	4	5	6	7	8+
Hospital								
Surgical								
General Practitioner								
Physiotherapy								
Chiropractor								
Osteopath								
Acupuncture								
Other (Please specify)								

PTO

Cricket Bowler

Q9. Of the injuries that you have incurred resulting in the loss of training for ***'one week'***, how many were as a result of a ***'muscular injury'*** ?

None 1 2-3 4-5 6-10 10+

(indicate as appropriate)

Please indicate which region of the body did they occur ?

Calf	Thigh	Hamstring	Groin	Abds	Back	Shoulder	Chest	Bicep	Tricep	Forearm

Q10. Of the injuries that you have incurred resulting in the loss of training for ***'one week'***, how many were as a result of a ***'ligament / joint injury'*** ?

None 1 2-3 4-5 6-10 10+

(indicate as appropriate)

Please indicate which region of the body did they occur ?

Ankle	Knee	Hip	Lower Back	Shoulder	Elbow	Wrist	Finger

Q11. Do you wear any athletic supports / strapping, during training / matches either to protect an old injury or help prevent injuries occurring ?

Yes / No

If Yes please indicate which region of the body.

Ankle	Knee	Thigh	Hamstring	Back	Shoulder	Elbow	Wrist

Q12. List any minor troublesome injuries which you regularly experience as a result of your sporting activity ?

a...
b...
c...
d...
e...

Your time and co-operation is greatly appreciated
Thank You

Paul Hurrion 1996

Cricket Bowler

Sports Injury Questionnaire 'Cricket Bowler'

Recreational (n = 10)

Subject	Age	Height	Mass
1	20	179	82
2	31	184	94
3	29	182	89
4	43	176	84
5	21	180	80
6	48	178	80
7	19	180	77
8	53	181	78
9	20	178	77
10	21	172	76
Average	30.50	179.00	81.70
S.E.	4.09	1.05	1.84

Have you experienced any Cricket injuries ?

Yes 4 No 6 40%

If Yes then how many injuries have you incurred ?

1	1
2-3	1
4-5	1
6-10	1
10+	

How many of these injuries were recurrent eposides of an original injury ?

None	1
1	2
2-3	1
4-5	
6-7	
8+	

3/4 People (75%)

Club (n = 24)

Subject	Age	Height	Mass
1	34	172	86
2	21	174	78
3	43	184	82
4	23	179	79
5	23	176	76
6	20	184	86
7	26	180	79
8	23	177	75
9	19	182	86
10	22	182	84
11	29	182	86
12	22	184	84
13	24	179	79
14	49	182	90
15	28	182	86
16	20	182	79
17	26	178	90
18	21	184	86
19	25	182	84
20	23	182	84
21	28	182	84
22	23	181	90
23	38	185	88
24	40	178	84
Average	27.08	180.54	83.54
S.E.	1.63	0.68	0.88

Have you experienced any Cricket injuries ?

Yes 18 No 6 7!

If Yes then how many injuries have you incurre

1	3
2-3	10
4-5	4
6-10	1
10+	

How many of these injuries were recurrent ep of an original injury ?

None	3
1	9
2-3	6
4-5	
6-7	
8+	

15/18 People (83%)

Fast-medium cricket bowling

How many of these injuries have necessitated medical attention of some description ?

None		**Hosptial**	1	
1	2	**Surgical**	1	
2-3	1	**G.P.**	7	
4-5	1	**Physio**	7	
6-10		**Chiropractor**		
10+		**Osteopath**		**24/10**
		Other ...	8	2.4 Injuries
		Total	**24**	per person

Muscular injury ?

Calf	1	**None**	1
Thigh		**1**	1
Hamstring		**2-3**	2
Groin	3	**4-5**	
Abs		**6-10**	
Back	1	**10+**	
Shoulder			
Chest			
Bicep			
Tricep			
Forearm			

Ligament / Joint Injury ?

Ankle	3	**None**	1
Knee	2	**1**	1
Hip		**2-3**	1
Back	3	**4-5**	1
Shoulder		**6-10**	
Elbow		**10+**	
Wrist			
Finger			

Do you wear any athletic supports ?

Yes 3 No 7 30%

If YES

Ankle	1
Knee	1
Thigh	
Hamstring	
Back	1
Shoulder	
Elbow	
Wrist	

How many of these injuries have necessitated medical attention of some description ?

None		**Hosptial**	7	
1	5	**Surgical**	5	
2-3	12	**G.P.**	23	
4-5	1	**Physio**	25	
6-10		**Chiropractor**	1	
10+		**Osteopath**	3	**70/**
		Other ...	6	2.9
		Total	**70**	per

Muscular injury ?

Calf	2	**None**	7
Thigh		**1**	6
Hamstring	3	**2-3**	5
Groin	5	**4-5**	
Abs	2	**6-10**	
Back	4	**10+**	
Shoulder	1		
Chest			
Bicep			
Tricep			
Forearm			

Ligament / Joint Injury ?

Ankle	4	**None**	2
Knee	12	**1**	9
Hip		**2-3**	7
Back	2	**4-5**	
Shoulder	2	**6-10**	
Elbow	1	**10+**	
Wrist			
Finger	2		

Do you wear any athletic supports ?

Yes 6 No 18 2

If YES

Ankle	1
Knee	4
Thigh	
Hamstring	1
Back	
Shoulder	
Elbow	
Wrist	

Fast-medium cricket bowling

Sports Injury Questionnaire 'Cricket Bowler'

County (n = 12)

Subject	Age	Height	Mass
1	26	184	78
2	28	186	88
3	22	188	94
4	30	185	90
5	27	183	88
6	22	183	83
7	23	182	88
8	23	181	86
9	28	186	84
10	18	188	92
11	23	182	84
12	25	178	93
Average	24.58	183.83	87.33
S.E.	0.97	0.85	1.34

Have you experienced any Cricket injuries ?

Yes 10 No 2 83%

If Yes then how many injuries have you incurred ?

1	3
2-3	5
4-5	2
6-10	
10+	

How many of these injuries were recurrent eposides of an original injury ?

None	2
1	6
2-3	2
4-5	
6-7	
8+	

8/10 People (80%)

National (n = 6)

Subject	Age	Height	Mass
1	30	184	94
2	23	190	88
3	26	179	89
4	29	195	92
5	28	188	88
6	30	186	80
Average	27.67	187.00	88.50
S.E.	1.12	2.22	1.96

Have you experienced any Cricket injuries ?

Yes 6 No 0 100'

If Yes then how many injuries have you incurred

1	
2-3	2
4-5	3
6-10	1
10+	

How many of these injuries were recurrent eposi of an original injury ?

None	1
1	1
2-3	4
4-5	
6-7	
8+	

5/6 People (83%)

Fast-medium cricket bowling

How many of these injuries have necessitated medical attention of some description ?

None	1	**Hosptial**	5	
1	5	**Surgical**	1	
2-3	3	**G.P.**	9	
4-5	1	**Physio**	12	
6-10		**Chiropractor**	1	
10+		**Osteopath**	2	**45/12**
		Other ...	15	3.8 Injuries
		Total	**45**	per person

(12/15 = Massage)

Muscular injury ?

Calf		**None**	2
Thigh		**1**	6
Hamstring	3	**2-3**	2
Groin	5	**4-5**	
Abs		**6-10**	
Back	5	**10+**	
Shoulder			
Chest			
Bicep			
Tricep			
Forearm			

Ligament / Joint Injury ?

Ankle	2	**None**	3
Knee	3	**1**	4
Hip		**2-3**	3
Back	5	**4-5**	
Shoulder		**6-10**	
Elbow		**10+**	
Wrist			
Finger			

Do you wear any athletic supports ?

Yes 5 No 7 42%

N.B. One person wears a 'Knee' and 'Back' support

If YES

Ankle	1
Knee	1
Thigh	
Hamstring	1
Back	3
Shoulder	
Elbow	
Wrist	

How many of these injuries have necessitated medical attention of some description ?

None		**Hosptial**	4	
1		**Surgical**	4	
2-3	3	**G.P.**	9	
4-5	3	**Physio**	19	
6-10		**Chiropractor**	1	
10+		**Osteopath**	4	**58/6**
		Other ...	17	9.7 Inj
		Total	**58**	per pe

(14/17=Massa

Muscular injury ?

Calf	1	**None**	
Thigh		**1**	
Hamstring	2	**2-3**	6
Groin	4	**4-5**	
Abs	1	**6-10**	
Back	6	**10+**	
Shoulder	1		
Chest			
Bicep			
Tricep			
Forearm			

Ligament / Joint Injury ?

Ankle	1	**None**	1
Knee	2	**1**	2
Hip		**2-3**	3
Back	3	**4-5**	
Shoulder	1	**6-10**	
Elbow	1	**10+**	
Wrist			
Finger			

Do you wear any athletic supports ?

Yes 1 No 5 17%

If YES

Ankle	
Knee	
Thigh	
Hamstring	
Back	1
Shoulder	
Elbow	
Wrist	

Fast-medium cricket bowling

Sports Injury Questionnaire 'Cricket Bowler'

otal (n=52)

	Age	Height	Mass
verage	27.48	181.83	83.01
S.E.	0.88	1.62	1.06

lave you experienced any Cricket injuries ?

Yes 38 No 14 73 %

Yes then how many injuries have you incurred ?

1	7
2-3	18
4-5	10
6-10	3
10+	-

low many of these injuries were recurrent eposides
f an original injury ?

None	7	
1	18	
2-3	13	
4-5	-	**31 People (82%) had a**
6-7	-	**recurrent eposide of**
8+	-	**an original injury**

low many of these injuries have necessitated
nedical attention of some description ?

None	1	**Hosptial**	17	
1	12	**Surgical**	11	
2-3	19	**G.P.**	48	
4-5	6	**Physio**	63	
6-10	-	**Chiropractor**	3	
10+	-	**Osteopath**	9	**197/52**
		Other ...	46	3.8 Injuries
		Total	**197**	per person

Ligament / Joint Injury

Ankle	10	**None**	7
Knee	19	**1**	16
Hip	-	**2-3**	14
Back	13	**4-5**	1
Shoulder	3	**6-10**	-
Elbow	2	**10+**	-
Wrist	-		
Finger	2		
TOTAL	49		

Muscular injury ?

Calf	4	**None**	10
Thigh	-	**1**	13
Hamstring	8	**2-3**	15
Groin	17	**4-5**	-
Abs	3	**6-10**	-
Back	16	**10+**	-
Shoulder	2		
Chest	-		
Bicep	-		
Tricep	-		
Forearm	-		
TOTAL	50		

Do you wear any athletic supports ?

Yes 15 No 37

N.B. One person wears a 'Knee' and 'Back' suppor

Ankle	3
Knee	6
Thigh	-
Hamstring	2
Back	5
Shoulder	-
Elbow	-
Wrist	-

Fast-medium cricket bowling

Q1. Gender — Male / Female

Q2. Age. — .... years

Q3. Approximate Weight — .... Kg
Height — .... Metres / Feet : Inches

Q4. Level of Competition

Club / County / National
(indicate as appropriate)

Q5. Have you experienced any 'Javelin Throwing / Training' sports related injuries that have prevented training for a period of '***one week***' or greater?

Yes / No (If **No** go to Q11)

Q6. **If Yes** then how many such injuries have you incurred ?

1 2-3 4-5 6-10 10+
(indicate as appropriate)

Q7. How many of these injuries were recurrent episodes of an original injury ?

None 1 2-3 4-5 6-7 8+
(indicate as appropriate)

Q8. How many of these *'Javelin Throwing'* injuries you experienced have necessitated medical attention of some description ?

None 1 2-3 4-5 6-10 10+
(indicate as appropriate)

Please indicate (by the means of a tick) which form of medical attention was required for each injury :

	1	2	3	4	5	6	7	8+
Hospital								
Surgical								
General Practitioner								
Physiotherapy								
Chiropractor								
Osteopath								
Acupuncture								
Other (Please specify)								

PT

Q9. Of the injuries that you have incurred resulting in the loss of training for *'one week'*, how many were as a result of a ***'muscular injury'*** ?

None 1 2-3 4-5 6-10 10+

(indicate as appropriate)

Please indicate which region of the body did they occur ?

Calf	Thigh	Hamstring	Groin	Abds	Back	Shoulder	Chest	Bicep	Tricep	Forea

Q10. Of the injuries that you have incurred resulting in the loss of training for *'one week'*, how many were as a result of a ***'ligament / joint injury'*** ?

None 1 2-3 4-5 6-10 10+

(indicate as appropriate)

Please indicate which region of the body did they occur ?

Ankle	Knee	Hip	Lower Back	Shoulder	Elbow	Wrist	Finger

Q11. Do you wear any athletic supports / strapping, during training / matches either to protect an old injury or help prevention injuries occurring ?

Yes / N

If Yes please indicate which region of the body.

Ankle	Knee	Thigh	Hamstring	Back	Shoulder	Elbow	Wrist

Q12. List any minor troublesome injuries which you regularly experience as a result of your sporting activity ?

a...

b...

c...

d...

e...

Your time and co-operation is greatly appreciated
Thank You

Paul Hurrion 19

Javelin

Sports Injury Questionnaire 'Javelin Thrower'

Club (n = 16)

Subject	Age	Height	Mass
1	35	182	88
2	25	176	80
3	34	184	84
4	32	180	80
5	19	185	89
6	21	178	78
7	25	182	87
8	22	176	80
9	21	184	88
10	22	182	92
11	20	184	85
12	36	180	90
13	30	175	84
14	22	186	90
15	32	180	85
16	18	175	76
Average	25.88	180.56	84.75
S.E.	1.56	0.92	1.20

Have you experienced any Javelin Throwing injuries?

Yes 14 No 2 88%

If Yes then how many injuries have you incurred ?

1	4
2-3	7
4-5	2
6-10	1
10+	-

How many of these injuries were recurrent eposides of an original injury ?

None	2	
1	8	
2-3	3	
4-5	1	
6-7	-	**12/14 People (86%)**
8+	-	

County (n = 12)

Subject	Age	Height	Mass
1	25	183	87
2	21	184	85
3	20	176	76
4	18	182	80
5	28	190	98
6	23	185	95
7	25	179	82
8	18	179	75
9	21	186	84
10	27	190	91
11	30	176	82
12	23	186	90
Average	23.25	183.00	85.42
S.E.	1.12	1.38	2.05

Have you experienced any Javelin throwing injur

Yes 11 No 1 92%

If Yes then how many injuries have you incurred

1	2
2-3	6
4-5	2
6-10	1
10+	-

How many of these injuries were recurrent eposi of an original injury ?

None	1	
1	6	
2-3	3	
4-5	1	
6-7	-	**10/11 People (91%)**
8+	-	

Javelin

How many of these injuries have necessitated medical attention of some description ?

None	1	**Hosptial**	2	
1	8	**Surgical**	1	
2-3	4	**G.P.**	20	
4-5	1	**Physio**	21	
6-10	-	**Chiropractor**	-	
10+	-	**Osteopath**	1	**57/16**
		Other ...	12	3.6 Injuries
		Total	**57**	per person

Muscular injury ?

Calf	1	**None**	1
Thigh	-	**1**	8
Hamstring	3	**2-3**	4
Groin	5	**4-5**	1
Abs	1	**6-10**	-
Back	7	**10+**	-
Shoulder	2		
Chest	1		
Bicep	-		
Tricep	-		
Forearm	-		

Ligament / Joint Injury ?

Ankle	1	**None**	1
Knee	5	**1**	7
Hip	-	**2-3**	5
Back	6	**4-5**	1
Shoulder	3	**6-10**	-
Elbow	7	**10+**	-
Wrist	-		
Finger	-		

Do you wear any athletic supports ?

Yes 8 No 8 50%

If YES

Ankle	-
Knee	1
Thigh	-
Hamstring	1
Back	4
Shoulder	-
Elbow	2
Wrist	-

How many of these injuries have necessitated medical attention of some description ?

None	1	**Hosptial**	4	
1	4	**Surgical**	1	
2-3	4	**G.P.**	12	
4-5	1	**Physio**	16	
6-10	1	**Chiropractor**	2	
10+	-	**Osteopath**	1	
		Other ...	18	**54/12**
		Total	**54**	4.5 Injur per pers

Muscular injury ?

Calf	1	**None**	1
Thigh	-	**1**	6
Hamstring	3	**2-3**	3
Groin	2	**4-5**	1
Abs	1	**6-10**	-
Back	6	**10+**	-
Shoulder	1		
Chest	1		
Bicep	1		
Tricep	-		
Forearm	-		

Ligament / Joint Injury ?

Ankle	1	**None**	1
Knee	4	**1**	7
Hip	-	**2-3**	2
Back	4	**4-5**	1
Shoulder	1	**6-10**	-
Elbow	3	**10+**	-
Wrist	-		
Finger	-		

Do you wear any athletic supports ?

Yes 6 No 6 50%

N.B. One person wears a 'Knee' and 'Back' suppor

If YES

Ankle	1
Knee	2
Thigh	-
Hamstring	-
Back	2
Shoulder	-
Elbow	2
Wrist	-

Javelin

Sports Injury Questionnaire 'Javelin Thrower'

tional (n = 6)

ject	Age	Height	Mass
1	33	178	91
2	29	192	105
3	22	186	96
4	23	178	86
5	24	188	94
6	28	190	100
verage	26.50	185.33	95.33
S.E.	1.73	2.46	2.73

ve you experienced any Javelin Throwing injuries ?

Yes 6 No 0 100%

Yes then how many injuries have you incurred ?

1	-
2-3	2
4-5	3
6-10	1
10+	-

w many of these injuries were recurrent eposides
an original injury ?

None	1	
1	2	
2-3	3	
4-5	-	
6-7	-	**5/6 People (83%)**
8+	-	

Total (n=34)

	Age	Height	Mass
Average	25.43	183.24	87.24
S.E.	0.97	1.57	1.68

Have you experienced any Javelin throwing injuries

Yes 31 No 3 91 %

If Yes then how many injuries have you incurred ?

1	6
2-3	15
4-5	7
6-10	3
10+	-

How many of these injuries were recurrent eposides
of an original injury ?

None	4	
1	16	
2-3	9	**27 People (87%) had a**
4-5	2	**recurrent eposide of**
6-7	-	**an original injury**
8+	-	

How many of these injuries have necessitated
medical attention of some description ?

None	2	**Hosptial**	8	
1	11	**Surgical**	4	
2-3	11	**G.P.**	44	**160/3**
4-5	4	**Physio**	55	4.7 in
6-10	-	**Chiropractor**	5	per p
10+	-	**Osteopath**	4	
		Other ...	40	
		Total	**160**	

ow many of these injuries have necessitated
edical attention of some description ?

None	-	Hosptial	2	
1	1	Surgical	2	
2-3	3	G.P.	12	
4-5	2	Physio	18	
6-10	-	Chiropractor	3	
10+	-	Osteopath	2	49/6
		Other ...	10	8.2 Injuries
		Total	**49**	per person

uscular injury ?

alf	-	None	-
high	1	1	1
amstring	2	2-3	4
roin	6	4-5	1
bs	2	6-10	-
ack	4	10+	-
houlder	2		
hest	-		
icep	-		
ricep	1		
orearm	-		

igament / Joint Injury ?

Ankle	1	None	-
Knee	4	1	2
Hip	-	2-3	3
Back	5	4-5	1
Shoulder	2	6-10	-
Elbow	4	10+	-
Wrist	-		
Finger	-		

Do you wear any athletic supports ?

Yes 5 No 1 83%

If YES

Ankle	-
Knee	1
Thigh	-
Hamstring	-
Back	2
Shoulder	-
Elbow	2
Wrist	-

Muscular injury ?

Calf	2	None	1
Thigh	1	1	11
Hamstring	8	2-3	13
Groin	13	4-5	5
Abs	4	6-10	1
Back	17	10+	-
Shoulder	5		
Chest	2		
Bicep	1		
Tricep	1		
Forearm	-		
TOTAL	54		

Ligament / Joint Injury

Ankle	3	None	2
Knee	13	1	16
Hip	-	2-3	9
Back	15	4-5	4
Shoulder	6	6-10	-
Elbow	14	10+	-
Wrist	-		
Finger	-		
TOTAL	51		

Do you wear any athletic supports ?

Yes 19 No 14 5

N.B. One person wears a 'Knee' and 'Back' suppo

Ankle	1
Knee	4
Thigh	-
Hamstring	1
Back	8
Shoulder	-
Elbow	6
Wrist	-

Javelin

APPENDIX C

A biomechanical investigation into fast-medium bowling in cricket. Experiment 1.

Subject 1 : Table of Means Indoor / Outdoor

	Peak Force (Newtons) / Body Weight %							Time to Peak Force (seconds)					Loading Rate
Indoor n=6	Medial Fx +ve	Lateral Fx -ve	Propulsive Fy +ve	Braking Fy -ve	Vertical Fz +ve	Approach Velocity (ms^{-1})	Time in Contact (second)	Fx +ve	Fx -ve	Fy +ve	Fy -ve	Fz +ve	**BW s^{-1}**
No Support	**365 0.39 ±14 ±0.01**	**130 0.14 0 0**	**243 0.26 ±13 ±0.01**	**1998 2.15 ±111 ±0.12**	**3519 3.80 ±132 ±0.14**	**5.00 ±0.07**	**0.45 ±0.01**	**0.02 0**	**0.04 0**	**0.29 0**	**0.03 0**	**0.03 0**	**127**
Knee Ordinary	**458 0.49 ±21 ±0.02**	**80 0.08 ±18 ±0.02**	**221 0.23 ±13 ±0.01**	**1898 2.01 ±100 ±0.11**	**3453 3.66 ±132 ±0.14**	**5.44 ±0.03**	**0.42 ±0.01**	**0.03 0**	**0.05 ±0.01**	**0.30 0**	**0.04 0**	**0.03 0**	**122**
Knee Braced	**403 0.43 ±19 ±0.02**	**91 0.10 ±24 ±0.03**	**231 0.25 ±10 ±0.01**	**2141 2.28 ±113 ±0.12**	**3733 3.98 ±151 ±0.16**	**5.42 ±0.05**	**0.40 ±0.01**	**0.03 0**	**0.04 0**	**0.26 0**	**0.04 0**	**0.03 0**	**133**
Back	**488 0.52 ±36 ±0.04**	**66 0.07 ±15 ±0.02**	**217 0.23 ±5 ±0.01**	**1888 2.00 ±83 ±0.09**	**3357 3.56 ±103 ±0.11**	**5.22 ±0.04**	**0.40 ±0.01**	**0.03 0**	**0.05 ±0.01**	**0.29 ±0.01**	**0.04 0**	**0.03 0**	**119**
Ankle	**348 0.37 ±20 ±0.02**	**92 0.10 ±23 ±0.02**	**222 0.24 ±11 ±0.01**	**2203 2.36 ±78 ±0.08**	**3755 4.02 ±70 ±0.08**	**5.16 ±0.07**	**0.43 ±0.02**	**0.03 0**	**0.04 ±0.01**	**0.29 ±0.02**	**0.03 0**	**0.03 0**	**134**
Outdoor n=30	**830 0.91 ±72 ±0.08**	**77 0.08 ±12 ±0.01**	**250 0.28 ±5 ±0.01**	**1776 1.96 ±43 ±0.05**	**3845 4.24 ±77 ±0.08**	**5.19 ±0.08**	**0.15 0**	**0.01 0**	**0.02 0**	**0.09 0**	**0.01 0**	**0.01 0**	**424**

EMG : Peak reading during the delivery stride

Subject 1		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	2	2397	3213	3350	2935	2686	2852
No Support	4	2554	3320	3164	2837	2881	2988
	6	2598	2935	3115	3008	2720	2705
	7	2734	3247	3071	3096	2681	2783
	8	2583	3193	3252	2974	2563	2866
	6	2676	2959	3149	2729	2534	2886
	Mean	**2590**	**3145**	**3184**	**2930**	**2678**	**2847**
	S.E.	**47**	**65**	**41**	**53**	**51**	**39**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	11	2690	3184	3066	2822	2695	2817
Ankle	14	2710	2905	3086	2832	2593	2949
	15	2544	3091	3154	2861	2573	2832
	16	2632	3013	3120	2681	2588	3091
	17	2681	3169	3027	2891	2637	2715
	18	2461	2852	3198	3027	2568	2949
	Mean	**2620**	**3036**	**3109**	**2852**	**2609**	**2892**
	S.E.	**40**	**56**	**25**	**46**	**20**	**54**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	27	2563	2773	3086	2969	2759	2988
Knee Ordinary	28	2808	2866	3018	2915	2705	2959
	29	2573	2744	3057	2842	2510	3008
	30	2715	3110	3022	2793	2646	2930
	31	2466	2876	2983	3057	2837	2969
	33	2617	3057	3071	3081	2690	2891
	Mean	**2624**	**2904**	**3040**	**2943**	**2691**	**2958**
	S.E.	**49**	**61**	**16**	**47**	**45**	**17**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	20	2578	3413	3096	2700	2612	3003
Knee Braced	21	2480	3018	3018	2617	2754	2837
	23	2627	3130	3062	2988	2827	2817
	24	2437	2788	3188	2856	2734	2871
	25	2544	2910	3037	2944	2446	2671
	26	2671	2905	3115	2749	2749	2754
	Mean	**2556**	**3027**	**3086**	**2809**	**2687**	**2826**
	S.E.	**36**	**90**	**25**	**59**	**56**	**46**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	35	2764	2837	2959	2910	2637	2856
Back	37	2520	3086	2993	2842	2549	2700
	39	2749	2764	3047	3018	2500	2544
	40	2490	2759	3115	2905	2505	2686
	41	2598	2910	3037	2896	2681	2656
	42	2573	2949	3052	2900	2642	2744
	Mean	**2616**	**2884**	**3034**	**2912**	**2586**	**2698**
	S.E.	**47**	**51**	**22**	**24**	**32**	**42**

Subject 2 : Table of Means Indoor / Outdoor

	Peak Force (Newtons) / Body Weight %							**Time to Peak Force (seconds)**					**Loading Rate**
Indoor n=6	Medial Fx +ve	Lateral Fx -ve	Propulsive Fy +ve	Braking Fy -ve	Vertical Fz +ve	Approach Velocity (ms^{-1})	Time in Contact (second)	Fx +ve	Fx -ve	Fy +ve	Fy -ve	Fz +ve	**BW s^{-1}**
No Support	**696 0.73 ±31 ±0.03**	**124 0.13 ±82 ±0.09**	**212 0.22 ±10 ±0.01**	**2448 2.56 ±112 ±0.12**	**4615 4.82 ±243 ±0.25**	**4.32 ±0.04**	**0.52 ±0.01**	**0.02 0**	**0.03 0**	**0.39 ±0.01**	**0.03 0**	**0.02 0**	**241**
Knee Ordinary	**790 0.83 ±51 ±0.05**	–	**248 0.26 ±5 ±0.01**	**2437 2.55 ±107 ±0.11**	**4836 5.06 ±80 ±0.08**	**4.25 ±0.05**	**0.52 ±0.01**	**0.03 0**	–	**0.34 ±0.02**	**0.03 0**	**0.03 0**	**169**
Knee Braced	**694 0.73 ±59 ±0.06**	–	**231 0.24 ±18 ±0.02**	**2428 2.54 ±73 ±0.08**	**4680 4.89 ±77 ±0.08**	**4.27 ±0.08**	**0.52 ±0.01**	**0.02 0**	–	**0.34 ±0.01**	**0.02 0**	**0.03 0**	**163**
Back	**896 0.93 ±55 ±0.06**	–	**218 0.23 ±12 ±0.01**	**2484 2.59 ±51 ±0.05**	**4915 5.12 ±131 ±0.14**	**4.36 ±0.07**	**0.51 ±0.01**	**0.03 0**	–	**0.30 0**	**0.02 0**	**0.03 0**	**171**
Ankle	**811 0.85 ±48 ±0.05**	–	**214 0.22 ±11 ±0.01**	**2432 2.55 ±165 ±0.17**	**4727 4.95 ±189 ±0.20**	**4.16 ±0.03**	**0.53 ±0.01**	**0.03 0**	–	**0.33 ±0.01**	**0.02 0**	**0.03 0**	**165**
Outdoor n=30	**1052 1.13 ±47 ±0.05**	**301 0.32 ±99 ±0.11**	**241 0.26 ±5 ±0.01**	**2937 3.14 ±50 ±0.05**	**4718 5.05 ±111 ±0.12**	**5.31 ±0.07**	**0.48 ±0.01**	**0.02 0**	**0.03 0**	**0.29 ±0.01**	**0.03 0**	**0.02 0**	**253**

EMG : Peak reading during the delivery stride

Subject 2		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	32	2505	3135	3374	2939	2476	2529
No	33	2354	2861	3267	2783	2402	2339
Support	34	2461	2881	3350	3013	2520	2163
	35	2515	3022	3135	2896	2427	2310
	36	2520	3032	3374	2988	2769	2310
	37	2495	3018	3062	2778	2798	2754
	Mean	**2475**	**2992**	**3260**	**2900**	**2565**	**2401**
	S.E.	**26**	**42**	**54**	**41**	**71**	**85**

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	12	2461	3091	3257	2837	2646	2285
Ankle	13	2437	3159	3433	2759	2813	2495
	14	2563	3086	3271	2886	2871	2085
	15	2480	3086	3179	2856	2451	2598
	16	2490	3149	3325	2842	2710	2607
	17	2505	3018	3242	2764	2603	2344
	Mean	**2489**	**3098**	**3285**	**2824**	**2682**	**2402**
	S.E.	**18**	**21**	**35**	**21**	**62**	**83**

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	18	2461	3154	3232	3037	2783	2603
Knee	19	2549	3208	3179	2835	2505	2188
Ordinary	21	2485	2891	3271	3027	2656	2769
	22	2778	2979	3168	2700	2734	2178
	23	2524	2876	3320	2920	2700	2158
	24	2568	3208	3252	2832	2598	2495
	Mean	**2561**	**3053**	**3237**	**2892**	**2663**	**2399**
	S.E.	**46**	**64**	**23**	**53**	**41**	**106**

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	25	2456	3091	3096	2808	2588	2446
Knee	26	2559	2896	3091	2754	2544	2202
Braced	27	2617	3125	3208	2832	2520	2349
	28	2427	3145	3125	2725	2593	2446
	29	2583	2983	3130	2822	2627	2622
	30	2549	3022	3101	3120	2671	2700
	Mean	**2532**	**3044**	**3125**	**2844**	**2591**	**2461**
	S.E.	**30**	**39**	**18**	**58**	**22**	**74**

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	3	2588	3252	3325	2935	3164	2212
Back	5	2637	3013	3384	2788	2578	2744
	6	2510	3145	3110	2681	2769	2422
	7	2576	3104	3309	2886	-	2501
	10	2627	2920	3335	2944	2412	2490
	11	2510	2964	3413	2944	2759	2681
	Mean	**2575**	**3066**	**3313**	**2863**	**2736**	**2508**
	S.E.	**22**	**51**	**44**	**44**	**126**	**78**

Subject 3 : Table of Means Indoor / Outdoor Note: Indoor n=23 Knee Ordinary =5 There is no 'Knee Braced' Condition

	Peak Force (Newtons) / Body Weight %							**Time to Peak Force (seconds)**					**Loading Rate**
Indoor n=6	Medial Fx +ve	Lateral Fx -ve	Propulsive Fy +ve	Braking Fy -ve	Vertical Fz +ve	Approach Velocity (ms^{-1})	Time in Contact (second)	Fx +ve	Fx -ve	Fy +ve	Fy -ve	Fz +ve	**BW s^{-1}**
No Support	**551 0.70 ±52 ±0.07**	**56 0.07 ±21 ±0.03**	**210 0.27 ±12 ±0.01**	**2095 2.61 ±158 ±0.20**	**3487 4.41 ±186 ±0.24**	**6.46 ±0.07**	**0.37 ±0.01**	**0.05 ±0.01**	**0.01 0**	**0.27 ±0.01**	**0.05 0**	**0.03 ±0.01**	**147**
Knee Ordinary	**575 0.73 ±25 ±0.03**	**33 0.04 ±3 ±0.01**	**195 0.25 ±11 ±0.01**	**2694 3.45 ±96 ±0.12**	**3803 4.85 ±96 ±0.12**	**5.79 ±0.17**	**0.37 ±0.01**	**0.03 ±0.01**	**0.01 0**	**0.27 ±0.01**	**0.04 0**	**0.03 ±0.01**	**162**
Back	**492 0.62 ±50 ±0.06**	**54 0.07 ±10 ±0.01**	**219 0.28 ±9 ±0.01**	**1969 2.49 ±131 ±0.17**	**3498 4.42 ±153 ±0.19**	**6.53 ±0.07**	**0.35 ±0.01**	**0.03 0**	**0.01 0**	**0.25 0**	**0.05 0**	**0.02 0**	**221**
Ankle	**682 0.87 ±38 ±0.05**	**32 0.04 ±3 ±0.01**	**210 0.27 ±10 ±0.01**	**2757 3.51 ±115 ±0.15**	**3817 4.86 ±203 ±0.26**	**6.14 ±0.04**	**0.38 ±0.01**	**0.05 0**	**0.01 0**	**0.26 ±0.01**	**0.04 0**	**0.04 0**	**122**
Outdoor n=30	**745 0.95 ±19 ±0.02**	**80 0.10 ±13 ±0.02**	**303 0.39 ±5 ±0.01**	**3020 3.86 ±66 ±0.08**	**4030 5.16 ±72 ±0.09**	**5.79 ±0.02**	**0.38 ±0.01**	**0.04 0**	**0.06 0**	**0.20 0**	**0.04 0**	**0.04 0**	**129**

EMG : Peak reading during the delivery stride

Subject 3		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	14	2778	3071	2983	-	2939	2612
No	15	2886	2881	2866	3433	3135	2485
Support	16	2817	2979	2803	-	2632	2588
	21	2803	3135	3071	2284	2964	2734
	22	2876	2886	2964	3218	3008	2773
	26	2813	2988	3032	2925	2842	2524
	Mean	**2829**	**2990**	**2953**	**2965**	**2920**	**2619**
	S.E.	**17**	**41**	**41**	**250**	**70**	**47**

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	28	2935	2969	2729	2988	3101	2645
Ankle	32	2852	2956	2971	3025	2965	2612
	33	2925	2954	3032	3081	2920	2563
	35	2861	2866	3135	3047	2949	2666
	36	2820	3076	2949	3081	2773	2617
	39	2837	3174	2925	2974	2915	2471
	Mean	**2872**	**2999**	**2957**	**3023**	**2937**	**2596**
	S.E.	**19**	**44**	**55**	**19**	**43**	**29**

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	43	2990	3047	2993	3057	2925	2773
Knee	44	2925	2983	2979	3271	2979	2607
Ordinary	48	3184	2979	3062	3237	2949	2808
	49	3247	3008	2930	3389	2891	2598
	50	3267	3032	2729	3232	3008	2461
	-	-	-	-	-	-	-
	Mean	**3123**	**3010**	**2939**	**3237**	**2950**	**2649**
	S.E.	**63**	**12**	**52**	**49**	**19**	**58**

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
		-	-	-	-	-	-
Knee		-	-	-	-	-	-
Braced		-	-	-	-	-	-
		-	-	-	-	-	-
		-	-	-	-	-	-
		-	-	-	-	-	-
	Mean	-	-	-	-	-	-
	S.E.	-	-	-	-	-	-

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	3	2793	3135	3057	3066	2788	2773
Back	4	2925	3105	2998	2959	2871	2622
	6	2821	2886	2866	3057	2954	2402
	7	2896	3105	2979	3086	2891	2734
	8	-	-	-	-	-	-
	13	2969	2905	2837	3037	2676	2510
	Mean	**2881**	**3027**	**2947**	**3041**	**2836**	**2608**
	S.E.	**33**	**54**	**41**	**22**	**48**	**69**

Subject 4 : Table of Means Indoor / Outdoor

	Peak Force (Newtons) / Body Weight %							Time to Peak Force (seconds)					Loading Rate
Indoor n=6	Medial Fx -ve	Lateral Fx +ve	Propulsive Fy +ve	Braking Fy -ve	Vertical Fz +ve	Approach Velocity (ms^{-1})	Time in Contact (second)	Fx +ve	Fx -ve	Fy +ve	Fy -ve	Fz +ve	BW s^{-1}
No Support	1250 1.26 ±33 ±0.03	83 0.08 ±24 ±0.02	698 0.71 ±29 ±0.03	849 0.86 ±92 ±0.09	5643 5.70 ±225 ±0.23	4.62 ±0.07	0.40 ±0.02	0.09 ±0.02	0.02 0	0.01 0	0.03 0	0.02 0	285
Knee Ordinary	1108 1.12 ±50 ±0.05	56 0.01 ±15 ±0.01	619 0.62 ±142 ±0.14	891 0.90 ±99 ±0.10	5201 5.24 ±308 ±0.31	4.70 ±0.09	0.47 ±0.02	0.08 ±0.03	0.02 0	0.01 0	0.04 ±0.01	0.02 0	262
Knee Braced	1210 1.22 ±89 ±0.09	28 0.03 ±14 ±0.01	863 0.87 ±84 ±0.08	776 0.78 ±40 ±0.04	5151 5.19 ±296 ±0.30	4.50 ±0.05	0.52 ±0.01	0.07 0	0.01 0	0.01 0	0.03 0	0.02 0	260
Back	851 0.87 ±52 ±0.05	68 0.07 ±29 ±0.03	527 0.54 ±49 ±0.05	777 0.79 ±29 ±0.03	3968 4.06 ±249 ±0.25	4.57 ±0.08	0.46 ±0.02	0.11 ±0.05	0.02 0	0.01 0	0.04 ±0.01	0.02 0	203
Ankle	879 0.90 ±88 ±0.09	72 0.07 ±17 ±0.02	541 0.55 ±121 ±0.12	708 0.72 ±55 ±0.06	4392 4.49 ±162 ±0.17	4.52 ±0.11	0.46 ±0.02	0.07 0	0.02 0	0.02 0	0.06 ±0.01	0.02 0	225
Outdoor n=30	455 0.46 ±36 ±0.04	55 0.06 ±8 ±0.01	388 0.40 ±16 ±0.02	846 0.86 ±37 ±0.04	2893 3.15 ±133 ±0.12	3.74 ±0.04	0.23 ±0.01	0.08 ±0.01	0.01 0	0.07 ±0.01	0.03 0	0.01 0	315

EMG : Peak reading during the delivery stride

Subject 4

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	1	2759	2705	3120	3066	2690	2026
No	2	2886	2876	3018	2852	2607	1816
Support	3	2886	2920	3003	2710	2783	1416
	4	2817	3130	2939	2876	2666	1709
	5	2808	2886	2974	2871	2568	1582
	6	2813	3135	2827	3267	2778	1821
	Mean	**2828**	**2942**	**2980**	**2940**	**2682**	**1728**
	S.E.	**20**	**68**	**39**	**80**	**36**	**86**

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	13	2912	3030	3010	2743	2751	-
Ankle	14	2969	3174	2891	2827	2684	2144
	15	2891	2930	3066	2949	2764	1689
	16	2853	2891	2975	2869	2789	1428
	17	2856	2891	2866	2896	2861	1489
	18	2842	2856	2893	2820	2786	1567
	Mean	**2887**	**2962**	**2950**	**2851**	**2773**	**1663**
	S.E.	**20**	**49**	**32**	**29**	**24**	**378**

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	7	2676	3101	3184	3198	2725	1479
Knee	8	2935	2930	2861	2959	2744	1558
Ordinary	9	2813	2964	3047	2930	2666	2012
	10	2885	2849	3004	2964	2680	-
	11	2656	2954	2832	3062	2666	2051
	12	2881	3232	3179	3213	2690	2222
	Mean	**2808**	**3005**	**3018**	**3054**	**2695**	**1864**
	S.E.	**48**	**56**	**62**	**51**	**13**	**146**

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	25	2734	3013	2871	2822	2593	2119
Knee	26	2817	2993	3018	2856	2676	1387
Braced	27	2769	2949	2856	2734	2559	1704
	28	2725	2959	2827	2979	2852	1357
	29	2808	3130	2964	2974	2788	1709
	30	2695	3076	3047	3032	2847	1367
	Mean	**2758**	**3020**	**2931**	**2900**	**2719**	**1607**
	S.E.	**20**	**29**	**37**	**46**	**52**	**123**

		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	19	2788	3071	2866	3096	2617	1694
Back	20	2837	2983	2939	2974	2852	1675
	21	3008	2964	3120	2769	2681	1475
	22	2744	3154	2930	2925	2788	2339
	23	2734	3066	3115	2930	2700	2354
	24	2979	3037	3394	3057	2769	-
	Mean	**2848**	**3046**	**3061**	**2959**	**2735**	**1907**
	S.E.	**48**	**28**	**79**	**47**	**35**	**183**

Subject 5 : Table of Means Indoor / Outdoor

	Peak Force (Newtons) / Body Weight %							Time to Peak Force (seconds)					Loading Rate
Indoor n=6	Medial Fx +ve	Lateral Fx -ve	Propulsive Fy +ve	Braking Fy -ve	Vertical Fz +ve	Approach Velocity (ms^{-1})	Time in Contact (second)	Fx +ve	Fx -ve	Fy +ve	Fy -ve	Fz +ve	BW s^{-1}
No Support	**428 0.49 ±18 ±0.02**	**385 0.44 ±22 ±0.03**	**361 0.41 ±8 ±0.01**	**2628 2.99 ±118 ±0.13**	**6915 7.87 ±123 ±0.14**	**4.21 ±0.06**	**0.44 ±0.01**	**0.03 ±0.01**	**0.03 0**	**0.16 0**	**0.03 0**	**0.03 0**	**262**
Knee Ordinary	**472 0.54 ±24 ±0.03**	**333 0.38 ±48 ±0.06**	**352 0.41 ±9 ±0.01**	**2620 2.99 ±147 ±0.17**	**6942 7.93 ±227 ±0.26**	**4.07 ±0.09**	**0.44 0**	**0.03 ±0.01**	**0.03 0**	**0.17 0**	**0.03 0**	**0.03 0**	**264**
Knee Braced	**479 0.54 ±24 ±0.03**	**451 0.51 ±99 ±0.11**	**372 0.42 ±18 ±0.02**	**2866 3.26 ±149 ±0.17**	**7053 8.00 ±279 ±0.32**	**4.01 ±0.08**	**0.42 ±0.01**	**0.02 0**	**0.04 ±0.01**	**0.16 0**	**0.03 0**	**0.03 0**	**267**
Back	**471 0.54 ±36 ±0.04**	**407 0.46 ±80 ±0.09**	**357 0.41 ±10 ±0.01**	**2677 3.05 ±130 ±0.15**	**7095 8.07 ±266 ±0.30**	**4.09 ±0.04**	**0.43 ±0.01**	**0.03 ±0.01**	**0.05 ±0.02**	**0.16 0**	**0.03 0**	**0.03 0**	**269**
Ankle	**409 0.46 ±33 ±0.04**	**447 0.51 ±65 ±0.07**	**367 0.42 ±7 ±0.01**	**2866 3.26 ±113 ±0.13**	**7246 8.24 ±191 ±0.22**	**4.06 ±0.11**	**0.42 ±0.01**	**0.03 ±0.01**	**0.03 0**	**0.16 0**	**0.03 0**	**0.03 0**	**275**
Outdoor n=30	**298 0.33 ±16 ±0.02**	**328 0.36 ±22 ±0.02**	**345 0.38 ±7 ±0.01**	**2859 3.17 ±40 ±0.04**	**7832 8.67 ±72 ±0.08**	**4.83 ±0.02**	**0.41 0**	**0.02 ±0.01**	**0.03 ±0.01**	**0.14 0**	**0.02 0**	**0.02 0**	**434**

EMG : Peak reading during the delivery stride

Subject 5		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	13	3608	2935	3052	3232	2729	2603
No	14	2910	3096	2930	3105	2808	2197
Support	15	3012	2914	2876	3149	2869	2228
	16	3027	3340	2925	3213	3169	2593
	17	2998	3037	2935	3081	3013	2534
	18	3120	3076	3257	3115	2900	2847
	Mean	**3113**	**3066**	**2996**	**3149**	**2915**	**2500**
	S.E.	**103**	**62**	**57**	**25**	**64**	**101**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	1	-	-	-	-	-	-
Ankle	2	3252	3306	3125	3203	3027	3096
	3	3007	3157	3046	3152	2957	2583
	4	3105	3296	3081	3232	2920	2796
	5	3052	3223	3118	3296	2964	2910
	6	2954	3315	3057	3081	2930	2544
	Mean	**3074**	**3259**	**3085**	**3193**	**2960**	**2786**
	S.E.	**51**	**30**	**16**	**36**	**19**	**103**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	7	3096	3086	3647	3045	2817	2695
Knee	8	2930	3491	2900	3115	2749	2622
Ordinary	9	2874	3172	3052	2938	2648	2704
	10	2864	3213	2910	3183	2871	2749
	11	2949	3154	3237	3164	2939	2466
	12	3008	3145	3022	3169	2896	2437
	Mean	**2954**	**3210**	**3128**	**3102**	**2820**	**2612**
	S.E.	**36**	**59**	**115**	**39**	**44**	**54**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	25	3042	3154	3242	-	2710	2754
Knee	26	3110	3105	2993	2944	2729	2593
Braced	27	2930	3105	2954	-	2813	2480
	28	-	-	-	-	-	-
	29	-	-	-	-	-	-
	30	-	-	-	-	-	-
	Mean	**3027**	**3121**	**3063**	**2944**	**2751**	**2609**
	S.E.	**52**	**16**	**90**	**-**	**32**	**80**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	19	-	-	-	-	-	-
Back	20	2871	2925	3237	3184	2773	2554
	21	-	-	-	-	-	-
	22	2854	2968	3182	3075	2793	2504
	23	-	-	-	-	-	-
	24	2983	3096	3027	2954	2847	2490
	Mean	**2903**	**2996**	**3149**	**3071**	**2804**	**2516**
	S.E.	**40**	**51**	**63**	**66**	**22**	**19**

Subject 6 : Table of Means Indoor / Outdoor Note : Knee Ordinary n=5

	Peak Force (Newtons) / Body Weight %							**Time to Peak Force (seconds)**					**Loading Rate**
Indoor n=6	Medial Fx +ve	Lateral Fx -ve	Propulsive Fy +ve	Braking Fy -ve	Vertical Fz +ve	Approach Velocity (ms^{-1})	Time in Contact (second)	Fx +ve	Fx -ve	Fy +ve	Fy -ve	Fz +ve	**BW s^{-1}**
No Support	**1005 1.38** **±36 ±0.05**	**68 0.09** **±28 ±0.04**	**305 0.42** **±40 ±0.05**	**1206 1.65** **±64 ±0.09**	**4334 5.93** **±292 ±0.40**	**4.67** **±0.07**	**0.36** **±0.01**	**0.02** **0**	**0.05** **±0.01**	**0.20** **±0.06**	**0.02** **0**	**0.02** **0**	**297**
Knee Ordinary	**963 1.29** **±35 ±0.05**	**75 0.10** **0 0**	**222 0.30** **±7 ±0.01**	**852 1.14** **±45 ±0.06**	**3587 4.79** **±110 ±0.15**	**4.52** **±0.01**	**0.38** **±0.01**	**0.03** **0**	**0.01** **0**	**0.23** **±0.01**	**0.03** **0**	**0.03** **0**	**160**
Knee Braced	**1010 1.35** **±30 ±0.04**	–	**229 0.31** **±6 ±0.01**	**1029 1.37** **±58 ±0.08**	**3841 5.13** **±146 ±0.20**	**4.46** **±0.09**	**0.38** **±0.01**	**0.03** **0**	–	**0.24** **0**	**0.03** **0**	**0.03** **0**	**171**
Back	**923 1.24** **±26 ±0.03**	–	**211 0.28** **±7 ±0.01**	**962 1.29** **±67 ±0.09**	**3665 4.90** **±205 ±0.27**	**4.55** **±0.04**	**0.35** **±0.01**	**0.03** **0**	–	**0.24** **0**	**0.03** **0**	**0.03** **0**	**163**
Ankle	**891 1.22** **±49 ±0.07**	**25 0.03** **±2 0**	**235 0.32** **±4 ±0.01**	**1093 1.49** **±113 ±0.15**	**3611 4.93** **±137 ±0.19**	**4.59** **±0.05**	**0.36** **±0.01**	**0.03** **0**	**0.12** **±0.03**	**0.24** **±0.01**	**0.03** **0**	**0.03** **0**	**164**
Outdoor **n=30**	**868 1.11** **±28 ±0.04**	**81 0.10** **±12 ±0.02**	**284 0.36** **±8 ±0.02**	**1060 1.36** **±46 ±0.06**	**3775 4.83** **±139 ±0.18**	**4.55** **±0.06**	**0.36** **±0.01**	**0.03** **0**	**0.02** **±0.01**	**0.19** **±0.02**	**0.03** **0**	**0.02** **0**	**242**

EMG : Peak reading during the delivery stride

Subject 6		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	1	2471	3306	3188	2139	2437	1436
No	2	2622	3286	3228	2334	2612	2002
Support	3	2713	3108	3207	2257	2756	1962
	4	2563	3047	3179	2056	2725	2026
	5	2657	3086	3128	2109	2607	2076
	6	2915	3042	3179	1943	2803	1533
	Mean	**2657**	**3146**	**3185**	**2140**	**2657**	**1839**
	S.E.	**62**	**49**	**14**	**57**	**54**	**114**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	7	2715	3311	3315	2021	2100	1426
Ankle	8	2402	3232	3296	2588	2227	1504
	9	2896	3208	3042	2358	2280	1387
	10	2529	3203	2959	1934	2349	1880
	11	2642	3311	3438	2139	2119	1875
	12	2759	3271	3022	2246	2217	1748
	Mean	**2657**	**3256**	**3179**	**2214**	**2215**	**1637**
	S.E.	**71**	**20**	**80**	**97**	**39**	**92**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	25	2632	3105	3042	1748	1929	1294
Knee	26	2437	2915	3032	1484	2114	1523
Ordinary	27	2412	2993	3218	2539	2168	1479
	28	2178	3105	3022	2456	2139	2012
	29	2529	3101	3062	2720	2510	1509
	30	2139	3091	3062	2290	2559	1372
	Mean	**2388**	**3052**	**3073**	**2206**	**2237**	**1532**
	S.E.	**79**	**33**	**30**	**198**	**100**	**103**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	19	2217	3091	3154	1758	2427	1748
Knee	20	2378	3146	3079	1785	2377	1652
Braced	21	2578	3130	2920	1606	2441	1899
	22	2437	3203	3009	2207	2461	2041
	23	2041	3154	2979	1489	2148	1392
	-	-	-	-	-	-	-
	Mean	**2330**	**3145**	**3028**	**1769**	**2371**	**1746**
	S.E.	**93**	**18**	**41**	**122**	**57**	**111**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	13	2334	3120	3096	2427	2563	1738
Back	14	2319	3120	3237	2070	2324	2012
	15	2490	3320	3105	2207	2153	2075
	16	2456	3330	3110	1606	2158	1470
	17	3105	3315	3828	2314	2114	2051
	18	2378	3228	3193	1846	2427	2451
	Mean	**2514**	**3239**	**3262**	**2078**	**2290**	**1966**
	S.E.	**121**	**40**	**116**	**125**	**73**	**136**

Subject 7 : Table of Means Indoor / Outdoor

	Peak Force (Newtons) / Body Weight %							Time to Peak Force (seconds)					Loading Rate
Indoor n=6	Medial Fx +ve	Lateral Fx -ve	Propulsive Fy +ve	Braking Fy -ve	Vertical Fz +ve	Approach Velocity (ms^{-1})	Time in Contact (second)	Fx +ve	Fx -ve	Fy +ve	Fy -ve	Fz +ve	BW s^{-1}
No Support	**677 0.91 ±20 ±0.03**	**122 0.16 ±9 ±0.01**	**280 0.38 ±16 ±0.02**	**808 1.08 ±47 ±0.06**	**3820 5.11 ±136 ±0.18**	**4.12 ±0.09**	**0.35 ±0.01**	**0.03 0**	**0.07 0**	**0.05 ±0.04**	**0.03 0**	**0.02 0**	**256**
Knee Ordinary	**609 0.82 ±41 ±0.06**	**98 0.13 ±8 ±0.01**	**179 0.24 ±6 ±0.01**	**984 1.32 ±58 ±0.08**	**4175 5.62 ±96 ±0.13**	**4.22 ±0.06**	**0.37 ±0.02**	**0.03 0**	**0.08 0**	**0.24 ±0.01**	**0.03 0**	**0.03 0**	**187**
Knee Braced	**758 1.00 ±52 ±0.07**	**86 0.11 ±11 ±0.01**	**272 0.36 ±31 ±0.04**	**937 1.24 ±74 ±0.10**	**3497 4.64 ±148 ±0.20**	**4.17 ±0.05**	**0.35 ±0.01**	**0.03 0**	**0.07 0**	**0.12 ±0.05**	**0.03 0**	**0.03 0**	**155**
Back	**615 0.82 ±31 ±0.04**	**106 0.14 ±34 ±0.05**	**248 0.33 ±19 ±0.03**	**688 0.92 ±70 ±0.09**	**3593 4.80 ±258 ±0.35**	**4.12 ±0.05**	**0.36 ±0.02**	**0.02 0**	**0.07 0**	**0.04 ±0.05**	**0.03 0**	**0.02 0**	**240**
Ankle	**712 0.96 ±34 ±0.05**	**126 0.17 ±7 ±0.01**	**221 0.30 ±30 ±0.04**	**843 1.13 ±51 ±0.07**	**3893 5.24 ±219 ±0.29**	**4.32 ±0.02**	**0.34 0**	**0.03 0**	**0.07 0**	**0.20 ±0.04**	**0.03 0**	**0.02 0**	**262**
Outdoor n=30	**901 1.19 ±23 ±0.03**	**48 0.06 ±11 ±0.01**	**302 0.40 ±12 ±0.02**	**1250 1.65 ±35 ±0.05**	**3975 5.24 ±69 ±0.09**	**4.13 ±0.05**	**0.36 ±0.01**	**0.02 0**	**0.01 0**	**0.18 ±0.02**	**0.02 0**	**0.02 0**	**262**

EMG : Peak reading during the delivery stride

Subject 7		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	13	2656	3091	3135	2676	1758	1904
No	14	2583	3306	3164	1958	2293	1738
Support	15	2246	2959	3242	2144	2061	1963
	16	2563	2905	3076	2217	1675	2578
	17	2178	2979	3252	2168	2690	1914
	18	2271	3198	3052	1680	2061	1684
	Mean	**2416**	**3073**	**3154**	**2141**	**2090**	**1964**
	S.E.	**84**	**63**	**34**	**134**	**151**	**131**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	7	2578	3228	2964	1895	2017	2036
Ankle	8	2510	3071	3169	2310	1592	1865
	9	2334	3223	3018	1685	2427	2070
	10	2197	3169	2974	1792	2437	1499
	11	2891	3022	3066	2271	1548	1748
	12	2285	3013	2954	2632	1733	1548
	Mean	**2466**	**3121**	**3024**	**2098**	**1959**	**1794**
	S.E.	**103**	**40**	**34**	**149**	**164**	**98**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	1	2354	3315	3472	1689	1899	2534
Knee	2	2178	3115	3071	1831	2695	2090
Ordinary	3	2793	2964	3115	1621	2031	2461
	4	2515	3320	3071	1714	1880	2026
	5	2290	3086	3140	1499	1807	1260
	6	2568	3154	3008	1372	1899	1333
	Mean	**2450**	**3159**	**3146**	**1621**	**2035**	**1951**
	S.E.	**90**	**56**	**68**	**67**	**135**	**222**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	25	2754	3223	2959	2007	1860	2715
Knee	26	2241	3125	3140	1221	2222	2744
Braced	27	2563	3071	3145	1689	2163	2690
	28	2158	3237	3159	1870	1851	2788
	29	2471	3091	3066	1787	1865	2715
	30	2095	3184	3154	1860	1890	2720
	Mean	**2380**	**3155**	**3104**	**1739**	**1975**	**2729**
	S.E.	**105**	**28**	**32**	**112**	**69**	**14**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	19	2407	3003	3071	2388	1533	2139
Back	20	2437	3086	3105	1855	2183	2690
	21	2168	3081	3066	2354	2148	2559
	22	2261	2852	3062	2368	2192	2651
	23	2451	3179	3081	1719	1709	2637
	24	2637	3037	2891	2412	2563	2700
	Mean	**2394**	**3040**	**3046**	**2183**	**2055**	**2563**
	S.E.	**67**	**45**	**32**	**127**	**152**	**87**

Subject 8 : Table of Means Indoor / Outdoor Note: ‘Back’ n=5

	Peak Force (Newtons) / Body Weight %							Time to Peak Force (seconds)					Loading Rate
Indoor n=6	Medial Fx +ve	Lateral Fx -ve	Propulsive Fy +ve	Braking Fy -ve	Vertical Fz +ve	Approach Velocity (ms^{-1})	Time in Contact (second)	Fx +ve	Fx -ve	Fy +ve	Fy -ve	Fz +ve	BW s^{-1}
No Support	**1034 1.19 ±54 ±0.06**	–	**232 0.27 ±18 ±0.02**	**3017 3.49 ±91 ±0.11**	**5344 6.17 ±146 ±0.17**	**5.42 ±0.07**	**0.36 ±0.02**	**0.05 0**	–	**0.19 ±0.01**	**0.04 0**	**0.04 0**	**154**
Knee Ordinary	**925 1.08 ±42 ±0.05**	–	**138 0.16 ±8 ±0.01**	**2936 3.42 ±107 ±0.12**	**5109 5.95 ±175 ±0.20**	**5.01 ±0.06**	**0.42 ±0.01**	**0.05 0**	–	**0.25 ±0.01**	**0.04 0**	**0.04 0**	**149**
Knee Braced	**963 1.12 ±26 ±0.03**	–	**130 0.15 ±9 ±0.01**	**3030 3.53 ±51 ±0.06**	**5100 5.94 ±114 ±0.13**	**4.99 ±0.06**	**0.40 ±0.02**	**0.04 0**	–	**0.21 ±0.01**	**0.04 ±0.01**	**0.04 0**	**149**
Back (n=5)	**1036 1.21 ±54 ±0.06**	–	**126 0.15 ±10 ±0.01**	**3150 3.66 ±151 ±0.18**	**5159 6.00 ±214 ±0.25**	**4.99 ±0.07**	**0.38 ±0.01**	**0.03 0**	–	**0.26 ±0.01**	**0.03 0**	**0.03 0**	**200**
Ankle	**849 0.98 ±53 ±0.04**	–	**179 0.21 ±23 ±0.03**	**3058 3.48 ±82 ±0.11**	**5042 5.82 ±185 ±0.22**	**5.07 ±0.07**	**0.40 ±0.02**	**0.04 0**	–	**0.21 ±0.01**	**0.04 0**	**0.04 0**	**146**
Outdoor n=30	**973 1.12 ±24 ±0.03**	**74 0.08 ±14 ±0.02 (n=5)**	**188 0.22 ±6 ±0.01**	**3259 3.73 ±49 ±0.06**	**5400 6.19 ±75 ±0.09**	**5.16 ±0.02**	**0.39 ±0.01**	**0.03 0**	**0.09 ±0.02 (n=5)**	**0.18 0**	**0.03 0**	**0.04 0**	**155**

EMG : Peak reading during the delivery stride

Subject 8		Calf	Quad	Hamstring	R. Back	L. Back	Abds
	1	3159	3286	3135	2842	3086	2212
No	2	3125	3091	3076	2969	3174	1919
Support	3	3101	3198	2979	3081	3091	1792
	4	3105	3076	2993	2832	3062	1650
	5	3127	3147	2989	2834	3048	1705
	6	3101	3213	2974	2754	3091	1631
	Mean	**3120**	**3169**	**3024**	**2885**	**3092**	**1818**
	S.E.	**9**	**32**	**27**	**48**	**18**	**90**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	7	3105	3291	3057	2900	3115	2256
Ankle	8	3140	3179	3237	3013	2988	2021
	9	3037	3120	3096	2769	3066	1758
	10	3218	3208	3145	2905	3086	2725
	11	2974	3003	3076	2852	3203	1699
	12	3027	3110	2980	2913	2959	1553
	Mean	**3084**	**3152**	**3099**	**2892**	**3070**	**2002**
	S.E.	**36**	**40**	**35**	**33**	**36**	**177**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	13	3086	3052	2988	2944	-	2051
Knee	14	2998	3184	2905	2796	-	1836
Ordinary	15	3164	3198	3164	2949	-	2187
	16	3062	3198	2983	2988	-	2842
	17	3135	3228	3115	2808	-	1914
	18	3013	2925	3237	2900	-	1885
	Mean	**3076**	**3131**	**3065**	**2898**	**-**	**2119**
	S.E.	**27**	**48**	**52**	**32**	**-**	**154**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	19	2974	3193	2954	3008	2998	2085
Knee	20	3091	3091	3037	2754	2925	1489
Braced	21	3125	3022	3003	2749	2725	1792
	22	3052	3086	3110	2896	-	-
	23	2959	3047	-	-	-	-
	24	3032	-	-	-	-	-
	Mean	**3039**	**3088**	**3026**	**2852**	**2883**	**1789**
	S.E.	**26**	**29**	**33**	**62**	**82**	**172**
		Calf	**Quad**	**Hamstring**	**R. Back**	**L. Back**	**Abds**
	25	-	-	-	-	-	-
Back	26	3164	3008	3306	2764	3018	1899
	27	3003	3086	3110	2979	3018	2231
	28	3784	3799	3140	3042	2964	1973
	29	3305	3148	3247	2849	2876	2093
	30	3149	3057	3125	2976	2977	2031
	Mean	**3281**	**3220**	**3186**	**2922**	**2971**	**2045**
	S.E.	**135**	**147**	**39**	**50**	**26**	**56**

SPSS for MS WINDOWS Release 6.1

EXPERIMENT 1 : FAST-MEDIUM BOWLING IN CRICKET

FRONT FOOT : GROUND REACTION FORCES AND ASSOCIATED TEMPORAL DATA.

(EIGHT SUBJECTS : FIVE TEST CONDITIONS)
N.B. KNEE 2 N=7 SUBJECTS

******** RESULTS OF ONE WAY ANOVA REPEATED DESIGN ********

MEDIAL

Number of valid observations (listwise) = 7.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
ANKLE	.83	.10	.28	.85	.37	1.22	8
BACK	.84	.10	.28	.72	.52	1.24	8
KNEE 1	.86	.10	.28	.80	.49	1.29	8
NO SUPPORT	.88	.13	.37	.99	.39	1.38	8
KNEE 2	.91	.13	.35	.92	.43	1.35	7

7 cases accepted.
0 cases rejected because of out-of-range factor values.
1 case rejected because of missing data.
1 non-empty cell.

1 design will be processed.

Tests involving '**CONDITION**' Within-Subject Effect.

AVERAGED Tests of Significance for MEAS.1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	.22	24	.01		
CONDITION	.04	4	.01	1.03	**.41**

Tests involving '**CONDITION**' Within-Subject Effect

Mauchly sphericity test, W = .03125
Chi-square approx. = 15.30645 with 9 D.F.
Significance = .083

LATERAL

Number of valid observations (listwise) = 4.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
KNEE 1	.12	.05	.13	.37	.01	.38	6
ANKLE	.15	.07	.18	.48	.03	.51	6
NO SUPPORT	.16	.05	.13	.37	.07	.44	7
BACK	.16	.08	.17	.39	.07	.46	5
KNEE 2	.19	.11	.22	.48	.03	.51	4

4 cases accepted.
0 cases rejected because of out-of-range factor values.
4 cases rejected because of missing data.
1 non-empty cell.

1 design will be processed.

ANOVA not performed due to small sample size.

BRAKING

Number of valid observations (listwise) = 7.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
BACK	2.10	.37	1.04	2.87	.79	3.66	8
KNEE 2	2.14	.40	1.05	2.75	.78	3.53	7
NO SUPPORT	2.17	.33	.92	2.63	.86	3.49	8
KNEE 1	2.22	.36	1.03	2.55	.90	3.45	8
ANKLE	2.31	.39	1.09	2.79	.72	3.51	8

7 cases accepted.
0 cases rejected because of out-of-range factor values.
1 case rejected because of missing data.
1 non-empty cell.

1 design will be processed.

Tests involving **'CONDITION'** Within-Subject Effect.

AVERAGED Tests of Significance for MEAS.1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	.41	24	.02		
CONDITION	.07	4	.02	.99	**.43**

Tests involving **'CONDITION'** Within-Subject Effect

Mauchly sphericity test, W = .3767
Chi-square approx. = 14.48231 with 9 D.F.
Significance = .106

PROPULSIVE

Number of valid observations (listwise) = 7.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
BACK	.31	.04	.12	.39	.15	.54	8
KNEE 1	.31	.05	.14	.46	.16	.62	8
ANKLE	.32	.04	.12	.34	.21	.55	8
NO SUPPORT	.37	.06	.16	.49	.22	.71	8
KNEE 2	.37	.09	.24	.72	.15	.87	7

7 cases accepted.
0 cases rejected because of out-of-range factor values.
1 case rejected because of missing data.
1 non-empty cell.

1 design will be processed.

ANOVA not performed due to data fails normality assumptions

VERTICAL

Number of valid observations (listwise) = 7.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
BACK	5.12	.49	1.40	4.51	3.56	8.07	8
ANKLE	5.32	.46	1.29	4.22	4.02	8.24	8
KNEE 1	5.39	.43	1.23	4.27	3.66	7.93	8
KNEE 2	5.40	.49	1.29	4.02	3.98	8.00	7
NO SUPPORT	5.48	.44	1.25	4.07	3.80	7.87	8

7 cases accepted.
0 cases rejected because of out-of-range factor values.
1 case rejected because of missing data.
1 non-empty cell.

1 design will be processed.

Tests involving '**CONDITION**' Within-Subject Effect.

AVERAGED Tests of Significance for MEAS.1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	2.89	24	.12		
CONDITION	.62	4	.16	1.30	**.30**

Tests involving '**CONDITION**' Within-Subject Effect

Mauchly sphericity test, W = .16091
Chi-square approx. = 8.06882 with 9 D.F.
Significance = .527

APPROACH VELOCITY

Number of valid observations (listwise) = 7.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
KNEE 2	4.55	.19	.50	1.41	4.01	5.42	7
KNEE 1	4.75	.22	.62	1.72	4.07	5.79	8
ANKLE	4.75	.24	.69	2.08	4.06	6.14	8
BACK	4.80	.28	.80	2.44	4.09	6.53	8
NO SUPPORT	4.85	.28	.78	2.34	4.12	6.46	8

7 cases accepted.
0 cases rejected because of out-of-range factor values.
1 case rejected because of missing data.
1 non-empty cell.

1 design will be processed.

Tests involving **'CONDITION'** Within-Subject Effect.

AVERAGED Tests of Significance for MEAS.1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	.36	24	.02		
CONDITION	.03	4	.01	.53	**.72**

Tests involving **'CONDITION'** Within-Subject Effect

Mauchly sphericity test, W = .05902
Chi-square approx. = 12.49836 with 9 D.F.
Significance = .187

LOADING RATES

Number of valid observations (listwise) = 7.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
KNEE 1	184.30	18.40	52.04	142.33	122.00	264.33	8
KNEE 2	185.14	20.64	54.61	134.00	132.67	266.67	7
ANKLE	186.44	20.93	59.20	153.17	121.50	274.67	8
BACK	198.21	16.69	47.22	150.33	118.67	269.00	8
NO SUPPORT	221.03	23.88	67.53	169.83	126.67	296.50	8

7 cases accepted.
0 cases rejected because of out-of-range factor values.
1 case rejected because of missing data.
1 non-empty cell.

1 design will be processed.

Tests involving **'CONDITION'** Within-Subject Effect.

AVERAGED Tests of Significance for MEAS.1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	23922.25	24	996.76		
CONDITION	9896.68	4	2474.17	2.48	**.07**

Tests involving **'CONDITION'** Within-Subject Effect

Mauchly sphericity test, W = .04537
Chi-square approx. = 13.66061 with 9 D.F.
Significance = .135

SPSS for MS WINDOWS 6.1

EXPERIMENT 1 : FAST-MEDIUM BOWLING IN CRICKET

The effect of athletic support location on ground reaction forces and electromyography during the delivery stride of fast-medium bowlers in cricket.

****** RESULTS OF ONE WAY ANOVA REPEATED DESIGN ******

ELECTROMYOGRAPHIC ANALYSIS : 6 SELECTED MUSCLES
MAXIMAL RECORDED VALUE DURING THE DELIVERY STRIDE

(EIGHT SUBJECTS : FIVE TEST CONDITIONS)

GASTRONEMIOUS (GA)

Number of valid observations (listwise) = 7.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
KNEE 2	2660.38	109.35	289.32	708.63	2330.20	3038.83	7
KNEE 1	2747.76	100.28	283.63	734.77	2387.83	3122.60	8
BACK	2751.29	100.34	283.79	887.50	2393.50	3281.00	8
NO SUPPORT	2753.44	94.64	267.67	703.50	2416.17	3119.67	8
ANKLE	2768.54	86.74	245.35	617.67	2465.83	3083.50	8

7 cases accepted.
0 cases rejected because of out-of-range factor values.
1 case rejected because of missing data.
1 non-empty cell.

1 design will be processed.

Tests involving '**CONDITION**' Within-Subject Effect.

AVERAGED Tests of Significance for MEAS.1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	139088.96	24	5795.37		
CONDITION	41910.65	4	10477.66	1.81	**.16**

Tests involving '**CONDITION**' Within-Subject Effect

Mauchly sphericity test, W = .02264
Chi-square approx. = 19.30562 with 9 D.F.
Significance = .063

RECTUS FEMORIS (RF)

Number of valid observations (listwise) = 7.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
BACK	3064.75	40.96	115.86	354.66	2884.17	3238.83	8
NO SUPPORT	3065.21	29.82	84.34	226.50	2942.00	3168.50	8
KNEE 1	3065.43	34.60	97.86	305.84	2904.33	3210.17	8
KNEE 2	3085.73	21.32	56.40	135.17	3020.00	3155.17	7
ANKLE	3110.41	39.04	110.43	297.40	2962.00	3259.40	8

7 cases accepted.
0 cases rejected because of out-of-range factor values.
1 case rejected because of missing data.
1 non-empty cell.

1 design will be processed.

Tests involving '**CONDITION**' Within-Subject Effect.

AVERAGED Tests of Significance for MEAS.1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	136550.38	24	5689.60		
CONDITION	14952.90	4	3738.22	.66	**.63**

Tests involving '**CONDITION**' Within-Subject Effect

Mauchly sphericity test, W = .27214
Chi-square approx. = 5.74804 with 9 D.F.
Significance = .765

BICEPS FEMORIS (BF)

Number of valid observations (listwise) = 7.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
KNEE 2	3051.81	24.55	64.96	194.67	2930.50	3125.17	7
KNEE 1	3080.68	31.93	90.31	298.40	2938.60	3237.00	8
ANKLE	3085.84	39.55	111.87	334.33	2950.17	3284.50	8
NO SUPPORT	3091.96	41.13	116.32	307.16	2953.17	3260.33	8
BACK	3124.54	43.98	124.39	365.27	2947.40	3312.67	8

7 cases accepted.
0 cases rejected because of out-of-range factor values.
1 case rejected because of missing data.
1 non-empty cell.

1 design will be processed.

Tests involving **'CONDITION'** Within-Subject Effect.

AVERAGED Tests of Significance for MEAS.1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	93015.39	24	3875.64		
CONDITION	34263.49	4	8565.87	2.21	**.10**

Tests involving **'CONDITION'** Within-Subject Effect

Mauchly sphericity test, W = .09684
Chi-square approx. = 10.31173 with 9 D.F.
Significance = .326

RIGHT LOWER LATTISSIMUS DORSI (RL)

Number of valid observations (listwise) = 7.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
KNEE 2	2550.82	206.41	546.10	1205.00	1739.00	2944.00	7
KNEE 1	2744.15	193.80	548.15	1616.20	1621.00	3237.20	8
ANKLE	2744.54	135.93	384.46	1095.30	2097.50	3192.80	8
BACK	2753.54	138.40	391.45	992.67	2078.33	3071.00	8
NO SUPPORT	2756.17	137.48	388.86	1009.50	2139.67	3149.17	8

7 cases accepted.
0 cases rejected because of out-of-range factor values.
33 cases rejected because of missing data.
1 non-empty cell.

1 design will be processed.

Tests involving **'CONDITION'** Within-Subject Effect.

AVERAGED Tests of Significance for MEAS.1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	335588.48	24	13982.85		
CONDITION	141770.51	4	35442.63	2.53	**.07**

Tests involving **'CONDITION'** Within-Subject Effect

Mauchly sphericity test, W = .093031
Chi-square approx. = 18.66043 with 9 D.F.
Significance = .140

LEFT LOWER LATTISSIMUS DORSI (LL)

Number of valid observations (listwise) = 6.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
KNEE 2	2568.00	115.49	305.57	907.50	1975.17	2882.67	7
KNEE 1	2584.44	123.63	327.10	915.23	2035.17	2950.40	7
BACK	2626.50	108.53	306.98	915.93	2054.67	2970.60	8
ANKLE	2650.55	136.18	385.16	1110.50	1959.00	3069.50	8
NO SUPPORT	2699.73	107.03	302.72	1002.33	2089.67	3092.00	8

6 cases accepted.
0 cases rejected because of out-of-range factor values.
2 cases rejected because of missing data.
1 non-empty cell.

1 design will be processed.

Tests involving **'CONDITION'** Within-Subject Effect.

AVERAGED Tests of Significance for MEAS.1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	178438.93	20	8921.95		
CONDITION	25643.90	4	6410.97	.72	**.59**

Tests involving **'CONDITION'** Within-Subject Effect

Mauchly sphericity test, W = .06844
Chi-square approx. = 9.16303 with 9 D.F.
Significance = .422

RECTUS ABDOMINUS (RA)

Number of valid observations (listwise) = 7.00

Variable	Mean	S.E.Mean	Std Dev	Range	Minimum	Maximum	Valid N
NO SUPPORT	2214.54	151.02	427.16	1118.34	1728.33	2846.67	8
ANKLE	2221.55	180.53	510.61	1255.50	1636.67	2892.17	8
KNEE 2	2252.32	195.99	518.54	1218.33	1607.17	2825.50	7
KNEE 1	2260.41	168.19	475.71	1426.00	1531.50	2957.50	8
BACK	2351.48	113.50	321.02	790.27	1907.40	2697.67	8

7 cases accepted.
0 cases rejected because of out-of-range factor values.
1 case rejected because of missing data.
1 non-empty cell.

1 design will be processed.

Tests involving **'CONDITION'** Within-Subject Effect.

AVERAGED Tests of Significance for MEAS.1 using UNIQUE sums of squares

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	938144.11	24	39089.34		
CONDITION	118713.18	4	29678.29	.76	**.56**

Tests involving **'CONDITION'** Within-Subject Effect

Mauchly sphericity test, W = .06006
Chi-square approx. = 12.42130 with 9 D.F.
Significance = .191

APPENDIX D

A biomechanical investigation into the effect of lumbar supports during the javelin throw.

Experiment 2.

Subject 1

Date of Testing : 7.7.1993

Age : 19.7 years   Body Weight : 912 Newtons   Height 1.85 m

	Belt A	Belt B	Belt C
GRF : Test Number	7	15	24
Peak VGRF (Newtons)	4911	5019	4408
Body Weight (BW)	5.38	5.50	4.83
Time to Peak (ms)	42.5	46.7	44.8
Loading Rate (BW s^{-1})	127	118	108
Peak APGRF (Newtons)	3763	3226	3030
Body Weight (BW)	4.12	3.54	3.32
Time to Peak (ms)	40.5	42.8	40.0
Contact Time (ms)	396	318	350
EMG : Test Number	7	11	16
2D Cinematography : File Name	C/JAV 2	C/JAV 5	C/JAV 7
Peak Linear Speed (m s^{-1})			
Right Hip	6.52	5.90	5.84
Right Shoulder	7.38	7.40	7.02
Right Elbow	13.41	11.79	11.63
Right Wrist	17.47	16.30	16.03
Right 3rd Finger	22.00	20.78	19.89
Grip	21.41	21.07	20.28
Javelin Attitude Angle (degrees) at the point of release.	34.0	31.4	32.6
DISTANCE (m)	52.66	49.74	44.10

Subject 2

Date of Testing : 26.07.1993

Age : 22.7 years   Body Weight : 897 Newtons   Height 1.87 m

	Belt A	Belt B	Belt C
GRF : Test Number	7	31	3
Peak VGRF (Newtons)	3696	3824	4433
Body Weight (BW)	4.12	4.26	4.94
Time to Peak (ms)	40.2	9.4	11.7
Loading Rate (BW s^{-1})	102	453	422
Peak APGRF (Newtons)	2969	3230	2827
Body Weight (BW)	3.31	3.60	3.15
Time to Peak (ms)	36.0	40.5	39.0
Contact Time (ms)	598	604	648
EMG : Test Number	7	22	5
2D Cinematography : File Name	C/AH1	C/AH3	C/AH6
Peak Linear Speed (m s^{-1})			
Right Hip	4.27	8.25	5.69
Right Shoulder	6.31	9.92	6.64
Right Elbow	10.20	14.67	14.14
Right Wrist	13.30	19.88	17.38
Right 3rd Finger	14.29	23.59	22.19
Grip	18.94	24.56	22.67
Javelin Attitude Angle (degrees) at the point of release.	35.6	37.4	38.9
DISTANCE (m)	52.51	56.90	49.43

Subject 3

Date of Testing : 23.3.1993 / 30.03.1993

Age : 21.4 years   Body Weight : 780 Newtons   Height 1.77 m

	Belt A	Belt B	Belt C
GRF : Test Number	7	27	47
Peak VGRF (Newtons)	5327	3485	3310
Body Weight (BW)	6.83	4.47	4.24
Time to Peak (ms)	33.1	33.4	38.6
Loading Rate (BW s^{-1})	206	134	110
Peak APGRF (Newtons)	2617	1758	5381
Body Weight (BW)	3.36	2.25	6.89
Time to Peak (ms)	31.8	31.8	43.3
Contact Time (ms)	431	428	396
EMG : Test Number	7	4	20
2D Cinematography : File Name	C/P1	C/P2	C/PAUL
Peak Linear Speed (m s^{-1})			
Right Hip	6.55	6.98	5.82
Right Shoulder	7.57	8.59	8.32
Right Elbow	14.24	15.60	13.18
Right Wrist	18.67	20.32	17.34
Right 3rd Finger	23.58	24.76	22.86
Grip	23.12	25.03	22.06
Javelin Attitude Angle (degrees) at the point of release.	40.4	38.9	38.6
DISTANCE (m)	52.89	55.58	48.36

APPENDIX E

An investigation of performance whilst wearing a lumbar support belt during an two-handed overhead throwing task.

Experiment 3 / 3A 'Medicine Ball'

EXPERIMENT 3

Group 1: 24 Male Subjects: Averages / Distances (metres) **Order A & B**

	10 Throws		
	No Belt	Belt	Difference
1A	10.37	11.09	**0.72**
2B	11.08	11.27	**0.19**
3A	10.03	10.13	**0.10**
4B	12.86	13.12	**0.26**
5A	12.32	12.16	**-0.16**
6B	11.87	11.80	**-0.07**
7A	12.81	13.33	**0.52**
8B	10.13	10.45	**0.32**
9A	10.71	11.18	**0.47**
10B	10.31	10.20	**-0.11**
11A	13.26	13.73	**0.47**
12B	12.41	12.47	**0.06**
13A	11.23	11.75	**0.52**
14B	10.83	11.06	**0.23**
15A	9.52	9.93	**0.41**
16B	8.74	8.84	**0.10**
17A	10.90	11.63	**0.73**
18B	11.59	11.39	**-0.20**
19A	10.72	11.25	**0.53**
20B	12.52	12.92	**0.40**
21A	10.77	11.78	**1.01**
22B	12.91	13.30	**0.39**
23A	12.34	12.70	**0.36**
24B	12.01	12.77	**0.76**
Average	**11.34**	**11.68**	**0.33**
S.E.	**0.24**	**0.25**	**0.06**

't' Value **5.27**

Differnce in the Mean Distances

Null Hypothesis Ho : No Difference in the means

Alterantive Hypothesis H1 : Difference in the Means

t = 5.27

Critical 't' value at 0.01 Level (two-tail) 23 DF = 2.807

Reject Null Hypothesis : Significant Difference between the two conditions

Group 1: 12 Male Subjects : Averages / Distances (metres) Order A

10 Throws

	No Belt	Belt	Difference
1A	10.37	11.09	**0.72**
3A	10.03	10.13	**0.10**
5A	12.32	12.16	**-0.16**
7A	12.81	13.33	**0.52**
9A	10.71	11.18	**0.47**
11A	13.26	13.73	**0.47**
13A	11.23	11.75	**0.52**
15A	9.52	9.93	**0.41**
17A	10.90	11.63	**0.73**
19A	10.72	11.25	**0.53**
21A	10.77	11.78	**1.01**
23A	12.34	12.70	**0.36**
Average	**11.25**	**11.72**	**0.47**
S.E.	**0.34**	**0.33**	**0.09**

Group 1: 12 Male Subjects : Averages / Distances (metres) Order B

10 Throws

	No Belt	Belt	Difference
2B	11.08	11.27	**0.19**
4B	12.86	13.12	**0.26**
6B	11.87	11.80	**-0.07**
8B	10.13	10.45	**0.32**
10B	10.31	10.20	**-0.11**
12B	12.41	12.47	**0.06**
14B	10.83	11.06	**0.23**
16B	8.74	8.84	**0.10**
18B	11.59	11.39	**-0.20**
20B	12.52	12.92	**0.40**
22B	12.91	13.30	**0.39**
24B	12.01	12.77	**0.76**
Average	**11.44**	**11.63**	**0.19**
S.E.	**0.37**	**0.39**	**0.08**

Summary Table 1A : Physical Characteristics
GROUP 1 : 12 Male Subjects : Order A (Novice)

Subject No Order A	Height (m)	Leg Length (m)	Length of Spine (m)	Mass (kg)
1A.	1.90	1.08	0.65	93.5
3A.	1.70	0.98	0.56	64.0
5A.	1.82	1.04	0.59	85.4
7A.	1.76	1.00	0.60	88.5
9A.	1.82	1.04	0.60	78.0
11A.	1.76	1.00	0.56	78.8
13A.	1.72	0.97	0.58	74.6
15A.	1.74	0.98	0.60	72.5
17A.	1.70	0.96	0.57	96.8
19A.	1.88	1.07	0.64	91.8
21A.	1.72	0.98	0.56	66.7
23A.	1.90	1.08	0.66	98.6
Mean	**1.79**	**1.02**	**0.60**	**82.4**
S.E. ±	**0.02**	**0.01**	**0.01**	**3.23**

Summary Table 1B : Physical Characteristics
GROUP 1 : 12 Male Subjects : Order B (Novice)

Subject No Order B	Height (m)	Leg Length (m)	Length of Spine (m)	Mass (kg)
2B.	1.91	1.09	0.66	95.2
4B.	1.75	0.99	0.60	88.7
6B.	1.76	1.02	0.57	83.0
8B.	1.80	1.02	0.60	80.6
10B.	1.84	1.05	0.61	81.0
12B.	1.84	1.05	0.59	82.3
14B.	1.73	0.98	0.58	72.0
16B.	1.72	0.97	0.58	69.3
18B.	1.69	0.97	0.56	73.4
20B.	1.80	1.00	0.64	80.2
22B.	1.84	1.04	0.64	90.4
24B.	1.76	0.98	0.62	74.2
Mean	**1.79**	**1.01**	**0.60**	**80.8**
S.E. ±	**0.02**	**0.01**	**0.01**	**2.17**

Group 2: 16 Female Subjects: Averages / Distances (metres) Order A & B

10 Throws

	No Belt	Belt	Difference
1A.	7.31	7.76	**0.45**
2B.	7.42	7.94	**0.52**
3A.	8.30	8.51	**0.21**
4B.	7.10	7.51	**0.41**
5A.	7.27	7.37	**0.10**
6B.	10.86	11.09	**0.23**
7A.	10.56	10.63	**0.07**
8B.	10.40	11.20	**0.80**
9A.	8.42	8.38	**-0.04**
10B.	13.13	14.08	**0.95**
11A.	10.79	11.11	**0.32**
12B.	10.15	10.16	**0.01**
13A.	11.92	12.54	**0.62**
14B.	10.39	10.33	**-0.06**
15A.	8.33	8.48	**0.15**
16B.	10.34	10.66	**0.32**
Average	**9.54**	**9.86**	**0.32**
S.E.	**0.46**	**0.49**	**0.07**

't' Value **4.28**

Differnce in the Mean Distances

Null Hypothesis Ho : No Difference in the means

Alterantive Hypothesis H1 : Difference in the Means

t = 4.28

Critical 't' value at 0.01 Level (two-tail) 15 DF = 2.947

Reject Null Hypothesis : i.e. Significant Difference between the two conditions

Group 2: 8 Female Subjects: Averages / Distances (metres) Order A
10 Throws

	No Belt	Belt	Difference
1A.	7.31	7.76	**0.45**
3A.	8.30	8.51	**0.21**
5A.	7.27	7.37	**0.10**
7A.	10.56	10.63	**0.07**
9A.	8.42	8.38	**-0.04**
11A.	10.79	11.11	**0.32**
13A.	11.92	12.54	**0.62**
15A.	8.33	8.48	**0.15**
Average	**9.11**	**9.35**	**0.24**
S.E.	**0.62**	**0.65**	**0.08**

Group 2: 8 Female Subjects: Averages / Distances (metres) Order B
10 Throws

	No Belt	Belt	Difference
2B.	7.42	7.94	**0.52**
4B.	7.10	7.51	**0.41**
6B.	10.86	11.09	**0.23**
8B.	10.40	11.20	**0.80**
10B.	13.13	14.08	**0.95**
12B.	10.15	10.16	**0.01**
14B.	10.39	10.33	**-0.06**
16B.	10.34	10.66	**0.32**
Average	**9.97**	**10.37**	**0.40**
S.E.	**0.68**	**0.72**	**0.13**

Summary Table 2A : Physical Characteristics
GROUP 2 : 8 Female Subjects : Order A (Novice)

Subject No Order A	Height (m)	Leg Length (m)	Length of Spine (m)	Mass (kg)
1A.	1.63	0.96	0.51	65.3
3A.	1.74	1.00	0.57	63.6
5A.	1.66	0.96	0.55	62.3
7A.	1.73	0.99	0.59	64.0
9A.	1.78	1.00	0.63	72.4
11A.	1.72	0.97	0.59	68.5
13A.	1.65	0.97	0.50	63.7
15A.	1.66	0.99	0.51	57.3
Mean	**1.70**	**0.98**	**0.56**	**64.6**
S.E. ±	**0.02**	**0.01**	**0.02**	**1.46**

Summary Table 2B : Physical Characteristics
GROUP 2 : 8 Female Subjects : Order B (Novice)

Subject No Order B	Height (m)	Leg Length (m)	Length of Spine (m)	Mass (kg)
2B.	1.66	0.97	0.53	56.0
4B.	1.60	0.97	0.49	56.8
6B.	1.75	0.98	0.61	68.6
8B.	1.69	0.97	0.57	67.2
10B.	1.80	1.00	0.64	76.5
12B.	1.79	1.01	0.60	70.4
14B.	1.70	1.05	0.51	67.8
16B.	1.74	1.00	0.53	62.5
Mean	**1.72**	**1.00**	**0.56**	**65.7**
S.E. ±	**0.02**	**0.01**	**0.02**	**2.30**

EXPERIMENT 3A

Summary Table 1 : Novice Subjects - Medicine Ball

GROUP 3 : 8 Male Subjects : Averages / Distances (m)

Order A & B

Subject	10 Throws No Belt	Belt	Difference
1A.	8.30	8.64	0.34
2B.	11.08	11.40	0.32
3A.	10.88	11.02	0.14
4B.	10.85	11.04	0.19
5A.	11.51	11.64	0.13
6B.	10.41	10.81	0.40
7A.	11.58	11.78	0.20
8B.	12.02	12.15	0.13
Mean	**10.83**	**11.06**	**0.23**
S.E.	**0.40**	**0.38**	**0.04**
't' Value			**6.13**

Differnce in the Mean Distances

Null Hypothesis Ho : No Difference in the means

Alterantive Hypothesis H1 : Difference in the Means

t = 6.13

Critical 't' value at 0.01 Level (one-tail) 7 DF = 2.998
Reject Null Hypothesis : i.e. Significant Difference between the two conditions

Summary Table 1A : GROUP 3 Order A : Belt 1st & 3rd

4 Male Subjects : Distances / Averages

Subject	10 Throws No Belt	Belt	Difference
1A.	8.30	8.64	0.34
3A.	10.88	11.02	0.14
5A.	11.51	11.64	0.13
7A.	11.58	11.78	0.20
Mean	**10.57**	**10.77**	**0.20**
S.E.	**0.77**	**0.73**	**0.05**

Summary Table 1B : GROUP 3 Order B : No Belt 1st & 3rd

4 Male Subjects : Distances / Averages

Subject	10 Throws No Belt	Belt	Difference
2B.	11.08	11.40	0.32
4B.	10.85	11.04	0.19
6B.	10.41	10.89	0.48
8B.	12.02	12.15	0.13
Mean	**11.09**	**11.37**	**0.28**
S.E.	**0.34**	**0.28**	**0.08**

Summary Table : Physical Characteristics
GROUP 3 : 4 Male Subjects : Order A (Novice)

Subject No Order A	Height (m)	Leg Length (m)	Length of Spine (m)	Mass (kg)
1A.	1.74	0.99	0.57	70.4
3A.	1.78	1.03	0.60	79.4
5A.	1.83	1.04	0.62	78.5
7A.	1.82	1.04	0.61	85.5
Mean	**1.79**	**1.03**	**0.60**	**78.5**
S.E. ±	**0.02**	**0.01**	**0.01**	**2.68**

Summary Table : Physical Characteristics
GROUP 3 : 4 Male Subjects : Order B (Novice)

Subject No Order B	Height (m)	Leg Length (m)	Length of Spine (m)	Mass (kg)
2B.	1.84	1.05	0.62	95.8
4B.	1.75	0.99	0.59	81.0
6B.	1.93	1.09	0.66	82.0
8B.	1.94	1.09	0.66	87.6
Mean	**1.87**	**1.06**	**0.63**	**86.6**
S.E. ±	**0.04**	**0.02**	**0.01**	**2.94**

Novice Group : Mean Linear Speeds (m s^{-1})

Belt Condition

Subject No.		Hip	Shoulder	Elbow	Wrist	Finger	Ball
1	Belt	1.50	1.72	2.64	5.87	10.26	8.49
2	Belt	1.68	1.97	4.32	11.16	13.26	10.18
3	Belt	1.60	1.92	3.59	10.21	12.22	10.26
4	Belt	1.41	2.15	3.80	9.11	10.97	9.99
5	Belt	1.70	3.06	4.05	8.64	11.92	10.47
6	Belt	2.35	2.27	3.05	7.00	9.67	8.38
7	Belt	1.46	2.07	3.57	9.47	12.00	10.34
8	Belt	1.54	2.59	3.56	8.88	13.20	13.63
	Mean	**1.66**	**2.22**	**3.57**	**8.79**	**11.69**	**10.22**
	S.E.	**0.11**	**0.15**	**0.19**	**0.60**	**0.46**	**0.57**

No Belt Condition

Subject No.		Hip	Shoulder	Elbow	Wrist	Finger	Ball
1	No Belt	1.61	1.89	2.69	5.72	9.44	8.34
2	No Belt	1.54	1.82	4.00	10.88	13.46	10.06
3	No Belt	1.65	2.11	3.59	10.35	12.17	10.32
4	No Belt	1.57	2.23	4.00	7.59	10.68	10.26
5	No Belt	1.65	2.60	3.76	8.03	11.40	10.96
6	No Belt	1.97	2.02	2.90	6.85	9.75	8.34
7	No Belt	1.65	2.19	4.63	9.66	11.75	10.30
8	No Belt	1.64	2.47	3.57	8.49	12.56	13.06
	Mean	**1.66**	**2.17**	**3.64**	**8.45**	**11.40**	**10.21**
	S.E.	**0.05**	**0.09**	**0.22**	**0.63**	**0.49**	**0.53**

Novice Group : Distance
(2 throws per condition per subject)

Belt Condition			No Belt Condition			(Belt - No Belt) Difference in the MEAN values	
Subject No.		**Distance**	**Subject No.**		**Distance**	**Subject No.**	**Distance**
1	Belt	8.53	1	No Belt	8.39	1	**0.14**
2	Belt	11.70	2	No Belt	11.17	2	**0.54**
3	Belt	10.89	3	No Belt	10.89	3	**0.01**
4	Belt	11.46	4	No Belt	11.20	4	**0.27**
5	Belt	11.58	5	No Belt	11.78	5	**-0.21**
6	Belt	10.81	6	No Belt	10.53	6	**0.29**
7	Belt	11.89	7	No Belt	11.50	7	**0.38**
8	Belt	12.04	8	No Belt	12.11	8	**-0.07**
	Mean	**11.11**		**Mean**	**10.94**	**Mean**	**0.17**
	S.E.	**0.40**		**S.E.**	**0.40**	**S.E.**	**0.09**
						't' Value	**1.92**

Critical 't' value at 0.01 Level (one-tail) 7 DF = 2.998

Progressive Linear Speed : Novice : NO BELT

Independent Group Analysis C:\PDH\EXP3\GROUP_3.DBF

Grouping variable is JOINT
Analysis variable is NO BELT

Group Means and Standard Deviations

1 (Hip)	: mean = 1.66	s.d. = 0.13	n = 8
2 (Shoulder)	: mean = 2.17	s.d. = 0.27	n = 8
3 (Elbow)	: mean = 3.64	s.d. = 0.62	n = 8
4 (Wrist)	: mean = 8.45	s.d. = 1.77	n = 8
5 (Finger)	: mean = 11.40	s.d. = 1.38	n = 8
6 (Ball)	: mean = 10.21	s.d. = 1.50	n = 8

Analysis of Variance Table

Source	S.S.	DF	MS	F	Appx P
Total	786.72	47			
Treatment	732.36	5	146.47	113.17	**<.001**
Error	54.36	42	1.29		

Error term used for comparisons = 1.29 with 42 d.f.

Newman-Keuls Multiple Comp.	Difference	P	Q	Critical q (.05)	
Mean(5.00)-Mean(1.00) =	9.7413	6	24.219	4.225	*
Mean(5.00)-Mean(2.00) =	9.235	5	22.96	4.033	*
Mean(5.00)-Mean(3.00) =	7.7587	4	19.29	3.786	*
Mean(5.00)-Mean(4.00) =	2.955	3	7.347	3.438	*
Mean(5.00)-Mean(6.00) =	1.1962	2	2.974	2.855	*
Mean(6.00)-Mean(1.00) =	8.545	5	21.244	4.033	*
Mean(6.00)-Mean(2.00) =	8.0387	4	19.986	3.786	*
Mean(6.00)-Mean(3.00) =	6.5625	3	16.316	3.438	*
Mean(6.00)-Mean(4.00) =	1.7587	2	4.373	2.855	*
Mean(4.00)-Mean(1.00) =	6.7863	4	16.872	3.786	*
Mean(4.00)-Mean(2.00) =	6.28	3	15.613	3.438	*
Mean(4.00)-Mean(3.00) =	4.8038	2	11.943	2.855	*
Mean(3.00)-Mean(1.00) =	1.9825	3	4.929	3.438	*
Mean(3.00)-Mean(2.00) =	1.4762	2	3.67	2.855	*
Mean(2.00)-Mean(1.00) =	0.5063	2	1.259	2.855	

Homogeneous Populations, groups ranked

```
Gp Gp Gp Gp Gp Gp
 1  2  3  4  6  5
------
      ---
         ---
            ---
               ---
```

This is a graphical representation of the Newman-Keuls multiple comparisons test. At the 0.05 significance level, the means of any two groups underscored by the same line are not significantly different.

Progressive Linear Speed : Novice : BELT

Independent Group Analysis C:\PDH\EXP3\GROUP_3.DBF

Grouping variable is JOINT
Analysis variable is BELT

Group Means and Standard Deviations

1 (Hip)	: mean = 1.66	s.d. = 0.30	n = 8
2 (Shoulder)	: mean = 2.22	s.d. = 0.43	n = 8
3 (Elbow)	: mean = 3.57	s.d. = 0.53	n = 8
4 (Wrist)	: mean = 8.79	s.d. = 1.69	n = 8
5 (Finger)	: mean = 11.69	s.d. = 1.30	n = 8
6 (Ball)	: mean = 10.22	s.d. = 1.61	n = 8

Analysis of Variance Table

Source	S.S.	DF	MS	F	Appx P
Total	823.69	47			
Treatment	769.89	5	153.98	120.21	**<.001**
Error	53.8	42	1.28		

Error term used for comparisons = 1.28 with 42 d.f.

Newman-Keuls Multiple Comp.	Difference	P	Q	Critical q (.05)
Mean(5.00)-Mean(1.00) =	10.0325	6	25.072	4.225 *
Mean(5.00)-Mean(2.00) =	9.4688	5	23.664	4.033 *
Mean(5.00)-Mean(3.00) =	8.115	4	20.28	3.786 *
Mean(5.00)-Mean(4.00) =	2.895	3	7.235	3.438 *
Mean(5.00)-Mean(6.00) =	1.47	2	3.674	2.855 *
Mean(6.00)-Mean(1.00) =	8.5625	5	21.399	4.033 *
Mean(6.00)-Mean(2.00) =	7.9987	4	19.99	3.786 *
Mean(6.00)-Mean(3.00) =	6.645	3	16.607	3.438 *
Mean(6.00)-Mean(4.00) =	1.425	2	3.561	2.855 *
Mean(4.00)-Mean(1.00) =	7.1375	4	17.838	3.786 *
Mean(4.00)-Mean(2.00) =	6.5738	3	16.429	3.438 *
Mean(4.00)-Mean(3.00) =	5.22	2	13.045	2.855 *
Mean(3.00)-Mean(1.00) =	1.9175	3	4.792	3.438 *
Mean(3.00)-Mean(2.00) =	1.3537	2	3.383	2.855 *
Mean(2.00)-Mean(1.00) =	0.5638	2	1.409	2.855

Homogeneous Populations, groups ranked

```
Gp Gp Gp Gp Gp Gp
 1  2  3  4  6  5
------
      ---
         ---
            ---
               ---
```

This is a graphical representation of the Newman-Keuls multiple comparisons test. At the 0.05 significance level, the means of any two groups underscored by the same line are not significantly different.

Novice : Linear Speed - Hip Joint Centre

Repeated Measures Analysis Summary C:\PDH\EXP3\HIP_3.DBF

Number of repeated measures is 2
Number of subjects read in 8

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 1.655 s.d. = 0.29857
2) NO_BELT: mean = 1.66 s.d. = 0.13191

Mean Difference = -0.005 s.d.(difference) = 0.18996

95% C.I. about Mean Difference is (-0.16384, 0.15384)

Paired t-test

Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.07445 with 7 D.F. **p = 0.94** (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

Novice : Linear Speed - Shoulder Joint Centre

Repeated Measures Analysis Summary :\PDH\EXP3\SHOULDER_3.DBF

Number of repeated measures is 2
Number of subjects read in 8

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 2.21875 s.d. = 0.42676
2) NO_BELT: mean = 2.16625 s.d. = 0.2688

Mean Difference = 0.0525 s.d.(difference) = 0.23138

95% C.I. about Mean Difference is (-0.14097, 0.24597)

Paired t-test

Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.64177 with 7 D.F. **p = 0.54** (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

Novice : Linear Speed - Elbow Joint Centre

```
Repeated Measures Analysis Summary              C:\PDH\EXP3\ELBOW_3.DBF
-------------------------------------------------------------------------
Number of repeated measures is 2
Number of subjects read in 8

Means and standard deviations for 2 repeated measures:

 1) BELT: mean = 3.5725              s.d. = 0.53205
 2) NO_BELT: mean = 3.6425           s.d. = 0.62234

 Mean Difference = -0.07            s.d.(difference) = 0.43687

 95% C.I. about Mean Difference is (-0.43529, 0.29529)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.4532 with 7 D.F.     p = 0.66 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Novice : Linear Speed - Wrist Joint Centre

```
Repeated Measures Analysis Summary              C:\PDH\EXP3\WRIST_3.DBF
-------------------------------------------------------------------------
Number of repeated measures is 2
Number of subjects read in 8

Means and standard deviations for 2 repeated measures:

 1) BELT: mean = 8.7925              s.d. = 1.68858
 2) NO_BELT: mean = 8.44625          s.d. = 1.76915

 Mean Difference = 0.34625          s.d.(difference) = 0.54177

 95% C.I. about Mean Difference is (-0.10675, 0.79925)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 1.80768 with 7 D.F.     p = 0.11 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Novice : Linear Speed - Finger Joint Centre

```
Repeated Measures Analysis Summary                C:\PDH\EXP3\FINGER_3.DBF
--------------------------------------------------------------------------
Number of repeated measures is 2
Number of subjects read in 8

Means and standard deviations for 2 repeated measures:

 1) BELT: mean = 11.6875             s.d. = 1.29937
 2) NO_BELT: mean = 11.40125         s.d. = 1.38291

 Mean Difference = 0.28625          s.d.(difference) = 0.35705

 95% C.I. about Mean Difference is (-0.0123, 0.5848)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 2.26758 with 7 D.F.     p = 0.06 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Novice : Linear Speed - Medicine Ball

```
Repeated Measures Analysis Summary                  C:\PDH\EXP3\BALL_3.DBF
--------------------------------------------------------------------------
Number of repeated measures is 2
Number of subjects read in 8

Means and standard deviations for 2 repeated measures:

 1) BELT: mean = 10.2175             s.d. = 1.60978
 2) NO_BELT: mean = 10.205           s.d. = 1.49875

 Mean Difference = 0.0125           s.d.(difference) = 0.31176

 95% C.I. about Mean Difference is (-0.24818, 0.27318)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.11341 with 7 D.F.     p = 0.91 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Summary Table 1 : Experienced Subjects - Medicine Ball

GROUP 4 'Experienced' 8 Male Subjects : Averages / Distances
Order A & B

Subject	10 Throws No Belt	Belt	Difference
1A.	13.24	13.60	0.36
2B.	14.69	15.34	0.65
3A.	12.91	13.31	0.40
4B.	13.93	14.45	0.52
5A.	11.12	11.39	0.27
6B.	13.54	14.08	0.54
7A.	15.97	16.88	0.91
8B.	14.47	15.10	0.63
Mean	**13.73**	**14.27**	**0.54**
S.E.	**0.51**	**0.57**	**0.07**

't' Value 7.54

Differnce in the Mean Distances

Null Hypothesis Ho : No Difference in the means

Alterantive Hypothesis H1 : Difference in the Means

t = 7.54

Critical 't' value at 0.01 Level (one-tail) 7 DF = 2.998

Reject Null Hypothesis : i.e. Significant Difference between the two conditions

Summary Table 1A : GROUP 4 Order A : Belt 1st & 3rd

4 Male Subjects : Distances / Averages

Subject	10 Throws No Belt	Belt	Difference
1A.	13.24	13.60	0.36
3A.	12.91	13.31	0.40
5A.	11.12	11.39	0.27
7A.	15.97	16.88	0.91
Mean	**13.31**	**13.80**	**0.48**
S.E.	**1.00**	**1.14**	**0.14**

Summary Table 1B : GROUP 3 Order B : No Belt 1st & 3rd

4 Male Subjects : Distances / Averages

Subject	10 Throws No Belt	Belt	Difference
2B.	14.69	15.34	0.65
4B.	13.93	14.45	0.52
6B.	13.54	14.08	0.54
8B.	14.47	15.10	0.63
Mean	**14.16**	**14.74**	**0.59**
S.E.	**0.26**	**0.29**	**0.03**

Summary Table : Physical Characteristics
GROUP 4 : 4 Male Subjects : Order A (Experienced)

Subject No Order A	Height (m)	Leg Length (m)	Length of Spine (m)	Mass (kg)
1A.	1.90	1.06	0.67	86.5
3A.	1.77	1.00	0.60	75.6
5A.	1.70	0.96	0.57	68.5
7A.	1.92	1.09	0.66	88.5
Mean	**1.80**	**1.02**	**0.61**	**79.0**
S.E. ±	**0.04**	**0.02**	**0.02**	**3.71**

Summary Table : Physical Characteristics
GROUP 4 : 4 Male Subjects : Order B (Experienced)

Subject No Order B	Height (m)	Leg Length (m)	Length of Spine (m)	Mass (kg)
2B.	1.84	1.05	0.62	88.5
4B.	1.85	1.05	0.63	96.0
6B.	1.89	1.07	0.65	90.4
8B.	1.78	1.02	0.60	80.2
Mean	**1.84**	**1.05**	**0.63**	**88.8**
S.E. ±	**0.02**	**0.01**	**0.01**	**2.83**

Experienced Group : Mean Linear Speeds (m s^{-1})

Belt Condition

Subject No.		Hip	Shoulder	Elbow	Wrist	Finger	Ball
1	Belt	1.84	3.89	5.23	11.07	13.77	11.60
2	Belt	1.36	3.30	5.73	10.74	13.09	12.39
3	Belt	1.77	3.16	5.32	10.81	12.97	12.29
4	Belt	2.16	3.02	4.92	12.50	16.18	13.89
5	Belt	1.26	2.24	3.73	8.10	10.65	10.17
6	Belt	1.76	3.69	5.23	11.11	13.17	11.83
7	Belt	1.60	3.90	6.87	11.49	13.96	16.54
8	Belt	1.33	3.12	5.38	9.42	11.93	12.42
	Mean	**1.64**	**3.29**	**5.30**	**10.66**	**13.22**	**12.64**
	S.E.	**0.11**	**0.20**	**0.31**	**0.47**	**0.57**	**0.67**

No Belt Condition

Subject No.		Hip	Shoulder	Elbow	Wrist	Finger	Ball
1	No Belt	1.69	3.71	5.13	10.26	13.84	12.07
2	No Belt	1.30	3.26	5.61	10.55	12.13	12.38
3	No Belt	1.70	3.67	5.51	11.18	13.13	11.87
4	No Belt	1.95	2.83	4.77	13.06	15.99	13.70
5	No Belt	1.39	2.35	3.99	8.54	10.90	10.28
6	No Belt	1.86	3.83	4.94	10.47	13.59	11.63
7	No Belt	1.55	3.93	6.71	13.29	14.61	16.05
8	No Belt	1.41	3.21	5.61	10.50	12.05	12.31
	Mean	**1.61**	**3.35**	**5.28**	**10.98**	**13.28**	**12.54**
	S.E.	**0.08**	**0.19**	**0.28**	**0.55**	**0.57**	**0.60**

Experienced Group : Distance

(2 throws per condition per subject)

Belt Condition			No Belt Condition			(Belt - No Belt) Difference in the MEAN values	
Subject No.		**Distance**	**Subject No.**		**Distance**	**Subject No.**	**Distance**
1	Belt	13.68	1	No Belt	13.82	1	**-0.14**
2	Belt	15.66	2	No Belt	14.80	2	**0.86**
3	Belt	13.41	3	No Belt	13.07	3	**0.34**
4	Belt	14.24	4	No Belt	14.03	4	**0.21**
5	Belt	11.66	5	No Belt	11.48	5	**0.18**
6	Belt	14.32	6	No Belt	13.46	6	**0.85**
7	Belt	16.85	7	No Belt	15.93	7	**0.92**
8	Belt	15.53	8	No Belt	14.60	8	**0.93**
Mean		**14.42**		**Mean**	**13.90**	**Mean**	**0.52**
S.E.		**0.57**		**S.E.**	**0.47**	**S.E.**	**0.15**
						't' Value	**3.50**

Critical 't' value at 0.01 Level (one-tail) 7 DF = 2.998

Progressive Linear Speed : Experienced : NO BELT

Independent Group Analysis C:\PDH\EXP3\GROUP_4.DBF

Grouping variable is JOINT
Analysis variable is NO BELT

Group Means and Standard Deviations

Group	Mean	s.d.	n
1 (Hip)	mean = 1.61	s.d. = 0.23	n = 8
2 (Shoulder)	mean = 3.35	s.d. = 0.55	n = 8
3 (Elbow)	mean = 5.28	s.d. = 0.79	n = 8
4 (Wrist)	mean = 10.98	s.d. = 1.55	n = 8
5 (Finger)	mean = 13.28	s.d. = 1.61	n = 8
6 (Ball)	mean = 12.54	s.d. = 1.71	n = 8

Analysis of Variance Table

Source	S.S.	DF	MS	F	Appx P
Total	1078.75	47			
Treatment	1016.65	5	203.33	137.52	**<.001**
Error	62.1	42	1.48		

Error term used for comparisons = 1.48 with 42 d.f.

Newman-Keuls Multiple Comp.	Difference	P	Q	Critical q (.05)	
Mean(5.00)-Mean(1.00) =	11.6737	6	27.154	4.225	*
Mean(5.00)-Mean(2.00) =	9.9312	5	23.101	4.033	*
Mean(5.00)-Mean(3.00) =	7.9962	4	18.6	3.786	*
Mean(5.00)-Mean(4.00) =	2.2987	3	5.347	3.438	*
Mean(5.00)-Mean(6.00) =	0.7437	2	1.73	2.855	
Mean(6.00)-Mean(1.00) =	10.93	5	25.424	4.033	*
Mean(6.00)-Mean(2.00) =	9.1875	4	21.371	3.786	*
Mean(6.00)-Mean(3.00) =	7.2525	3	16.87	3.438	*
Mean(6.00)-Mean(4.00) =	1.555	2	3.617	2.855	*
Mean(4.00)-Mean(1.00) =	9.375	4	21.807	3.786	*
Mean(4.00)-Mean(2.00) =	7.6325	3	17.754	3.438	*
Mean(4.00)-Mean(3.00) =	5.6975	2	13.253	2.855	*
Mean(3.00)-Mean(1.00) =	3.6775	3	8.554	3.438	*
Mean(3.00)-Mean(2.00) =	1.935	2	4.501	2.855	*
Mean(2.00)-Mean(1.00) =	1.7425	2	4.053	2.855	*

Homogeneous Populations, groups ranked

```
Gp Gp Gp Gp Gp Gp
 1  2  3  4  6  5
             ------
---
   ---
      ---
         ---
```

This is a graphical representation of the Newman-Keuls multiple Comparisons test. At the 0.05 significance level, the means of any two Groups underscored by the same line are not significantly different.

Progressive Linear Speed : Experienced : BELT

Independent Group Analysis C:\PDH\EXP3\GROUP_4.DBF

Grouping variable is JOINT
Analysis variable is BELT

Group Means and Standard Deviations

1 (Hip)	: mean = 1.64	s.d. = 0.31	n = 8
2 (Shoulder)	: mean = 3.29	s.d. = 0.55	n = 8
3 (Elbow)	: mean = 5.30	s.d. = 0.87	n = 8
4 (Wrist)	: mean = 10.66	s.d. = 1.34	n = 8
5 (Finger)	: mean = 13.22	s.d. = 1.60	n = 8
6 (Ball)	: mean = 12.64	s.d. = 1.88	n = 8

Analysis of Variance Table

Source	S.S.	DF	MS	F	Appx P
Total	1067.43	47			
Treatment	1004.01	5	200.8	132.98	**<.001**
Error	63.42	42	1.51		

Error term used for comparisons = 1.51 with 42 d.f.

Newman-Keuls Multiple Comp.	Difference	P	Q	Critical q (.05)
Mean(5.00)-Mean(1.00) =	11.58	6	26.654	4.225 *
Mean(5.00)-Mean(2.00) =	9.925	5	22.844	4.033 *
Mean(5.00)-Mean(3.00) =	7.9138	4	18.215	3.786 *
Mean(5.00)-Mean(4.00) =	2.56	3	5.892	3.438 *
Mean(5.00)-Mean(6.00) =	0.5737	2	1.321	2.855
Mean(6.00)-Mean(1.00) =	11.0063	5	25.333	4.033 *
Mean(6.00)-Mean(2.00) =	9.3513	4	21.524	3.786 *
Mean(6.00)-Mean(3.00) =	7.34	3	16.894	3.438 *
Mean(6.00)-Mean(4.00) =	1.9863	2	4.572	2.855 *
Mean(4.00)-Mean(1.00) =	9.02	4	20.761	3.786 *
Mean(4.00)-Mean(2.00) =	7.365	3	16.952	3.438 *
Mean(4.00)-Mean(3.00) =	5.3537	2	12.323	2.855 *
Mean(3.00)-Mean(1.00) =	3.6662	3	8.439	3.438 *
Mean(3.00)-Mean(2.00) =	2.0113	2	4.629	2.855 *
Mean(2.00)-Mean(1.00) =	1.655	2	3.809	2.855 *

Homogeneous Populations, groups ranked

```
Gp Gp Gp Gp Gp Gp
 1  2  3  4  6  5
             ------
---
   ---
      ---
         ---
```

This is a graphical representation of the Newman-Keuls multiple Comparisons test. At the 0.05 significance level, the means of any two Groups underscored by the same line are not significantly different.

Experienced : Linear Speed - Hip Joint Centre

```
Repeated Measures Analysis Summary                  C:\PDH\EXP3\HIP_4.DBF
-------------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  8

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 1.635               s.d. = 0.30752
 2) NO BELT: mean = 1.60625          s.d. = 0.23317

 Mean Difference = 0.02875         s.d.(difference) = 0.12206

 95% C.I. about Mean Difference is (-0.07331, 0.13081)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.66622 with 7 D.F.     p = 0.53 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experienced : Linear Speed - Shoulder Joint Centre

```
Repeated Measures Analysis Summary             C:\PDH\EXP3\SHOULDER_4.DBF
-------------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  8

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 3.29                s.d. = 0.54947
 2) NO BELT: mean = 3.34875          s.d. = 0.54732

 Mean Difference = -0.05875        s.d.(difference) = 0.22145

 95% C.I. about Mean Difference is (-0.24392, 0.12642)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.75037 with 7 D.F.     p = 0.48 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experienced : Linear Speed - Elbow Joint Centre

```
Repeated Measures Analysis Summary                C:\PDH\EXP3\ELBOW_4.DBF
--------------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  8

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 5.30125             s.d. = 0.86814
 2) NO BELT: mean = 5.28375          s.d. = 0.79082

 Mean Difference = 0.0175          s.d.(difference) = 0.2107

 95% C.I. about Mean Difference is (-0.15867, 0.19367)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.23492 with 7 D.F.     p = 0.82 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experienced : Linear Speed - Wrist Joint Centre

```
Repeated Measures Analysis Summary                C:\PDH\EXP3\WRIST_4.DBF
--------------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  8

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 10.655              s.d. = 1.33977
 2) NO BELT: mean = 10.98125         s.d. = 1.55148

 Mean Difference = -0.32625        s.d.(difference) = 0.8702

 95% C.I. about Mean Difference is (-1.05387, 0.40137)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 1.06041 with 7 D.F.     p = 0.32 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experienced : Linear Speed - Finger Joint Centre

Repeated Measures Analysis Summary C:\PDH\EXP3\FINGER_4.DBF

Number of repeated measures is 2
Number of subjects read in 8

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 13.215 s.d. = 1.60189
2) NO BELT: mean = 13.28 s.d. = 1.60557

Mean Difference = -0.065 s.d.(difference) = 0.48258

95% C.I. about Mean Difference is (-0.46851, 0.33851)

Paired t-test

Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.38097 with 7 D.F. **p = 0.71** (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

Experienced : Linear Speed - Medicine Ball

Repeated Measures Analysis Summary C:\PDH\EXP3\BALL_4.DBF

Number of repeated measures is 2
Number of subjects read in 8

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 12.64125 s.d. = 1.88393
2) NO BELT: mean = 12.53625 s.d. = 1.70502

Mean Difference = 0.105 s.d.(difference) = 0.30463

95% C.I. about Mean Difference is (-0.14972, 0.35972)

Paired t-test

Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.9749 with 7 D.F. **p = 0.36** (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

****** Two-Way Analysis of Variance ******

Data Summary : Cell means, standard deviation and counts.

SKILL :	EXPERT	NOVICE
ORDER	0.49	0.20
	0.29	0.10
ORDER-A	n = 4	n = 4
	0.58	0.28
	0.06	0.16
ORDER-B	n = 4	n = 4

SKILL is a Fixed Factor. ORDER is a Fixed Factor.

Analysis of Variance Table

Source	S.S.	DF	MS	F	P	
Total	.74	15				
Cells	.38	3				
ORDER	.03	1	.03	1.04	.327	
SKILL	.35	1	.35	11.43	.005	**
INTERACTION	.00	1	.00	.02	.899	
Within Cells	.36	12	.03			

The interaction effect is non-significant, multiple comparisons of marginal means is appropriate.

The following multiple comparisons will be performed:

Marginal means comparisons

MAIN EFFECTS (Compare marginal means) - SKILL Number of levels = 2

SKILL (Marginal means)

Means compared are:

SKILL (Gp) 1 = EXPERT) Mean= .535 n = 8

SKILL (Gp) 2 = NOVICE) Mean= .24125 n = 8

Error term used for comparisons = .03 with 12 d.f.

Newman-Keuls Multiple Comp.	Difference	P	Q	Critical q (.05)	
Mean (EXPERT)-Mean (NOVICE) =	0.2938	2	4.781	3.082	**

Homogeneous Populations, groups ranked

Gp 1 refers to SKILL (Marginal means)=EXPERT

Gp 2 refers to SKILL (Marginal means)=NOVICE

```
Gp Gp
 2  1
---
  ---
```

This is a graphical representation of the Newman-Keuls multiple comparisons test. The means of the two groups are significantly different at the 0.05 level.

MAIN EFFECTS (Compare marginal means) - ORDER Number of levels = 2

ORDER (Marginal means)

Means compared are:

ORDER(Gp) 1 = ORDER-A) Mean= .34375 n = 8

ORDER(Gp) 2 = ORDER-B) Mean= .4325 n = 8

Error term used for comparisons = .03 with 12 d.f.

Newman-Keuls Multiple Comp.	Difference	P	Q	Critical q (.05)
Mean (ORDER-B)-Mean (ORDER-A) =	0.0888	2	1.444	3.082

Homogeneous Populations, groups ranked

Gp 1 refers to ORDER (Marginal means)=ORDER-A

Gp 2 refers to ORDER (Marginal means)=ORDER-B

```
Gp Gp
 1  2
------
```

This is a graphical representation of the Newman-Keuls multiple comparisons test. At the 0.05 significance level, the means of any two groups underscored by the same line are not significantly different.

APPENDIX F

FAST-MEDIUM BOWLING IN CRICKET

An investigation into the effect of a lumbar support belt on fast-medium cricket bowling.

Experiment 4

<u>Subject 1</u>	Normal Bowling Condition		Belt 1	
3D Cinematography : File Name	C3/CBN1 NB1	C3/CBN3 NB2	C3/CBB1 B1	C3/CBB2 B2
Back Foot Angle° :	313	328	314	320
Shoulder Alignment°				
Back Foot Contact :	219	223	222	220
Front Foot Contact :	206	198	202	212
Ball Release :	273	302	284	285
Change FFC to BR°	67	104	82	73
3D Hip/Shoulder Separation°				
Back Foot Contact :	34.8	31.0	27.7	29.7
Front Foot Contact :	-8.78	-21.1	-12.2	-16.8
Ball Release :	42.0	48.8	38.1	45.7
Speed of Run-up ($m\ s^{-1}$): Hip Joint Centre at the end of the pre-delivery stride : (BFC)	6.88	6.40	6.02	6.04
% Contribution of run-up speed on ball release speed :	24.5 %	20.6 %	18.6 %	19.2 %
Peak Linear Speed ($m\ s^{-1}$): Time Before/After Release				
Mass Centre	8.54 0.28	6.83 0.31	6.92 0.32	6.68 0.11
Right Hip	8.37 0.28	8.23 0.14	8.04 0.12	7.81 0.12
Right Shoulder	8.93 0.08	9.94 0.07	10.16 0.07	9.49 0.08
Right Elbow	12.71 0.03	14.29 0.04	14.20 0.04	13.98 0.05
Right Wrist	18.89 0.02	22.41 0.01	21.69 0.02	21.41 0.02
Right 3rd Finger	21.09 0.01	26.37 0.00	24.66 0.01	25.03 0.01
Ball Release Speed	28.14 -0.01	31.03 -0.01	32.32 -0.01	31.48 -0.01
Shoulder-Hip Joints	0.56 0.20	1.71 0.07	2.12 0.05	1.69 0.04
Back Knee Angle° :				
Back Foot Contact	154	154	153	158
Front Foot Contact	133	143	137	138
Ball Release	97.0	89.7	96.9	87.6
Front Knee Angle° :				
Front Foot Contact	171	167	168	167
Ball Release	121	121	126	126
Release Height :	1.84m	1.91m	1.99m	1.94m
(% Height)	105%	109%	114%	111%
Delivery Stride Length :	1.13m	1.08m	1.12m	1.14m
(% Height)	65%	62%	64%	65%
Trunk Angle to Right Horizontal° : Ball Release	-16.9	-12.3	-13.3	-14.7
Maximum Trunk Angle° :	7.82	1.96	-0.06	1.44
Time (seconds) :	(0.27)	(0.26)	(0.30)	(0.24)
Total Angle of Trunk : Movement°	24.7	14.3	13.3	16.1
Time (seconds) :	(0.13)	(0.12)	(0.09)	(0.15)

Subject 2	Normal Bowling Condition		Belt 1	
3D Cinematography : File Name	C3/PNB1 NB1	C3/PNB2 NB2	C3/PHB1 B1	C3/PHB2 B2
Back Foot Angle° :	306	299	286	304
Shoulder Alignment°				
Back Foot Contact :	188	189	193	186
Front Foot Contact :	189	180	184	184
Ball Release :	268	272	277	273
Change FFC to BR°	79	92	93	89
3D Hip/Shoulder Separation°				
Back Foot Contact :	-14.1	-11.6	-9.09	-10.2
Front Foot Conmtact :	-16.5	-18.0	-23.7	-20.3
Ball Release :	38.3	46.3	43.4	44.1
Speed of Run-up (m s^{-1}): Hip Joint Centre at the end of the pre-delivery stride : (BFC)	6.35	6.03	5.84	6.15
% Contribution of run-up speed on ball release speed :	19.6 %	18.5 %	17.9 %	18.8 %
Peak Linear Speed (m s^{-1}) / Time Before/After Release				
Mass Centre	7.00 0.13	6.48 0.18	6.86 0.13	6.46 0.15
Right Hip	7.61 0.14	6.70 0.15	7.42 0.14	6.88 0.11
Right Shoulder	8.97 0.08	9.62 0.08	9.62 0.07	9.82 0.09
Right Elbow	12.32 0.04	12.63 0.06	13.45 0.04	13.05 0.05
Right Wrist	20.93 0.03	21.87 0.01	22.96 0.01	22.35 0.02
Right 3rd Finger	24.39 0.01	27.56 0.01	28.00 0.00	27.07 0.01
Ball Release Speed	32.33 -0.02	32.63 -0.02	32.69 -0.02	32.71 -0.02
Shoulder-Hip Joints	1.36 0.06	2.92 0.07	2.20 0.07	2.94 0.02
Back Knee Angle° :				
Back Foot Contact	146	149	151	154
Front Foot Contact	139	130	139	133
Ball Release	88.6	92.3	94.0	83.7
Front Knee Angle° :				
Front Foot Contact	176	169	168	169
Ball Release	129	127	123	127
Release Height :	1.88m	1.83m	1.85m	1.80m
(% Height)	106%	103%	104%	101%
Delivery Stride Length :	1.26m	1.23m	1.24m	1.25m
(% Height)	71%	69%	70%	70%
Trunk Angle to Right Horizontal° : Ball Release	-1.59	4.72	-3.02	-3.53
Maximum Trunk Angle° :	7.95	8.77	7.00	6.20
Time (seconds) :	(0.27)	(0.35)	(0.34)	(0.26)
Total Angle of Trunk Movement°:	9.54	4.05	10.02	9.73
Time (seconds) :	(0.09)	(0.03)	(0.04)	(0.12)

<u>Subject 3</u> **(Left Hand)**	Normal Bowling Condition		Belt 1	
3D Cinematography : File Name	C3/BBN1 NB1	C3/BBN2 NB2	C3/BBB1 B1	C3/BBB2 B2
Back Foot Angle° :	334	318	320	324
Shoulder Alignment°				
Back Foot Contact :	234	241	242	238
Front Foot Contact :	192	188	186	190
Ball Release :	277	284	272	290
Change FFC to BR°	85	96	86	100
3D Hip/Shoulder Separation°				
Back Foot Contact :	-35.9	-36.5	-37.3	-39.0
Front Foot Contact :	12.5	16.8	15.4	13.5
Ball Release :	-40.5	-43.3	-37.5	-48.3
Speed of Run-up (m s^{-1}): Hip Joint Centre at the end of the pre-delivery stride : (BFC)	5.80	6.27	6.16	6.03
% Contribution of run-up speed on ball release speed :	18.8 %	19.3 %	18.1 %	18.5 %
Peak Linear Speed (m s^{-1}) / Time Before/After Release				
Mass Centre	7.01 0.41	6.89 0.39	6.53 0.36	6.66 0.38
Right Hip	6.81 0.42	6.42 0.38	6.18 0.35	6.03 0.35
Right Shoulder	8.33 0.11	8.55 0.09	8.23 0.08	7.93 0.08
Right Elbow	14.36 0.04	13.97 0.04	14.97 0.03	14.46 0.03
Right Wrist	22.77 0.03	23.67 0.02	22.24 0.01	21.85 0.00
Right 3rd Finger	26.09 0.01	26.25 0.01	25.69 -0.01	25.50 -0.01
Ball Release Speed	30.86 -0.01	32.42 -0.01	34.05 -0.02	32.60 -0.01
Shoulder-Hip Joints	1.51 0.31	2.12 0.29	2.05 0.27	1.91 0.27
Back Knee Angle° :				
Back Foot Contact	161	151	148	143
Front Foot Contact	144	139	142	145
Ball Release	102	92.6	98.2	95.7
Front Knee Angle° :				
Front Foot Contact	162	161	154	155
Ball Release	119	131	120	120
Release Height :	2.00m	2.02m	2.06m	2.05m
(% Height)	110%	110%	112%	112%
Delivery Stride Length :	1.31m	1.25m	1.20m	1.23m
(% Height)	74%	68%	65%	67%
Trunk Angle to Right Horizontal° : Ball Release	-13.8	-12.9	-13.6	-13.9
Maximum Trunk Angle° :	-3.41	-4.70	-3.05	-6.84
Time (seconds) :	(0.33)	(0.31)	(0.26)	(0.26)
Total Angle of Trunk : Movement°	10.34	8.16	10.54	7.08
Time (seconds) :	(0.15)	(0.11)	(0.14)	(0.14)

Subject 4	Normal Bowling Condition		Belt 1	
3D Cinematography : File Name	C3/GGN1 NB1	C3/GGN2 NB2	C3/GGB1 B1	C3/GGB2 B2
Back Foot Angle° :	302	312	304	313
Shoulder Alignment°				
Back Foot Contact :	214	218	218	216
Front Foot Contact :	215	215	209	233
Ball Release :	305	302	314	308
Change FFC to BR°	90	87	105	75
3D Hip/Shoulder Separation°				
Back Foot Contact :	31.7	25.1	26.6	21.2
Front Foot Contact :	-12.5	-17.3	-14.3	-20.1
Ball Release :	39.7	34.4	43.5	36.5
Speed of Run-up ($m\ s^{-1}$): Hip Joint Centre at the end of the pre-delivery stride : (BFC)	4.79	4.89	4.87	3.94
% Contribution of run-up speed on ball release speed :	14.4%	15.1%	14.0%	12.0%
Peak Linear Speed ($m\ s^{-1}$) / Time Before/After Release				
Mass Centre	5.09 0.26	5.17 0.18	5.63 0.13	5.36 0.25
Right Hip	6.01 0.13	6.05 0.17	6.07 0.16	6.23 0.21
Right Shoulder	8.48 0.07	8.44 0.08	8.66 0.09	8.63 0.12
Right Elbow	13.67 0.04	14.00 0.05	14.63 0.05	13.05 0.09
Right Wrist	21.86 0.01	22.48 0.01	23.17 0.01	21.94 0.00
Right 3rd Finger	24.51 0.00	26.79 0.01	27.00 0.01	24.57 -0.01
Ball Release Speed	33.25 -0.02	32.31 -0.01	34.88 -0.01	32.73 -0.01
Shoulder-Hip Joints	2.47 0.06	2.39 0.09	2.59 0.07	2.40 0.09
Back Knee Angle° :				
Back Foot Contact	143	144	148	141
Front Foot Contact	140	145	144	136
Ball Release	112	115	106	113
Front Knee Angle° :				
Front Foot Contact	161	165	172	164
Ball Release	169	167	171	167
Release Height :	1.94m	1.98m	1.95m	1.92m
(% Height)	109%	111%	109%	108%
Delivery Stride Length :	1.02m	0.99m	1.05m	0.95m
(% Height)	57%	56%	59%	53%
Trunk Angle to Right Horizontal° : Ball Release	7.91	12.7	8.93	10.4
Maximum Trunk Angle° :	11.4	13.1	11.0	13.0
Time (seconds) :	(0.29)	(0.37)	(0.28)	(0.33)
Total Angle of Trunk : Movement°	3.44	0.42	2.06	2.59
Time (seconds) :	(0.09)	(0.02)	(0.10)	(0.09)

Subject 5	Normal Bowling Condition		Belt 1	
3D Cinematography : File Name	C3/ANB1 NB1	C3/ANB2 NB2	C3/ABB1 B1	C3/ABB2 B2
Back Foot Angle° :	320	312	327	305
Shoulder Alignment°				
Back Foot Contact :	206	211	208	199
Front Foot Contact :	200	204	209	212
Ball Release :	280	280	284	289
Change FFC to BR°	80	76	75	77
3D Hip/Shoulder Separation°				
Back Foot Contact :	18.7	18.6	5.20	10.3
Front Foot Contact :	-19.3	-23.5	-21.6	-11.1
Ball Release :	-16.9	-35.2	-13.8	-29.7
Speed of Run-up (m s^{-1}): Hip Joint Centre at the end of the pre-delivery stride : (BFC)	5.98	6.34	5.90	6.61
% Contribution of run-up speed on ball release speed :	17.7%	18.7%	18.7%	20.7%
Peak Linear Speed (m s^{-1}) / Time Before/After Release				
Mass Centre	6.57 0.11	7.04 0.12	6.37 0.34	6.23 0.30
Right Hip	8.07 0.10	8.00 0.14	7.53 0.15	7.18 0.17
Right Shoulder	9.35 0.09	8.94 0.12	8.80 0.09	8.51 0.06
Right Elbow	14.34 0.03	14.77 0.04	13.82 0.04	12.84 0.05
Right Wrist	23.39 0.01	23.58 0.02	22.99 0.02	21.94 0.01
Right 3rd Finger	27.12 0.01	26.30 0.01	25.34 0.01	24.05 0.00
Ball Release Speed	33.82 -0.02	33.98 0.00	31.60 -0.01	31.95 -0.01
Shoulder-Hip Joints	1.28 0.01	0.94 0.02	1.27 0.06	1.33 0.11
Back Knee Angle° :				
Back Foot Contact	134	145	141	131
Front Foot Contact	133	139	143	135
Ball Release	96.4	92.6	109	109
Front Knee Angle° :				
Front Foot Contact	172	173	172	167
Ball Release	149	146	151	142
Release Height :	2.14m	2.18m	2.16m	2.15m
(% Height)	113%	115%	113%	113%
Delivery Stride Length :	1.36m	1.44m	1.42m	1.41m
(% Height)	72%	76%	75%	74%
Trunk Angle to Right Horizontal° : Ball Release	13.1	11.8	10.0	16.0
Maximum Trunk Angle° :	14.3	13.2	13.3	18.4
Time (seconds) :	(0.31)	(0.36)	(0.35)	(0.35)
Total Angle of Trunk : Movement°	1.24	1.41	3.26	2.41
Time (seconds) :	(0.08)	(0.05)	(0.06)	(0.06)

<u>Subject 6</u> **(Left Hand)**	Normal Bowling Condition		Belt 1	
3D Cinematography : File Name	C3/ABN1 NB1	C3/ABN2 NB2	C3/ABB1 B1	C3/ABB2 B2
Back Foot Angle° :	322	307	318	320
Shoulder Alignment°				
Back Foot Contact :	214	212	208	216
Front Foot Contact :	256	246	264	268
Ball Release :	295	298	299	304
Change FFC to BR°	39	48	35	36
3D Hip/Shoulder Separation°				
Back Foot Contact :	-26.2	-22.0	-23.8	-24.3
Front Foot Contact :	27.1	33.5	-39.4	-34.4
Ball Release :	-35.0	-39.2	-42.6	-41.7
Speed of Run-up (m s^{-1}): Hip Joint Centre at the end of the pre-delivery stride : (BFC)	4.00	4.23	3.60	4.05
% Contribution of run-up speed on ball release speed :	13.8%	14.6%	12.4%	13.5%
Peak Linear Speed (m s^{-1}) / Time Before/After Release				
Mass Centre	4.76 0.38	4.50 0.34	4.77 0.33	4.60 0.40
Right Hip	4.91 0.38	4.28 0.35	3.93 0.33	4.39 0.20
Right Shoulder	7.40 0.11	6.71 0.04	6.96 0.11	7.66 0.04
Right Elbow	12.86 0.04	12.36 0.04	12.88 0.06	13.43 0.03
Right Wrist	19.71 0.00	18.98 0.01	19.37 0.01	19.74 0.03
Right 3rd Finger	22.96 -0.01	21.84 0.00	22.75 0.00	23.14 0.01
Ball Release Speed	28.95 -0.02	28.98 -0.02	29.00 -0.01	29.92 -0.01
Shoulder-Hip Joints	2.49 0.27	2.42 0.31	3.03 0.22	3.27 0.16
Back Knee Angle° :				
Back Foot Contact	147	148	147	145
Front Foot Contact	124	142	127	124
Ball Release	112	134	125	116
Front Knee Angle° :				
Front Foot Contact	170	166	170	171
Ball Release	164	161	167	167
Release Height :	2.11m	2.12m	2.13m	2.11m
(% Height)	114%	115%	115%	114%
Delivery Stride Length :	1.15m	1.17m	1.08m	1.09m
(% Height)	62%	63%	58%	59%
Trunk Angle to Right Horizontal° : Ball Release	10.9	14.3	10.1	12.5
Maximum Trunk Angle° :	12.8	16.4	11.8	12.8
Time (seconds) :	(0.39)	(0.38)	(0.38)	(0.40)
Total Angle of Trunk : Movement°	1.86	2.04	1.64	0.35
Time (seconds) :	(0.04)	(0.05)	(0.04)	(0.02)

			Shoulder Aligment				3D Hip/Shoulder Seperation			Hip joint	Contribution
		Back Foot Angle	BFC	FFC	BR	Change FFC to BR	BFC	FFC	BR	speed at BFC	(%) to BR
Subject 1	**B1**	314	222	202	284	82	27.7	-12.2	38.1	6.02	18.6
	B2	320	220	212	285	73	29.7	-16.8	45.7	6.04	19.2
	NB1	313	219	206	273	67	34.8	-8.78	42	6.88	24.5
	NB2	328	223	198	302	104	31	-21.1	48.8	6.40	20.6
Subject 2	**B1**	286	193	184	277	93	-9.09	-23.7	43.4	5.84	17.9
	B2	304	186	184	273	89	-10.2	-20.3	44.1	6.15	18.8
	NB1	306	188	189	268	79	-14.1	-16.5	38.3	6.35	19.6
	NB2	299	189	180	272	92	-11.6	-18	46.3	6.03	18.5
Subject 3	**B1**	320	242	186	272	86	37.3	-15.4	37.5	6.16	18.1
	B2	324	238	190	290	100	39	-13.5	48.3	6.03	18.5
	NB1	334	234	192	277	85	35.9	-12.5	40.5	5.80	18.8
	NB2	318	241	188	284	96	36.5	-16.8	43.3	6.27	19.3
Subject 4	**B1**	304	218	209	314	105	26.6	-14.3	43.5	4.87	14
	B2	313	216	233	308	75	21.2	-20.1	36.5	3.94	12
	NB1	302	210	215	305	90	31.7	-12.5	39.7	4.79	14.4
	NB2	312	218	215	302	87	25	-17.3	34.4	4.89	15.1
Subject 5	**B1**	327	208	209	284	75	5.2	-21.6	13.8	5.90	18.7
	B2	305	199	212	289	77	10.3	-11.1	29.7	6.61	20.7
	NB1	320	206	200	280	80	18.7	-19.3	16.9	5.98	17.7
	NB2	312	211	204	280	76	18.6	-23.5	35.2	6.34	18.7
Subject 6	**B1**	318	208	264	299	35	23.8	-39.4	42.6	3.60	12.4
	B2	320	216	268	304	36	24.3	-34.4	41.7	4.05	13.5
	NB1	322	214	256	295	39	26.2	-27.1	35	4.00	13.8
	NB2	307	212	246	298	48	22	-33.5	39.2	4.23	14.6
Average	**n=24**	**314**	**214**	**210**	**288**	**77.9**	**20**	**-19.6**	**38.5**	**5.55**	**17.4**
S.E.		**2.19**	**3.20**	**5.23**	**2.72**	**4.11**	**3.35**	**1.57**	**1.74**	**0.20**	**0.62**
Belt	**n=12**	**313**	**214**	**213**	**290**	**77.2**	**18.8**	**-20.2**	**38.7**	**5.43**	**16.9**
S.E.		**3.31**	**4.77**	**8.31**	**3.95**	**6.33**	**3.68**	**2.48**	**1.89**	**0.3**	**0.86**
No Belt	**n=12**	**314**	**214**	**207**	**286**	**78.6**	**21.2**	**-18.9**	**38.3**	**5.66**	**18**
S.E.		**3.02**	**3.85**	**6.64**	**3.84**	**5.52**	**4.03**	**2.86**	**2.07**	**0.27**	**0.89**

BFC : Back Foot Contact **FFC : Front Foot Contact** **BR : Ball Release**

		Trunk Angle at Release	Max. Trunk Angle	Total angle of trunk movement	Time of trunk movement	Front Knee Angle			Back Knee Angle			Release Height	% Height	Delivery Stride Length	% Height
						FFC	BR	Difference (BR-FFC)	BFC	FFC	BR				
Subject 1	**B1**	-13.3	-0.06	13.2	0.09	168	126	-42	153	137	97	1.99	114	1.12	64
	B2	-14.7	1.44	16.1	0.15	166	126	-40	158	138	88	1.94	111	1.14	65
	NB1	-16.9	7.82	24.7	0.13	171	121	-50	154	133	97	1.84	105	1.13	65
	NB2	-12.3	1.96	14.3	0.12	167	121	-46	154	143	90	1.91	109	1.08	62
Subject 2	**B1**	-3.02	7.00	10	0.04	168	123	-45	151	139	94	1.85	104	1.24	70
	B2	-3.53	6.20	9.73	0.12	169	127	-42	154	133	84	1.80	101	1.25	70
	NB1	-1.59	7.95	9.54	0.09	176	129	-47	146	139	89	1.88	106	1.26	71
	NB2	4.72	8.77	4.05	0.03	169	127	-42	149	130	92	1.83	103	1.23	69
Subject 3	**B1**	-13.6	-3.05	10.6	0.14	154	120	-34	148	142	98	2.06	112	1.20	65
	B2	-13.9	-6.84	7.06	0.14	155	120	-35	143	145	96	2.05	112	1.23	67
	NB1	-13.8	-3.41	10.4	0.15	162	119	-43	161	144	102	2.00	110	1.31	74
	NB2	-12.9	-4.70	8.2	0.11	161	131	-30	151	139	93	2.02	110	1.25	68
Subject 4	**B1**	8.93	10.99	2.06	0.10	172	171	-1	148	144	106	1.95	109	1.05	59
	B2	10.4	13.03	2.63	0.09	164	167	3	141	136	113	1.92	108	0.95	53
	NB1	7.91	11.35	3.44	0.09	161	169	8	143	140	112	1.94	109	1.02	57
	NB2	12.7	13.10	0.4	0.02	165	167	2	144	145	115	1.98	111	0.99	56
Subject 5	**B1**	10	13.28	3.28	0.06	172	151	-21	141	143	109	2.16	113	1.42	75
	B2	16	18.37	2.37	0.06	167	142	-25	131	135	109	2.15	113	1.41	74
	NB1	13.1	14.29	1.19	0.08	172	149	-23	134	133	96	2.14	113	1.36	72
	NB2	11.8	13.21	1.41	0.05	173	146	-27	145	139	93	2.18	115	1.44	76
Subject 6	**B1**	10.1	11.75	1.65	0.04	170	167	-3	147	127	125	2.13	115	1.08	58
	B2	12.5	12.84	0.34	0.02	171	162	-9	145	124	116	2.11	114	1.09	59
	NB1	10.9	12.79	1.89	0.04	170	164	-6	147	124	112	2.11	114	1.15	62
	NB2	14.3	16.37	2.07	0.05	166	161	-5	148	142	134	2.12	115	1.17	63
Average	**n=24**	**0.99**	**7.69**	**6.69**	**0.08**	**167**	**142**	**-25.1**	**147**	**137**	**102**	**2.00**	**110**	**1.19**	**65.6**
S.E.		**2.43**	**1.47**	**1.25**	**0.01**	**1.11**	**4.00**	**3.87**	**1.40**	**1.29**	**2.57**	**0.02**	**0.82**	**0.03**	**1.33**
Belt	**n=12**	**0.49**	**7.08**	**6.59**	**0.09**	**166**	**142**	**-24.6**	**147**	**137**	**103**	**2.01**	**111**	**1.18**	**64.9**
S.E.		**3.47**	**2.22**	**1.51**	**0.01**	**1.74**	**5.94**	**5.17**	**2.07**	**1.88**	**3.48**	**0.03**	**1.24**	**0.04**	**1.95**
No Belt	**n=12**	**1.50**	**8.29**	**6.80**	**0.08**	**168**	**142**	**-25.7**	**148**	**138**	**102**	**2.00**	**110**	**1.20**	**66.3**
S.E.		**3.53**	**1.99**	**2.07**	**0.01**	**1.42**	**5.64**	**6.01**	**1.97**	**1.83**	**3.94**	**0.03**	**1.13**	**0.04**	**1.87**

BFC : Back Foot Contact **FFC : Front Foot Contact** **BR : Ball Release**

Linear Speed (m s^{-1})

Belt Condition

Subject No.		1 Mass Centre	2 Leading Hip	3 Leading Shoulder	4 Leading Elbow	5 Leading Wrist	6 Leading 3rd Finger	7 Cricket Ball
1	Belt	6.80	7.92	9.83	14.09	21.55	24.85	31.90
2	Belt	6.66	7.15	9.72	13.25	22.66	27.54	32.70
3	Belt	6.59	6.10	8.08	14.72	22.04	25.59	33.33
4	Belt	5.50	6.15	8.65	13.84	22.55	25.79	33.80
5	Belt	6.30	7.35	8.65	13.33	22.47	24.69	31.77
6	Belt	4.68	4.16	7.31	13.16	19.55	22.94	29.46
	Mean	**6.09**	**6.47**	**8.71**	**13.73**	**21.80**	**25.23**	**32.16**
	S.E.	**0.34**	**0.55**	**0.39**	**0.25**	**0.48**	**0.62**	**0.63**

No Belt Condition

Subject No.		1 Mass Centre	2 Leading Hip	3 Leading Shoulder	4 Leading Elbow	5 Leading Wrist	6 Leading 3rd Finger	7 Cricket Ball
1	No Belt	7.68	8.30	9.43	13.50	20.65	23.73	29.59
2	No Belt	6.74	7.15	9.29	12.48	21.40	25.98	32.48
3	No Belt	6.95	6.62	8.44	14.17	23.22	26.17	31.64
4	No Belt	5.13	6.03	8.46	13.84	22.17	25.65	32.78
5	No Belt	6.80	8.04	9.14	14.55	23.48	26.71	33.90
6	No Belt	4.63	4.60	7.06	12.61	19.34	22.40	28.97
	Mean	**6.32**	**6.79**	**8.64**	**13.52**	**21.71**	**25.11**	**31.56**
	S.E.	**0.48**	**0.56**	**0.36**	**0.34**	**0.64**	**0.68**	**0.78**

Average Difference (Belt - No Belt)

Subject No.		1 Mass Centre	2 Leading Hip	3 Leading Shoulder	4 Leading Elbow	5 Leading Wrist	6 Leading 3rd Finger	7 Cricket Ball
1		-0.88	-0.37	0.39	0.59	0.90	1.12	2.31
2		-0.08	-0.00	0.42	0.77	1.26	1.56	0.22
3		-0.36	-0.52	-0.36	0.55	-1.17	-0.58	1.69
4		0.37	0.12	0.19	0.00	0.38	0.14	1.02
5		-0.51	-0.68	-0.49	-1.22	-1.02	-2.01	-2.12
6		0.05	-0.44	0.25	0.55	0.21	0.54	0.49
	Mean	**-0.23**	**-0.32**	**0.07**	**0.21**	**0.09**	**0.13**	**0.60**
	S.E.	**0.18**	**0.13**	**0.16**	**0.30**	**0.41**	**0.53**	**0.63**

Time of Peak Linear Speed Before/After Point of Release

		1 Mass Centre	2 Leading Hip	3 Leading Shoulder	4 Leading Elbow	5 Leading Wrist	6 Leading 3rd Finger	7 Cricket Ball
Subject 1	**B1**	0.32	0.12	0.07	0.04	0.01	0.00	-0.01
	B2	0.11	0.12	0.08	0.05	0.02	0.01	-0.01
	NB1	0.28	0.28	0.08	0.03	0.02	0.01	-0.01
	NB2	0.32	0.20	0.07	0.04	0.02	0.01	-0.01
Subject 2	**B1**	0.13	0.14	0.07	0.04	0.01	0.00	-0.02
	B2	0.15	0.11	0.09	0.05	0.02	0.01	-0.02
	NB1	0.13	0.14	0.08	0.04	0.03	0.01	-0.02
	NB2	0.18	0.15	0.08	0.06	0.01	0.01	-0.02
Subject 3	**B1**	0.36	0.35	0.08	0.03	0.01	-0.01	-0.02
	B2	0.38	0.35	0.08	0.03	0.00	-0.01	-0.01
	NB1	0.41	0.42	0.11	0.04	0.03	0.01	-0.01
	NB2	0.39	0.38	0.09	0.04	0.02	0.01	-0.01
Subject 4	**B1**	0.13	0.16	0.09	0.05	0.01	0.01	-0.01
	B2	0.25	0.21	0.12	0.09	0.00	-0.01	-0.01
	NB1	0.26	0.13	0.07	0.04	0.01	0.00	-0.02
	NB2	0.18	0.17	0.08	0.05	0.01	0.01	-0.01
Subject 5	**B1**	0.34	0.15	0.09	0.04	0.02	0.01	-0.01
	B2	0.30	0.17	0.06	0.05	0.01	0.00	-0.01
	NB1	0.11	0.10	0.09	0.03	0.01	0.01	-0.02
	NB2	0.12	0.14	0.12	0.04	0.02	0.01	0.00
Subject 6	**B1**	0.33	0.33	0.11	0.06	0.01	0.00	-0.01
	B2	0.40	0.20	0.04	0.03	0.03	0.01	-0.01
	NB1	0.38	0.38	0.11	0.04	0.00	-0.01	-0.02
	NB2	0.34	0.35	0.04	0.04	0.01	0.00	-0.02
Average	**n=24**	**0.26**	**0.22**	**0.08**	**0.04**	**0.01**	**0.00**	**-0.01**
Belt	**n=12**	**0.27**	**0.20**	**0.08**	**0.05**	**0.01**	**0.00**	**-0.01**
No Belt	**n=12**	**0.26**	**0.23**	**0.09**	**0.04**	**0.02**	**0.01**	**-0.01**

Progressive Linear Speed : Fast-Medium Cricket : NO BELT

Independent Group Analysis C:\PDH\EXP4\GROUP.DBF

Grouping variable is JOINT
Analysis variable is NO BELT

Group Means and Standard Deviations

1 (Mass Centre)	: mean = 6.32	s.d. = 1.18	n = 6
2 (Hip)	: mean = 6.79	s.d. = 1.37	n = 6
3 (Shoulder)	: mean = 8.64	s.d. = 0.88	n = 6
4 (Elbow)	: mean = 13.53	s.d. = 0.84	n = 6
5 (Wrist)	: mean = 21.71	s.d. = 1.58	n = 6
6 (Finger)	: mean = 25.11	s.d. = 1.67	n = 6
7 (Ball)	: mean = 31.56	s.d. = 1.92	n = 6

Analysis of Variance Table

Source	S.S.	DF	MS	F	Appx P
Total	3645.1	41			
Treatment	3576.59	6	596.1	304.54	**<.001**
Error	68.51	35	1.96		

Error term used for comparisons = 1.96 with 35 d.f.

Newman-Keuls Multiple Comp.	Difference	P	Q	Critical q (.05)
Mean(7.00)-Mean(1.00) =	25.2383	7	44.187	4.427 *
Mean(7.00)-Mean(2.00) =	24.77	6	43.367	4.267 *
Mean(7.00)-Mean(3.00) =	22.9233	5	40.134	4.071 *
Mean(7.00)-Mean(4.00) =	18.035	4	31.576	3.818 *
Mean(7.00)-Mean(5.00) =	9.85	3	17.245	3.464 *
Mean(7.00)-Mean(6.00) =	6.4533	2	11.298	2.873 *
Mean(6.00)-Mean(1.00) =	18.785	6	32.889	4.267 *
Mean(6.00)-Mean(2.00) =	18.3167	5	32.069	4.071 *
Mean(6.00)-Mean(3.00) =	16.47	4	28.836	3.818 *
Mean(6.00)-Mean(4.00) =	11.5817	3	20.277	3.464 *
Mean(6.00)-Mean(5.00) =	3.3967	2	5.947	2.873 *
Mean(5.00)-Mean(1.00) =	15.3883	5	26.942	4.071 *
Mean(5.00)-Mean(2.00) =	14.92	4	26.122	3.818 *
Mean(5.00)-Mean(3.00) =	13.0733	3	22.889	3.464 *
Mean(5.00)-Mean(4.00) =	8.185	2	14.33	2.873 *
Mean(4.00)-Mean(1.00) =	7.2033	4	12.612	3.818 *
Mean(4.00)-Mean(2.00) =	6.735	3	11.792	3.464 *
Mean(4.00)-Mean(3.00) =	4.8883	2	8.558	2.873 *
Mean(3.00)-Mean(1.00) =	2.315	3	4.053	3.464 *
Mean(3.00)-Mean(2.00) =	1.8467	2	3.233	2.873 *
Mean(2.00)-Mean(1.00) =	0.4683	2	.82	2.873

Homogeneous Populations, groups ranked

```
Gp Gp Gp Gp Gp Gp Gp
 1  2  3  4  5  6  7
------
      ---
         ---
            ---
               ---
                  ---
```

This is a graphical representation of the Newman-Keuls multiple Comparisons test. At the 0.05 significance level, the means of any two Groups underscored by the same line are not significantly different.

Progressive Linear Speed : Fast-Medium Cricket : BELT

Independent Group Analysis C:\PDH\EXP4\GROUP.DBF

Grouping variable is JOINT
Analysis variable is BELT

Group Means and Standard Deviations

1 (Mass Centre)	: mean = 6.09	s.d. = 0.83	n = 6
2 (Hip)	: mean = 6.47	s.d. = 1.34	n = 6
3 (Shoulder)	: mean = 8.71	s.d. = 0.96	n = 6
4 (Elbow)	: mean = 13.73	s.d. = 0.61	n = 6
5 (Wrist)	: mean = 21.80	s.d. = 1.18	n = 6
6 (Finger)	: mean = 25.23	s.d. = 1.51	n = 6
7 (Ball)	: mean = 32.16	s.d. = 1.54	n = 6

Analysis of Variance Table

Source	S.S.	DF	MS	F	Appx P
Total	3809.65	41			
Treatment	3760.55	6	626.76	446.75	**<.001**
Error	49.1	35	1.4		

Error term used for comparisons = 1.4 with 35 d.f.

Newman-Keuls Multiple Comp.	Difference	P	Q	Critical q (.05)	
Mean(7.00)-Mean(1.00) =	26.0717	7	53.917	4.427	*
Mean(7.00)-Mean(2.00) =	25.6883	6	53.124	4.267	*
Mean(7.00)-Mean(3.00) =	23.4533	5	48.502	4.071	*
Mean(7.00)-Mean(4.00) =	18.4283	4	38.111	3.818	*
Mean(7.00)-Mean(5.00) =	10.3567	3	21.418	3.464	*
Mean(7.00)-Mean(6.00) =	6.9267	2	14.325	2.873	*
Mean(6.00)-Mean(1.00) =	19.145	6	39.593	4.267	*
Mean(6.00)-Mean(2.00) =	18.7617	5	38.8	4.071	*
Mean(6.00)-Mean(3.00) =	16.5267	4	34.178	3.818	*
Mean(6.00)-Mean(4.00) =	11.5017	3	23.786	3.464	*
Mean(6.00)-Mean(5.00) =	3.43	2	7.093	2.873	*
Mean(5.00)-Mean(1.00) =	15.715	5	32.499	4.071	*
Mean(5.00)-Mean(2.00) =	15.3317	4	31.706	3.818	*
Mean(5.00)-Mean(3.00) =	13.0967	3	27.084	3.464	*
Mean(5.00)-Mean(4.00) =	8.0717	2	16.693	2.873	*
Mean(4.00)-Mean(1.00) =	7.6433	4	15.807	3.818	*
Mean(4.00)-Mean(2.00) =	7.26	3	15.014	3.464	*
Mean(4.00)-Mean(3.00) =	5.025	2	10.392	2.873	*
Mean(3.00)-Mean(1.00) =	2.6183	3	5.415	3.464	*
Mean(3.00)-Mean(2.00) =	2.235	2	4.622	2.873	*
Mean(2.00)-Mean(1.00) =	0.3833	2	.793	2.873	

Homogeneous Populations, groups ranked

```
Gp Gp Gp Gp Gp Gp Gp
 1  2  3  4  5  6  7
------
      ---
         ---
            ---
               ---
                  ---
```

This is a graphical representation of the Newman-Keuls multiple Comparisons test. At the 0.05 significance level, the means of any two Groups underscored by the same line are not significantly different.

Experiment 4 : Linear Speed : Mass Centre

Repeated Measures Analysis Summary C:\PDH\EXP4\MASS.DBF

Number of repeated measures is 2
Number of subjects read in 6

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 6.08833 s.d. = 0.83178
2) NO BELT: mean = 6.32167 s.d. = 1.1769

Mean Difference = -0.23333 s.d.(difference) = 0.44116

95% C.I. about Mean Difference is (-0.6971, 0.23044)

Paired t-test

Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 1.29554 with 5 D.F. **p = 0.25** (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

Experiment 4 : Linear Speed : Hip Joint Centre

Repeated Measures Analysis Summary C:\PDH\EXP4\HIP.DBF

Number of repeated measures is 2
Number of subjects read in 6

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 6.47167 s.d. = 1.33527
2) NO BELT: mean = 6.79 s.d. = 1.36929

Mean Difference = -0.31833 s.d.(difference) = 0.31333

95% C.I. about Mean Difference is (-0.64772, 0.01105)

Paired t-test

Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 2.48859 with 5 D.F. **p = 0.06** (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

Experiment 4 : Linear Speed : Shoulder Joint Centre

```
Repeated Measures Analysis Summary              C:\PDH\EXP4\SHOULDER.DBF
-----------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  6

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 8.70667            s.d. = 0.96317
 2) NO BELT: mean = 8.63667         s.d. = 0.87924

 Mean Difference = 0.07           s.d.(difference) = 0.39593

 95% C.I. about Mean Difference is (-0.34622, 0.48622)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.43307 with 5 D.F.     p = 0.68 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experiment 4 : Linear Speed : Elbow Joint Centre

```
Repeated Measures Analysis Summary                 C:\PDH\EXP4\ELBOW.DBF
-----------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  6

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 13.73167           s.d. = 0.60615
 2) NO BELT: mean = 13.525          s.d. = 0.83615

 Mean Difference = 0.20667        s.d.(difference) = 0.7454

 95% C.I. about Mean Difference is (-0.57693, 0.99026)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.67913 with 5 D.F.     p = 0.53 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experiment 4 : Linear Speed : Wrist Joint Centre

```
Repeated Measures Analysis Summary                 C:\PDH\EXP4\WRIST.DBF
--------------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  6

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 21.80333          s.d. = 1.17754
 2) NO BELT: mean = 21.71          s.d. = 1.5787

 Mean Difference = 0.09333        s.d.(difference) = 0.99462

 95% C.I. about Mean Difference is (-0.95225, 1.13892)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.22986 with 5 D.F.     p = 0.83 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experiment 4 : Linear Speed : Finger Joint Centre

```
Repeated Measures Analysis Summary                 C:\PDH\EXP4\FINGER.DBF
--------------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  6

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 25.23333          s.d. = 1.51394
 2) NO BELT: mean = 25.10666       s.d. = 1.67219

 Mean Difference = 0.12667        s.d.(difference) = 1.28994

 95% C.I. about Mean Difference is (-1.22937, 1.4827)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.24053 with 5 D.F.     p = 0.82 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experiment 4 : Linear Speed : Cricket Ball

Repeated Measures Analysis Summary C:\PDH\EXP4\BALL.DBF

Number of repeated measures is 2
Number of subjects read in 6

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 32.16 s.d. = 1.54017
2) NO BELT: mean = 31.56 s.d. = 1.91861

Mean Difference = 0.6 s.d.(difference) = 1.5426

95% C.I. about Mean Difference is (-1.02164, 2.22164)

Paired t-test

Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.95274 with 5 D.F. **p = 0.38** (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

Experiment 4 : Approach Velocity : Linear Hip Speed at BFC

Repeated Measures Analysis Summary C:\PDH\EXP4\APPRO_V.DBF

Number of repeated measures is 2
Number of subjects read in 6

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 5.43167 s.d. = 1.04364
2) NOBELT: mean = 5.665 s.d. = 0.96743

Mean Difference = -0.23333 s.d.(difference) = 0.27413

95% C.I. about Mean Difference is (-0.52151, 0.05484)

Paired t-test

Hypotheses:

Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 2.08496 with 5 D.F. **p = 0.09** (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

WINKS 4.21 : EXPERIMENT 4 : FAST-MEDIUM CRICKET BOWLING

Linear Speed ($m\ s^{-1}$) : (SHOULDER - HIP JOINT)

	BELT	NO BELT
Subject 1	1.90	1.14
Subject 2	2.57	2.14
Subject 3	1.98	1.82
Subject 4	2.50	2.43
Subject 5	1.30	1.11
Subject 6	3.15	2.46

Repeated Measures Analysis Summary

Number of repeated measures is 2
Number of subjects read in 6

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 2.23 s.d. = 0.64
2) NO BELT: mean = 1.85 s.d. = 0.61

Mean Difference = 0.38 s.d.(difference) = 0.29

95% C.I. about Mean Difference is (0.08, 0.69)

Paired t-test

Hypotheses:

Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t value = **3.23** with 5 D.F. p = 0.02 (two-sided)
p = 0.01 (one-sided)

Since p <= 0.05, at the 0.05 significance level you have evidence to reject the null hypothesis and conclude that the mean difference between pairs is not 0.

WINKS 4.21 : EXPERIMENT 4 : FAST-MEDIUM CRICKET BOWLING

Time Between Peak Linear Speed (ms) : (SHOULDER - HIP JOINT)

	BELT	NO BELT
Subject 1	45	125
Subject 2	45	65
Subject 3	270	300
Subject 4	80	75
Subject 5	85	15
Subject 6	190	290

Repeated Measures Analysis Summary

Number of repeated measures is 2
Number of subjects read in 6

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 119 s.d. = 91
2) NO BELT: mean = 258 s.d. = 268

Mean Difference = -138 s.d.(difference) = 267

95% C.I. about Mean Difference is (-419, 142)

Paired t-test

Hypotheses:

Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = **1.27** with 5 D.F. p = 0.26 (two-sided)
p = 0.13 (one-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.

Cricket Bowling : Average (n=6)

	No Belt Condition				Belt Condition			
	Back Foot		Front Foot		Back Foot		Front Foot	
	Newtons	S.E.	Newtons	S.E.	Newtons	S.E.	Newtons	S.E.
Fz	1953	89.5	4809	920	2022	117	4873	911
Fy -ve	770	122	2933	565	806	94.6	2949	577
Fy +ve	142	44	257	39.2	142	44.2	263	48
Fx -ve	404	66.1	548	136	484	72.4	517	122
Fx+ve	356	77.8	380	124	337	72.2	358	120

Cricket Bowling : Average (n=6)

	No Belt Condition				Belt Condition			
	Back Foot		Front Foot		Back Foot		Front Foot	
	B.W.	S.E.	B.W.	S.E.	B.W.	S.E.	B.W.	S.E.
Fz	2.38	0.14	5.75	0.98	2.46	0.18	5.82	0.98
Fy -ve	0.95	0.16	3.54	0.67	0.99	0.13	3.55	0.69
Fy +ve	0.17	0.05	0.31	0.05	0.17	0.05	0.32	0.06
Fx -ve	0.49	0.05	0.65	0.05	0.59	0.05	0.62	0.06
Fx+ve	0.45	0.10	0.46	0.15	0.42	0.10	0.43	0.14

Cricket Bowling : Fz +ve Average Peak Forces

	No Belt Condition				Belt Condition			
	Back Foot		Front Foot		Back Foot		Front Foot	
	Fz +ve	B.W.	Fz +ve	B.W.	Fz +ve	B.W.	Fz +ve	B.W.
Subject 1	2170	2.68	4012	4.96	1965	2.42	4187	5.15
Subject 2	1939	2.53	4097	5.34	2231	2.88	4599	5.93
Subject 3	1841	2.31	5121	6.44	2044	2.56	5021	6.28
Subject 4	* **1590**	**1.76**	8570	9.47	* **1483**	**1.64**	8582	9.50
Subject 5	2013	2.32	5362	6.18	2139	2.47	5211	6.01
Subject 6	2165	2.66	1694	2.08	2270	2.80	1637	2.02
Average	**1953**	**2.38**	**4809**	**5.75**	**2022**	**2.46**	**4873**	**5.82**
S.D.	219	0.34	2254	2.40	287	0.44	2232	2.40
S.E.	90	0.14	920	0.98	117	0.18	911	0.98

Average Peak Forces Fz : Difference : Belt - No Belt Conditions

	Back Foot		Front Foot	
	Newtons	B.W.	Newtons	B.W.
Subject 1	-205	-0.26	175	0.19
Subject 2	292	0.35	502	0.59
Subject 3	203	0.25	-100	-0.16
Subject 4	-107	-0.12	12	0.03
Subject 5	126	0.15	-151	-0.17
Subject 6	105	0.14	-57	-0.06
Average	**69**	**0.08**	**64**	**0.07**
S.D.	189	0.23	243	0.29
S.E.	77	0.09	99	0.12

Cricket Bowling : Fy +ve Average Peak Forces

	No Belt Condition				Belt Condition			
	Back Foot		Front Foot		Back Foot		Front Foot	
	Fy +ve	B.W.	Fy +ve	B.W.	Fy +ve	B.W.	Fy +ve	B.W.
Subject 1	127	0.16	206	0.25	125	0.15	184	0.23
Subject 2	239	0.31	143	0.19	264	0.34	117	0.15
Subject 3	98	0.12	199	0.25	93	0.12	202	0.25
Subject 4	67	0.07	293	0.32	65	0.07	320	0.35
Subject 5	301	0.35	288	0.33	283	0.33	313	0.36
Subject 6	17	0.02	415	0.51	19	0.02	442	0.55
Average	**142**	**0.17**	**257**	**0.31**	**142**	**0.17**	**263**	**0.32**
S.D.	108	0.13	96	0.11	108	0.13	118	0.14
S.E.	44	0.05	39	0.05	44	0.05	48	0.06

Average Peak Forces Fy +ve : Difference : Belt - No Belt Conditions

	Back Foot		Front Foot	
	Newtons	B.W.	Newtons	B.W.
Subject 1	-2	-0.01	-22	-0.02
Subject 2	25	0.03	-26	-0.04
Subject 3	-5	0	3	0.00
Subject 4	-2	0	27	0.03
Subject 5	-18	-0.02	25	0.03
Subject 6	2	0	27	0.04
Average	**0**	**0.00**	**6**	**0.01**
S.D.	14	0.02	25	0.03
S.E.	6	0.01	10	0.01

Cricket Bowling : Fy -ve Average Peak Forces

		No Belt Condition					Belt Condition				
		Back Foot			Front Foot			Back Foot			Front Foot	
		Fy -ve	B.W.		Fy -ve	B.W.		Fy -ve	B.W.		Fy -ve	B.W.
Subject 1	*	**967**	**1.20**		2387	2.95	*	**916**	**1.13**		2478	3.05
Subject 2		947	1.23		3459	4.51		957	1.23		3812	4.92
Subject 3		890	1.12		3727	4.69		934	1.17		3426	4.29
Subject 4	*	**178**	**0.20**	*	**3963**	**4.38**	*	**350**	**0.39**	*	**4226**	**4.68**
Subject 5		754	0.87		3718	4.29		782	0.90		3435	3.96
Subject 6		882	1.09		344	0.42		899	1.11		314	0.39
Average		**770**	**0.95**		**2933**	**3.54**		**806**	**0.99**		**2949**	**3.55**
S.D.		299	0.39		1385	1.65		232	0.31		1415	1.68
S.E.		122	0.16		565	0.67		95	0.13		577	0.69

Average Peak Forces Fy -ve : Difference : Belt - No Belt Conditions

	Back Foot		Front Foot	
	Newtons	B.W.	Newtons	B.W.
Subject 1	-51	-0.07	91	0.10
Subject 2	10	0	353	0.41
Subject 3	44	0.05	-301	-0.40
Subject 4	172	0.19	263	0.30
Subject 5	28	0.03	-283	-0.33
Subject 6	17	0.02	-30	-0.03
Average	**37**	**0.04**	**16**	**0.01**
S.D.	74	0.09	273	0.33
S.E.	30	0.03	111	0.13

Cricket Bowling : Fx +ve Average Peak Forces

	No Belt Condition				Belt Condition			
	Back Foot		Front Foot		Back Foot		Front Foot	
	Fx +ve	B.W.	Fx +ve	B.W.	Fx +ve	B.W.	Fx +ve	B.W.
Subject 1	* **546**	**0.67**	251	0.31	* **487**	**0.60**	143	0.18
Subject 2	610	0.80	151	0.20	583	0.75	139	0.18
Subject 3	348	0.44	* **829**	**1.04**	340	0.43	* **705**	**0.88**
Subject 4	107	0.12	669	0.74	119	0.13	737	0.82
Subject 5	239	0.31	64	0.06	178	0.21	85	0.10
Subject 6	283	0.35	318	0.39	312	0.38	337	0.42
Average	**356**	**0.45**	**380**	**0.46**	**337**	**0.42**	**358**	**0.43**
S.D.	191	0.25	303	0.37	177	0.23	294	0.34
S.E.	78	0.10	124	0.15	72	0.10	120	0.14

Average Peak Forces Fx +ve : Difference : Belt - No Belt Conditions

	Back Foot		Front Foot	
	Newtons	B.W.	Newtons	B.W.
Subject 1	-59	-0.07	-108	-0.13
Subject 2	-27	-0.05	-12	-0.02
Subject 3	-8	-0.01	-124	-0.16
Subject 4	12	0.01	68	0.08
Subject 5	-61	-0.1	21	0.04
Subject 6	29	0.03	19	0.03
Average	**-19**	**-0.03**	**-23**	**-0.03**
S.D.	37	0.05	77	0.10
S.E.	15	0.02	31	0.04

Cricket Bowling : Fx -ve Average Peak Forces

		No Belt Condition					Belt Condition			
		Back Foot		**Front Foot**			**Back Foot**		**Front Foot**	
		Fx -ve	**B.W.**	**Fx -ve**	**B.W.**		**Fx -ve**	**B.W.**	**Fx -ve**	**B.W.**
Subject 1		459	0.57	659	0.81		427	0.53	698	0.86
Subject 2	*	**407**	**0.53**	615	0.80	*	**618**	**0.80**	540	0.70
Subject 3		499	0.63	-	-		531	0.66	78	0.10
Subject 4	*	**179**	**0.20**	508	0.56	*	**334**	**0.37**	491	0.54
Subject 5		620	0.71	947	1.09		731	0.84	780	0.90
Subject 6		257	0.32	12	0.01		260	0.32	-	-
Average		**404**	**0.49**	**548**	**0.65**		**484**	**0.59**	**517**	**0.62**
S.D.		162	0.19	305	0.36		177	0.22	272	0.32
S.E.		66	0.08	136	0.16		72	0.09	122	0.14

Average Peak Forces Fx -ve : Difference : Belt - No Belt Conditions

	Back Foot		**Front Foot**	
	Newtons	B.W.	Newtons	B.W.
Subject 1	-32	-0.04	39	0.05
Subject 2	211	0.27	-75	-0.10
Subject 3	32	0.03	-	-
Subject 4	155	0.17	-17	-0.02
Subject 5	111	0.13	-167	-0.19
Subject 6	3	0	-	-
Average	**80**	**0.09**	**-55**	**-0.07**
S.D.	94	0.12	76	0.09
S.E.	39	0.05	38	0.04

Cricket Bowling : Time in Contact (ms)

	No Belt Condition		Belt Condition	
	Back Foot	Front Foot	Back Foot	Front Foot
Subject 1	199	293	195	296
Subject 2	* **231**	* **319**	* **210**	* **374**
Subject 3	298	346	293	337
Subject 4	180	401	186	392
Subject 5	211	* **319**	221	* **352**
Subject 6	279	* **417**	275	* **399**
Average	**233**	**349**	**230**	**358**
S.D.	46	50	44	39
S.E.	19	20	18	16

Time in Contact (ms) : Difference : Belt - No Belt Conditions

	Back Foot	Front Foot
Subject 1	-4	3
Subject 2	-21	55
Subject 3	-5	-9
Subject 4	6	-9
Subject 5	10	33
Subject 6	-4	-18
Average	**-3**	**9**
S.D.	11	29
S.E.	4	12

Cricket Bowling : Time to Peak Vertical Force (ms)

	No Belt Condition		Belt Condition	
	Back Foot	Front Foot	Back Foot	Front Foot
Subject 1	* **32**	* **29**	* **45**	* **24**
Subject 2	72	35	70	35
Subject 3	* **36**	25	* **42**	22
Subject 4	* **58**	18	* **64**	17
Subject 5	63	25	54	22
Subject 6	55	* **21**	51	* **23**
Average	**53**	**26**	**54**	**24**
S.D.	16	6	11	6
S.E.	6	2	4	2

Average Time to Peak Vertical Force : Difference : Belt - No Belt Conditions

	Back Foot	Front Foot
Subject 1	13	-5
Subject 2	-2	0
Subject 3	6	-3
Subject 4	6	-1
Subject 5	-9	-3
Subject 6	-4	2
Average	**2**	**-2**
S.D.	8	3
S.E.	3	1

Cricket Bowling : Loading Rates (Body Weight per second)

	No Belt Condition		Belt Condition	
	Back Foot	Front Foot	Back Foot	Front Foot
Subject 1	84.9	176	71.9	214
Subject 2	36.2	154	41.3	171
Subject 3	66.3	269	61.7	297
Subject 4	* **30.1**	540	* **25.7**	551
Subject 5	37.1	255	51.3	289
Subject 6	48.7	98.2	54.7	88.2
Average	**50.6**	**249**	**51.1**	**268**
S.D.	21.2	156	16.1	159
S.E.	8.65	63.8	6.58	64.8

Average Loading Rates : Difference : Belt - No Belt Conditions

	Back Foot	Front Foot
Subject 1	-13	38
Subject 2	5.1	17
Subject 3	-4.6	28
Subject 4	-4.4	11
Subject 5	14.2	34
Subject 6	6	-10
Average	**0.55**	**19.7**
S.D.	9.71	17.7
S.E.	3.96	7.24

Cricket Bowling : Total Time in Contact (ms)

(Total Time = Back Foot Contact to Toe off Front Foot)

Overlap Time : Toe off (Back Foot) / Heel Contact (Front Foot)
+ Overlap - Gap

	No Belt Condition		Belt Condition	
	Total Time in Contact	**Overlap Time**	**Total Time in Contact**	**Overlap Time**
Subject 1	487	* **5**	492	* **-2**
Subject 2	510	* **39**	577	* **17**
Subject 3	632	20	615	15
Subject 4	620	-39	598	-20
Subject 5	547	-10	581	-8
Subject 6	725	-30	714	39
Average	**587**	**-3**	**596**	**7**
S.D.	89	30	72	21
S.E.	37	12	29	9

Average Differences : Total Time in contact : Overlap Time
(Belt - No Belt Conditions)

	Total Time in Contact	**Overlap Time**
Subject 1	5	-7
Subject 2	67	-22
Subject 3	-17	-5
Subject 4	-22	19
Subject 5	34	2
Subject 6	-11	69
Average	**9**	**9**
S.D.	35	32
S.E.	14	13

EMG Data : Mean

No Belt : Average 6 Subjects

	Quad	Hamstring	Calf	Abs	R. Back	L. Back
Subject 1	3374	2913	2451	3315	2617	2480
Subject 2	2810	3126	3024	2738	3115	3026
Subject 3	3137	3099	3120	3111	3043	3028
Subject 4	3070	3079	3040	-	3142	3043
Subject 5	2964	2982	2735	-	3255	-
Subject 6	3003	3070	3259	-	-	-
Average	**3060**	**3045**	**2938**	**3055**	**3034**	**2894**
S.E.	**77**	**33**	**120**	**169**	**110**	**138**

Belt : Average 6 Subjects

	Quad	Hamstring	Calf	Abs	R. Back	L. Back
Subject 1	-	2960	2486	-	-	2486
Subject 2	2781	3092	3202	2676	3235	3011
Subject 3	3153	3198	3140	-	-	-
Subject 4	3091	3023	2945	-	3044	3133
Subject 5	2820	3028	2808	-	-	-
Subject 6	2864	3087	3152	-	-	-
Average	**2942**	**3065**	**2956**	**2676**	**3140**	**2877**
S.E.	**75**	**33**	**112**	**-**	**95**	**198**

Differences : Belt - No Belt

	Quad	Hamstring	Calf	Abs	R. Back	L. Back
Subject 1	-	47	35	-	-	6
Subject 2	-29	-34	178	-62	120	-15
Subject 3	16	99	20	-	-	-
Subject 4	21	-56	-95	-	-98	90
Subject 5	-144	46	73	-	-	-
Subject 6	-139	17	-107	-	-	-
Average	**-55**	**20**	**17**	**-62**	**11**	**27**
S.E.	**36**	**23**	**44**	**-**	**109**	**32**

APPENDIX G

JAVELIN THROWING

An investigation into the effect of a lumbar support belt on javelin throwing.

Experiment 5

Subject 1	Normal Throwing Condition				Belt 1			
3D Cinematography : File Name	C3/PNB1 NB1		C3/PNB2 NB2		C3/PHB1 B1		C3/PHB2 B2	
Shoulder Alignment°								
Back Foot Contact :	186		183		184		180	
Front Foot Contact :	194		188		190		184	
Release :	275		276		271		268	
Change FFC to Release :	81		88		81		84	
3D Hip/Shoulder Separation°								
Back Foot Contact :	-13.5		-14.2		-19.5		-9.68	
Front Foot Contact :	-19.0		-19.6		-18.1		-21.2	
Javelin Release :	32.4		34.3		37.9		35.2	
Speed of Run-up (m s^{-1}): Hip Joint Centre at BFC	5.48		5.29		5.21		5.46	
Peak Linear Speed (m s^{-1}) / Time Before/After Release								
Mass Centre	5.85	0.29	6.39	0.32	6.08	0.26	5.82	0.32
Right Hip	6.38	0.04	6.61	0.14	6.73	0.09	6.56	0.14
Right Shoulder	7.95	0.04	8.08	0.10	8.24	0.06	8.37	0.10
Right Elbow	14.20	0.05	14.23	0.06	14.19	0.03	13.77	0.04
Right Wrist	19.68	0.01	20.35	0.00	21.04	-0.01	19.80	-0.02
Right 3rd Finger	24.35	0.00	24.31	0.00	25.28	-0.01	24.02	-0.02
Grip Release Speed	22.49	0.01	22.30	0.00	23.93	0.00	22.74	0.00
Shoulder-Hip Joints	1.57	0.00	1.47	0.04	1.51	0.03	1.81	0.04
Back Knee Angle° BFC	133		134		138		136	
FFC	139		139		135		136	
Release	93.8		96.4		94.5		89.7	
Front Knee Angle° FFC	167		164		165		165	
Release	163		136		141		144	
Release Height :	1.99m		1.94m		1.94m		1.96m	
(% Height)	114%		111%		111%		112%	
Delivery Stride Length :	1.32m		1.32m		1.34m		1.30m	
(% Height)	76%		76%		77%		74%	
Trunk Angle° to RH: Release	6.53		8.51		5.31		6.10	
Maximum Trunk Angle° :	-0.95		1.97		-1.69		-4.07	
Time (seconds) :	(0.11)		(0.11)		(0.12)		(0.10)	
Total Angle° of Trunk Movement	7.48		6.54		7.00		10.17	
Time (seconds) :	(0.24)		(0.24)		(0.23)		(0.26)	
Javelin Attitude Angle° at release	37.2		37.8		38.5		37.0	
DISTANCE (m)	49.71		48.32		50.98		50.63	

Subject 2	Normal Throwing Condition		Belt 1	
3D Cinematography : File Name	C3/DNB1 NB1	C3/DNB2 NB2	C3/DBB1 B1	C3/DBB2 B2
Shoulder Alignment°				
Back Foot Contact :	173	172	171	175
Front Foot Contact :	192	186	186	184
Release :	278	277	277	273
Change FFC to Release :	86	91	91	89
3D Hip/Shoulder Separation°				
Back Foot Contact :	-55.5	-47.5	-50.8	-50.4
Front Foot Contact :	-31.0	-38.7	-39.7	-40.5
Javelin Release :	-23.4	-22.4	-23.7	-25.3
Speed of Run-up ($m\ s^{-1}$): Hip Joint Centre at BFC	5.34	5.82	6.02	5.51
Peak Linear Speed ($m\ s^{-1}$) / Time Before/After Release				
Mass Centre	5.48 0.34	6.01 0.31	6.07 0.15	5.48 0.25
Right Hip	6.68 0.34	6.52 0.29	6.91 0.25	6.34 0.18
Right Shoulder	8.57 0.11	8.42 0.08	8.44 0.06	8.37 0.09
Right Elbow	13.30 0.05	12.53 0.06	13.35 0.05	13.13 0.06
Right Wrist	19.68 0.01	19.67 0.01	20.22 0.01	20.48 0.01
Right 3rd Finger	22.12 0.00	21.91 0.00	22.35 0.01	22.85 0.00
Grip Release Speed	22.78 -0.01	22.70 -0.01	24.09 -0.01	23.67 -0.01
Shoulder-Hip Joints	1.89 0.23	1.90 0.21	1.53 0.19	2.03 0.09
Back Knee Angle° BFC	139	131	130	135
FFC	133	133	131	133
Release	145	131	136	141
Front Knee Angle° FFC	171	170	167	167
Release	165	148	147	154
Release Height :	1.93m	1.96m	1.93m	1.95m
(% Height)	107%	109%	107%	108%
Delivery Stride Length :	1.44m	1.46m	1.48m	1.46m
(% Height)	80%	81%	82%	81%
Trunk Angle° to RH: Release	23.0	26.2	24.5	27.0
Maximum Trunk Angle° :	8.58	8.79	8.47	12.7
Time (seconds) :	(0.12)	(0.12)	(0.12)	(0.13)
Total Angle° of Trunk Movement	14.4	17.4	16.0	14.2
Time (seconds) :	(0.25)	(0.20)	(0.21)	(0.22)
Javelin Attitude Angle° at release	30.8	30.0	25.7	31.3
DISTANCE (m)	50.46	49.78	54.70	55.67

Subject 3	Normal Throwing Condition				Belt 1			
3D Cinematography : File Name	C3/LNB1 NB1		C3/LNB2 NB2		C3/LHB1 B1		C3/LHB2 B2	
Shoulder Alignment°								
Back Foot Contact :	168		164		165		164	
Front Foot Contact :	187		183		180		184	
Release :	292		280		280		282	
Change FFC to Release :	105		97		100		98	
3D Hip/Shoulder Separation°								
Back Foot Contact :	-24.0		-21.4		-23.6		-24.9	
Front Foot Contact :	-21.9		-28.8		-29.9		-30.6	
Javelin Release :	-19.2		-18.1		-19.8		-18.2	
Speed of Run-up (m s^{-1}): Hip Joint Centre at BFC	6.18		5.89		6.49		6.25	
Peak Linear Speed (m s^{-1}) / Time Before/After Release								
Mass Centre	6.15	0.16	6.41	0.19	6.53	0.35	6.57	0.18
Right Hip	6.98	0.15	6.82	0.17	6.94	0.34	7.12	0.17
Right Shoulder	8.31	0.09	8.37	0.07	8.60	0.07	8.43	0.09
Right Elbow	14.03	0.05	13.73	0.04	13.26	0.07	13.57	0.04
Right Wrist	19.18	0.01	19.14	0.00	18.32	0.01	18.87	0.00
Right 3rd Finger	21.86	-0.01	22.42	-0.01	22.03	-0.01	21.80	-0.01
Grip Release Speed	23.11	-0.01	22.27	-0.01	22.82	-0.01	22.99	-0.01
Shoulder-Hip Joints	1.33	0.06	1.90	0.10	1.66	0.27	1.31	0.08
Back Knee Angle° BFC	138		127		131		128	
FFC	152		151		151		150	
Release	118		132		128		118	
Front Knee Angle° FFC	169		168		168		161	
Release	176		178		162		167	
Release Height :	1.99m		1.91m		1.96m		2.03m	
(% Height)	108%		104%		107%		110%	
Delivery Stride Length :	1.39m		1.40m		1.40m		1.37m	
(% Height)	75%		76%		76%		74%	
Trunk Angle° to RH: Release	26.4		25.2		27.0		24.4	
Maximum Trunk Angle° :	-15.1		-17.1		-9.83		-14.3	
Time (seconds) :	(0.12)		(0.07)		(0.10)		(0.07)	
Total Angle° of Trunk Movement	41.5		42.3		36.9		38.8	
Time (seconds) :	(0.28)		(0.28)		(0.27)		(0.28)	
Javelin Attitude Angle° at release	21.6		22.1		24.3		23.4	
DISTANCE (m)	50.60		49.53		49.84		51.29	

Subject 4	Normal Throwing Condition				Belt 1			
3D Cinematography : File Name	C3/MR1 NB1		C3/MR3 NB2		C3/MR2 B1		C3/MR4 B2	
Shoulder Alignment°								
Back Foot Contact :	168		168		172		165	
Front Foot Contact :	183		195		187		199	
Release :	289		276		287		285	
Change FFC to Release :	106		81		100		86	
3D Hip/Shoulder Separation°								
Back Foot Contact :	-35.4		-31.5		-35.9		-41.0	
Front Foot Contact :	-33.6		-35.5		-38.5		-31.7	
Javelin Release :	-25.8		-21.7		-29.2		-23.7	
Speed of Run-up (m s^{-1}) Hip Joint Centre at BFC	6.02		6.24		6.04		6.39	
Peak Linear Speed (m s^{-1}) / Time Before/After Release								
Mass Centre	6.22	0.19	6.86	0.29	6.49	0.25	6.49	0.29
Right Hip	6.52	0.18	6.99	0.29	6.81	0.25	6.68	0.29
Right Shoulder	8.97	0.14	7.66	0.09	9.08	0.14	9.11	0.09
Right Elbow	15.83	0.04	12.19	0.04	15.39	0.04	16.39	0.06
Right Wrist	23.65	0.01	21.21	0.01	22.94	0.01	24.13	0.01
Right 3rd Finger	27.48	-0.01	24.25	0.00	26.83	-0.01	27.86	0.00
Grip Release Speed	29.49	0.00	28.67	0.00	30.02	0.00	30.48	0.00
Shoulder-Hip Joints	2.45	0.04	0.67	0.20	2.27	0.11	2.43	0.20
Back Knee Angle° BFC	126		128		129		132	
FFC	140		129		135		141	
Release	127		130		129		127	
Front Knee Angle° FFC	166		165		163		182	
Release	164		144		148		154	
Release Height :	2.05m		2.16m		2.06m		2.03m	
(% Height)	107%		113%		107%		106%	
Delivery Stride Length :	1.64m		1.63m		1.68m		1.72m	
(% Height)	85%		85%		88%		89%	
Trunk Angle° to RH: Release	20.0		26.0		23.8		18.5	
Maximum Trunk Angle° :	11.5		10.3		10.8		10.0	
Time (seconds) :	(0.04)		(0.06)		(0.03)		(0.06)	
Total Angle° of Trunk Movement	8.42		8.46		13.0		8.46	
Time (seconds) :	(0.27)		(0.25)		(0.29)		(0.25)	
Javelin Attitude Angle° at release	33.1		29.4		28.0		29.4	
DISTANCE (m)	76.03		74.53		77.57		81.85	

Subject 5	Normal Throwing Condition		Belt 1	
3D Cinematography : File Name	C3/CNB1 NB1	C3/CNB2 NB2	C3/CMB1 B1	C3/CMB2 B2
Shoulder Alignment°				
Back Foot Contact :	180	179	175	180
Front Foot Contact :	185	190	202	204
Release :	284	286	284	290
Change FFC to Release :	99	96	82	86
3D Hip/Shoulder Separation°				
Back Foot Contact :	-47.2	-37.2	-43.3	-44.2
Front Foot Contact :	-49.9	-29.8	-25.5	-31.7
Javelin Release :	22.9	29.1	28.0	28.4
Speed of Run-up (m s^{-1}) Hip Joint Centre at BFC	6.64	6.11	6.84	6.09
Peak Linear Speed (m s^{-1}) / Time Before/After Release				
Mass Centre	6.98 0.30	8.06 0.20	6.50 0.22	6.51 0.31
Right Hip	7.70 0.15	7.76 0.15	7.21 0.16	6.83 0.21
Right Shoulder	10.14 0.09	10.50 0.06	10.34 0.05	9.51 0.08
Right Elbow	17.11 0.05	16.60 0.05	16.92 0.05	16.35 0.04
Right Wrist	23.65 0.01	25.63 0.01	26.07 0.01	23.59 0.00
Right 3rd Finger	27.61 0.00	30.60 0.00	30.40 0.01	26.74 0.00
Grip Release Speed	30.72 -0.01	30.93 -0.02	30.58 -0.01	28.47 -0.01
Shoulder-Hip Joints	2.44 0.06	2.74 0.09	3.13 0.11	2.68 0.13
Back Knee Angle° BFC	155	153	157	161
FFC	129	137	143	143
Release	142	133	138	121
Front Knee Angle° FFC	167	170	172	167
Release	175	166	170	165
Release Height :	1.82m	1.85m	1.88m	1.83m
(% Height)	102%	104%	106%	103%
Delivery Stride Length :	1.02m	0.98m	0.96m	0.97m
(% Height)	57%	55%	54%	54%
Trunk Angle° to RH Release	-7.25	-9.04	-8.56	-9.42
Maximum Trunk Angle°	8.77	10.9	11.9	11.1
Time (seconds) :	(0.20)	(0.21)	(0.24)	(0.22)
Total Angle° of Trunk Movement	16.0	20.0	20.4	20.5
Time (seconds) :	(0.16)	(0.14)	(0.12)	(0.17)
Javelin Attitude Angle° at release	34.8	34.3	32.5	34.5
DISTANCE (m)	74.88	76.02	77.52	69.20

Subject 6	Normal Throwing Condition		Belt 1	
3D Cinematography : File Name	C3/JNB1 NB1	C3/JNB2 NB2	C3/JHB1 B1	C3/JHB2 B2
Shoulder Alignment°				
Back Foot Contact :	175	177	180	176
Front Foot Contact :	206	200	206	198
Release :	277	276	284	278
Change FFC to Release :	71	76	78	80
3D Hip/Shoulder Separation°				
Back Foot Contact :	-32.3	-34.2	-29.3	-25.1
Front Foot Contact :	-40.2	-39.5	-29.6	-40.4
Javelin Release :	35.1	32.5	32.7	34.9
Speed of Run-up (m s^{-1}): Hip Joint Centre at BFC	5.95	5.91	5.44	6.22
Peak Linear Speed (m s^{-1}) / Time Before/After Release				
Mass Centre	6.10 0.37	6.16 0.34	5.85 0.42	6.43 0.37
Right Hip	6.46 0.30	6.48 0.15	6.13 0.22	6.54 0.15
Right Shoulder	7.88 0.10	8.24 0.10	7.95 0.12	9.05 0.10
Right Elbow	12.80 0.04	13.50 0.06	11.75 0.05	13.36 0.06
Right Wrist	19.67 0.01	21.66 0.01	19.28 0.02	20.90 0.01
Right 3rd Finger	22.58 0.00	24.73 0.01	22.09 0.01	23.37 0.00
Grip Release Speed	23.17 -0.01	25.04 -0.01	24.23 -0.02	25.07 -0.01
Shoulder-Hip Joints	1.42 0.20	1.76 0.05	1.82 0.10	2.51 0.05
Back Knee Angle° BFC	147	150	152	150
FFC	140	138	137	143
Release	121	121	118	111
Front Knee Angle° FFC	161	161	168	160
Release	158	151	159	143
Release Height :	1.95m	1.97m	1.90m	1.96m
(% Height)	106%	107%	103%	107%
Delivery Stride Length :	1.34m	1.32m	1.36m	1.34m
(% Height)	73%	72%	74%	73%
Trunk Angle° to RH: Release	-9.69	-8.54	-7.60	-12.2
Maximum Trunk Angle°	12.5	14.3	15.9	12.9
Time (seconds) :	(0.21)	(0.20)	(0.23)	(0.22)
Total Angle° of Trunk Movement	22.2	22.8	23.5	25.0
Time (seconds) :	(0.21)	(0.21)	(0.22)	(0.20)
Javelin Attitude Angle° at release	36.5	36.5	29.3	31.0
DISTANCE (m)	55.28	59.53	53.68	58.64

		Javelin Attitude angle at Release	Shoulder Aligment BFC	FFC	Release	Change FFC to R	3D Hip/Shoulder Seperation BFC	FFC	Release	Hip joint speed at BFC
Subject 1	**B1**	38.5	184	190	271	81	-19.5	-18.1	37.9	5.21
	B2	37	180	184	268	84	-9.68	-21.2	35.2	5.46
	NB1	37.2	186	194	275	81	-13.5	-19	32.4	5.48
	NB2	37.8	183	188	276	88	-14.2	-19.6	34.3	5.29
Subject 2	**B1**	25.7	171	186	277	91	-50.8	-39.7	-23.7	6.02
	B2	31.3	175	184	273	89	-50.4	-40.5	-25.3	5.51
	NB1	30.8	173	192	278	86	-55.5	-30.9	-23.4	5.34
	NB2	30	172	186	277	91	-47.5	-38.7	-22.4	5.82
Subject 3	**B1**	24.3	165	180	280	100	-23.6	-29.9	-19.8	6.49
	B2	23.4	164	184	282	98	-24.9	-30.6	-18.2	6.25
	NB1	21.6	168	187	292	105	-24	-21.9	-19.2	6.18
	NB2	22.1	164	183	280	97	-21.4	-28.8	-18.1	5.89
Subject 4	**B1**	28	172	187	287	100	-35.9	-38.5	-29.2	6.04
	B2	29.4	165	199	285	86	-40.9	-31.7	-23.7	6.39
	NB1	33.1	168	183	289	106	-35.4	-33.6	-25.8	6.02
	NB2	29.4	168	195	276	81	-31.5	-35.5	-21.7	6.24
Subject 5	**B1**	32.5	175	202	284	82	-43.3	-25.5	27.9	6.84
	B2	34.5	180	204	290	86	-44.2	-31.7	28.4	6.09
	NB1	34.8	180	185	284	99	-47.2	-49.9	22.9	6.64
	NB2	34.3	179	190	286	96	-37.2	-29.8	29.1	6.11
Subject 6	**B1**	29.3	180	206	284	78	-29.3	-29.6	32.7	5.44
	B2	31	176	198	278	80	-25.1	-40.4	34.9	6.22
	NB1	36.5	175	206	277	71	-32.3	-40.2	35.1	5.95
	NB2	36.5	177	200	276	76	-34.2	-39.4	32.5	5.91
Average	**n=24**	**31.2**	**174**	**191**	**280**	**8.88**	**-32.9**	**-31.9**	**4.70**	**5.95**
S.E.		**1.04**	**1.34**	**1.64**	**1.25**	**1.94**	**2.61**	**1.68**	**5.73**	**0.09**
Belt	**n=12**	**30.4**	**174.00**	**192**	**280**	**87.9**	**-33.1**	**-31.4**	**4.77**	**6.00**
S.E.		**1.37**	**1.92**	**2.65**	**1.94**	**2.25**	**3.77**	**2.14**	**8.53**	**0.14**
No Belt	**n=12**	**32**	**174**	**191**	**281**	**89.8**	**-32.8**	**-32.3**	**4.64**	**5.91**
S.E.		**1.59**	**1.96**	**2.03**	**1.67**	**3.24**	**3.79**	**2.67**	**8.03**	**0.11**

BFC : Back Foot Contact **FFC : Front Foot Contact** **R : Release of Javelin**

		Trunk Angle at Release	Max. Trunk Angle	Total angle of trunk movement	Time of trunk movement	Front Knee Angle			Back Knee Angle			Release Height	% Height	Delivery Stride Length	% Height
						FFC	Release	Difference (R-FFC)	BFC	FFC	Release				
Subject 1	**B1**	5.31	-1.69	7	0.23	165	141	-24	138	135	94.5	1.94	111	1.34	77
	B2	6.10	-4.07	10.2	0.26	165	144	-21	136	136	89.7	1.96	112	1.30	74
	NB1	6.53	-0.95	7.48	0.24	167	163	-4	133	139	93.8	1.99	114	1.32	76
	NB2	8.51	1.97	6.54	0.24	164	136	-28	134	139	96.4	1.94	111	1.32	76
Subject 2	**B1**	24.5	8.47	16	0.21	167	147	-20	130	131	136	1.93	107	1.48	82
	B2	27	12.7	14.2	0.22	167	154	-13	135	133	141	1.95	108	1.46	70
	NB1	23	8.58	14.4	0.25	171	165	-6	139	133	145	1.93	107	1.44	80
	NB2	26.2	8.79	17.4	0.20	170	148	-22	131	132	131	1.96	109	1.46	81
Subject 3	**B1**	27	-9.83	36.9	0.27	168	162	-6	131	151	128	1.96	107	1.40	76
	B2	24.4	-14.3	38.8	0.28	161	167	6	128	150	118	2.03	110	1.37	74
	NB1	26.4	-15.1	41.5	0.28	169	176	7	138	152	118	1.99	108	1.39	75
	NB2	25.2	-17.1	42.3	0.28	168	178	10	127	151	132	1.91	104	1.40	76
Subject 4	**B1**	23.8	10.8	13	0.29	163	148	-15	129	135	129	2.06	107	1.68	88
	B2	18.5	10	8.46	0.25	182	154	-28	132	141	127	2.03	106	1.72	89
	NB1	20	11.5	8.42	0.27	166	164	-2	126	139	127	2.05	107	1.64	85
	NB2	26	10.3	8.46	0.25	165	144	-21	128	129	130	2.16	113	1.63	85
Subject 5	**B1**	-8.56	11.9	20.4	0.12	172	170	-2	157	143	138	1.88	106	0.96	54
	B2	-9.42	11.1	20.5	0.17	167	165	-2	161	143	121	1.83	103	0.97	54
	NB1	-7.25	8.77	16	0.16	167	175	8	155	129	142	1.82	102	1.02	57
	NB2	-9.04	10.9	20	0.14	170	166	-4	153	137	133	1.85	104	0.98	55
Subject 6	**B1**	-7.6	15.9	23.5	0.22	168	159	-9	152	137	118	1.90	103	1.36	74
	B2	-12.2	12.9	25	0.20	160	143	-17	150	143	111	1.96	107	1.34	73
	NB1	-9.69	12.5	22.2	0.21	161	158	-3	147	140	121	1.95	106	1.34	73
	NB2	-8.54	14.3	22.8	0.21	161	151	-10	150	138	121	1.97	107	1.32	72
Average	**n=24**	**10.3**	**4.93**	**19.2**	**0.23**	**167**	**157**	**-9.38**	**139**	**139**	**123**	**1.96**	**107**	**1.36**	**74**
S.E.		**3.16**	**2.06**	**2.25**	**0.01**	**0.94**	**2.43**	**2.34**	**2.23**	**1.39**	**3.20**	**0.02**	**0.65**	**0.04**	**2.05**
Belt	**n=12**	**9.90**	**5.32**	**19.5**	**0.23**	**167**	**155**	**-12.6**	**140**	**140**	**121**	**1.95**	**107**	**1.37**	**73.8**
S.E.		**4.62**	**2.91**	**2.98**	**0.01**	**1.67**	**2.88**	**2.92**	**3.38**	**1.82**	**4.64**	**0.02**	**0.80**	**0.07**	**3.16**
No Belt	**n=12**	**10.6**	**4.54**	**18.9**	**0.23**	**166**	**160**	**-6.17**	**138**	**138**	**124**	**1.96**	**108**	**1.36**	**74.3**
S.E.		**4.51**	**3.04**	**3.50**	**0.01**	**0.93**	**3.82**	**3.49**	**2.99**	**2.08**	**4.53**	**0.03**	**1.05**	**0.06**	**2.74**

BFC : Back Foot Contact **FFC : Front Foot Contact** **R : Release of Javelin**

Linear Speed (m s^{-1})

Belt Condition

Subject No.		Distance (metres)	1 Mass Centre	2 Right Hip	3 Right Shoulder	4 Right Elbow	5 Right Wrist	6 Right 3rd Finger	7 Javelin (Grip)
1	Belt	50.81	5.95	6.65	8.31	13.98	20.42	24.65	23.33
2	Belt	55.19	5.78	6.63	8.41	13.24	20.35	22.60	23.88
3	Belt	50.57	6.55	7.03	8.52	13.42	18.60	21.92	22.91
4	Belt	79.71	6.49	6.75	9.10	15.89	23.54	27.35	30.25
5	Belt	73.36	6.51	7.02	9.92	16.63	24.83	28.57	29.53
6	Belt	56.44	6.14	6.34	8.50	12.55	20.09	22.73	24.65
Mean		**61.01**	**6.24**	**6.73**	**8.79**	**14.29**	**21.30**	**24.63**	**25.76**
S.E.		**5.07**	**0.13**	**0.11**	**0.25**	**0.66**	**0.97**	**1.13**	**1.33**

No Belt Condition

Subject No.		Distance (metres)	1 Mass Centre	2 Right Hip	3 Right Shoulder	4 Right Elbow	5 Right Wrist	6 Right 3rd Finger	7 Javelin (Grip)
1	No Belt	49.02	6.12	6.49	8.01	14.22	20.02	24.33	22.40
2	No Belt	50.12	5.75	6.60	8.50	12.92	19.68	22.02	22.74
3	No Belt	50.07	6.28	6.90	8.34	13.88	19.16	22.14	22.69
4	No Belt	75.28	6.54	6.76	8.32	14.01	22.43	25.87	29.08
5	No Belt	75.45	7.52	7.73	10.32	16.85	24.64	29.10	30.83
6	No Belt	57.41	6.13	6.47	8.06	13.15	20.66	23.65	24.10
Mean		**59.56**	**6.39**	**6.82**	**8.59**	**14.17**	**21.10**	**24.52**	**25.31**
S.E.		**5.15**	**0.25**	**0.19**	**0.35**	**0.58**	**0.85**	**1.09**	**1.51**

Average Difference (Belt - No Belt)

Subject No.	Distance (metres)	1 Mass Centre	2 Right Hip	3 Right Shoulder	4 Right Elbow	5 Right Wrist	6 Right 3rd Finger	7 Javelin (Grip)
1	1.79	-0.17	0.15	0.29	-0.23	0.40	0.32	0.94
2	5.06	0.03	0.03	-0.09	0.33	0.68	0.59	1.14
3	0.50	0.27	0.13	0.18	-0.46	-0.57	-0.23	0.22
4	4.43	-0.05	-0.01	0.78	1.88	1.11	1.48	1.17
5	-2.09	-1.01	-0.71	-0.40	-0.22	0.19	-0.54	-1.30
6	-0.97	0.01	-0.14	0.44	-0.60	-0.58	-0.93	0.55
Mean	**1.45**	**-0.15**	**-0.09**	**0.20**	**0.11**	**0.21**	**0.12**	**0.45**
S.E.	**1.17**	**0.18**	**0.13**	**0.17**	**0.38**	**0.28**	**0.35**	**0.38**

Time to Peak Linear Speed : (Before / After Point of Release)

		1 Mass Centre	2 Right Hip	3 Right Shoulder	4 Right Elbow	5 Right Wrist	6 Right 3rd Finger	7 Javelin Grip
Subject 1	**B1**	0.26	0.09	0.06	0.03	-0.01	-0.01	0.00
	B2	0.32	0.14	0.10	0.04	-0.02	-0.02	0.00
	NB1	0.29	0.04	0.04	0.05	0.01	0.00	0.01
	NB2	0.32	0.14	0.10	0.06	0.00	0.00	0.00
Subject 2	**B1**	0.15	0.25	0.06	0.05	0.01	0.01	-0.01
	B2	0.25	0.18	0.09	0.06	0.01	0.00	-0.01
	NB1	0.34	0.34	0.11	0.05	0.01	0.00	-0.01
	NB2	0.31	0.29	0.08	0.06	0.01	0.00	-0.01
Subject 3	**B1**	0.35	0.34	0.07	0.07	0.01	-0.01	-0.01
	B2	0.18	0.17	0.09	0.04	0.00	-0.01	-0.01
	NB1	0.16	0.15	0.09	0.05	0.01	-0.01	-0.01
	NB2	0.19	0.17	0.07	0.04	0.00	-0.01	-0.01
Subject 4	**B1**	0.25	0.25	0.14	0.04	0.01	-0.01	0.00
	B2	0.29	0.29	0.09	0.06	0.01	0.00	0.00
	NB1	0.19	0.18	0.14	0.04	0.01	-0.01	0.00
	NB2	0.29	0.29	0.09	0.04	0.01	0.00	0.00
Subject 5	**B1**	0.22	0.16	0.05	0.05	0.01	0.01	-0.01
	B2	0.31	0.21	0.08	0.04	0.00	0.00	-0.01
	NB1	0.30	0.15	0.09	0.05	0.01	0.00	-0.01
	NB2	0.20	0.15	0.06	0.05	0.01	0.00	-0.02
Subject 6	**B1**	0.42	0.22	0.12	0.05	0.02	0.01	-0.02
	B2	0.37	0.15	0.10	0.06	0.01	0.00	-0.01
	NB1	0.37	0.30	0.10	0.04	0.01	0.00	-0.01
	NB2	0.34	0.15	0.10	0.60	0.01	0.01	-0.01
Average	**(24)**	**0.28**	**0.20**	**0.09**	**0.07**	**0.01**	**-0.00**	**-0.01**
Belt	**(12)**	**0.28**	**0.20**	**0.09**	**0.05**	**0.01**	**-0.00**	**-0.01**
No Belt	**(12)**	**0.28**	**0.20**	**0.09**	**0.09**	**0.01**	**-0.00**	**-0.01**

Progressive Linear Speed : Javelin Throw : NO BELT

Independent Group Analysis C:\PDH\EXP5\GROUP.DBF

Grouping variable is JOINT
Analysis variable is NO BELT

Group Means and Standard Deviations

1 (Mass Centre)	: mean = 6.39	s.d. = 0.61	n = 6
2 (Hip)	: mean = 6.83	s.d. = 0.47	n = 6
3 (Shoulder)	: mean = 8.59	s.d. = 0.87	n = 6
4 (Elbow)	: mean = 14.17	s.d. = 1.41	n = 6
5 (Wrist)	: mean = 21.10	s.d. = 2.07	n = 6
6 (Finger)	: mean = 24.52	s.d. = 2.66	n = 6
7 (Grip)	: mean = 25.31	s.d. = 3.69	n = 6

Analysis of Variance Table

Source	S.S.	DF	MS	F	Appx P
Total	2638.95	41			
Treatment	2497.29	6	416.21	102.83	**<.001**
Error	141.66	35	4.05		

Error term used for comparisons = 4.05 with 35 d.f.

Newman-Keuls Multiple Comp.	Difference	P	Q	Critical q (.05)
Mean(7.00)-Mean(1.00) =	18.9167	7	23.032	4.427 *
Mean(7.00)-Mean(2.00) =	18.4817	6	22.502	4.267 *
Mean(7.00)-Mean(3.00) =	16.715	5	20.351	4.071 *
Mean(7.00)-Mean(4.00) =	11.135	4	13.557	3.818 *
Mean(7.00)-Mean(5.00) =	4.2083	3	5.124	3.464 *
Mean(7.00)-Mean(6.00) =	0.7883	2	.96	2.873
Mean(6.00)-Mean(1.00) =	18.1283	6	22.072	4.267 *
Mean(6.00)-Mean(2.00) =	17.6933	5	21.542	4.071 *
Mean(6.00)-Mean(3.00) =	15.9267	4	19.391	3.818 *
Mean(6.00)-Mean(4.00) =	10.3467	3	12.597	3.464 *
Mean(6.00)-Mean(5.00) =	3.42	2	4.164	2.873 *
Mean(5.00)-Mean(1.00) =	14.7083	5	17.908	4.071 *
Mean(5.00)-Mean(2.00) =	14.2733	4	17.378	3.818 *
Mean(5.00)-Mean(3.00) =	12.5067	3	15.227	3.464 *
Mean(5.00)-Mean(4.00) =	6.9267	2	8.433	2.873 *
Mean(4.00)-Mean(1.00) =	7.7817	4	9.474	3.818 *
Mean(4.00)-Mean(2.00) =	7.3467	3	8.945	3.464 *
Mean(4.00)-Mean(3.00) =	5.58	2	6.794	2.873 *
Mean(3.00)-Mean(1.00) =	2.2017	3	2.681	3.464
Mean(3.00)-Mean(2.00) =	1.7667	(Do not test)		
Mean(2.00)-Mean(1.00) =	0.435	(Do not test)		

Homogeneous Populations, groups ranked

```
Gp Gp Gp Gp Gp Gp Gp
 1  2  3  4  5  6  7
                ------

---------
          ---
             ---
```

This is a graphical representation of the Newman-Keuls multiple comparisons test. At the 0.05 significance level, the means of any two groups underscored by the same line are not significantly different.

Progressive Linear Speed : Javelin Throw : BELT

Independent Group Analysis C:\PDH\EXP5\GROUP.DBF

Grouping variable is JOINT
Analysis variable is BELT

Group Means and Standard Deviations

1 (Mass Centre)	: mean = 6.24	s.d. = 0.33	n = 6
2 (Hip)	: mean = 6.74	s.d. = 0.26	n = 6
3 (Shoulder)	: mean = 8.79	s.d. = 0.62	n = 6
4 (Elbow)	: mean = 14.29	s.d. = 1.61	n = 6
5 (Wrist)	: mean = 21.31	s.d. = 2.36	n = 6
6 (Finger)	: mean = 24.64	s.d. = 2.76	n = 6
7 (Grip)	: mean = 25.76	s.d. = 3.26	n = 6

Analysis of Variance Table

Source	S.S.	DF	MS	F	Appx P
Total	2723.22	41			
Treatment	2588.35	6	431.39	111.94	**<.001**
Error	134.88	35	3.85		

Error term used for comparisons = 3.85 with 35 d.f.

Newman-Keuls Multiple Comp.	Difference	P	Q	Critical q (.05)
Mean(7.00)-Mean(1.00) =	19.5217	7	24.359	4.427 *
Mean(7.00)-Mean(2.00) =	19.0217	6	23.735	4.267 *
Mean(7.00)-Mean(3.00) =	16.965	5	21.169	4.071 *
Mean(7.00)-Mean(4.00) =	11.4733	4	14.316	3.818 *
Mean(7.00)-Mean(5.00) =	4.4533	3	5.557	3.464 *
Mean(7.00)-Mean(6.00) =	1.1217	2	1.4	2.873
Mean(6.00)-Mean(1.00) =	18.4	6	22.959	4.267 *
Mean(6.00)-Mean(2.00) =	17.9	5	22.335	4.071 *
Mean(6.00)-Mean(3.00) =	15.8433	4	19.769	3.818 *
Mean(6.00)-Mean(4.00) =	10.3517	3	12.917	3.464 *
Mean(6.00)-Mean(5.00) =	3.3317	2	4.157	2.873 *
Mean(5.00)-Mean(1.00) =	15.0683	5	18.802	4.071 *
Mean(5.00)-Mean(2.00) =	14.5683	4	18.178	3.818 *
Mean(5.00)-Mean(3.00) =	12.5117	3	15.612	3.464 *
Mean(5.00)-Mean(4.00) =	7.02	2	8.759	2.873 *
Mean(4.00)-Mean(1.00) =	8.0483	4	10.043	3.818 *
Mean(4.00)-Mean(2.00) =	7.5483	3	9.419	3.464 *
Mean(4.00)-Mean(3.00) =	5.4917	2	6.852	2.873 *
Mean(3.00)-Mean(1.00) =	2.5567	3	3.19	3.464
Mean(3.00)-Mean(2.00) =	2.0567	(Do not test)		
Mean(2.00)-Mean(1.00) =	0.5	(Do not test)		

Homogeneous Populations, groups ranked

```
Gp Gp Gp Gp Gp Gp Gp
 1  2  3  4  5  6  7
                ------
---------
         ---
            ---
```

This is a graphical representation of the Newman-Keuls multiple comparisons test. At the 0.05 significance level, the means of any two Groups underscored by the same line are not significantly different.

Experiment 5 : Distance (m)

```
Repeated Measures Analysis Summary                C:\PDH\EXP5\DISTANCE.DBF
--------------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  6

Means and standard deviations for  2  repeated measures:

 1)BELT: mean = 61.01          s.d. = 12.41
 2)NO BELT: mean = 59.56       s.d. = 12.61

 Mean Difference = 1.45          s.d.(difference) = 2.88

 95% C.I. about Mean Difference is (-1.57, 4.48)

Paired t-test
--------------
Hypotheses:

Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 1.24 with 5 D.F.     p = 0.27 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experiment 5 : Linear Speed : Mass Centre

```
Repeated Measures Analysis Summary                      C:\PDH\EXP5\MASS.DBF
-------------------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  6

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 6.23667          s.d. = 0.32776
 2) NO BELT: mean = 6.39          s.d. = 0.61018

 Mean Difference = -0.15333      s.d.(difference) = 0.4437

 95% C.I. about Mean Difference is (-0.61976, 0.3131)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.8465 with 5 D.F.     p = 0.44 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experiment 5 : Linear Speed : Hip Joint Centre

```
Repeated Measures Analysis Summary                      C:\PDH\EXP5\HIP.DBF
-------------------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  6

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 6.73667          s.d. = 0.2618
 2) NO BELT: mean = 6.825         s.d. = 0.47281

 Mean Difference = -0.08833      s.d.(difference) = 0.32177

 95% C.I. about Mean Difference is (-0.42659, 0.24993)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.67244 with 5 D.F.     p = 0.53 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experiment 5 : Linear Speed : Shoulder Joint Centre

```
Repeated Measures Analysis Summary                    :\PDH\EXP5\SHOULDER.DBF
-----------------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  6

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 8.79333          s.d. = 0.61721
 2) NO BELT: mean = 8.59167       s.d. = 0.86645

 Mean Difference = 0.20167       s.d.(difference) = 0.41194

 95% C.I. about Mean Difference is (-0.23138, 0.63472)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 1.19915 with 5 D.F.     p = 0.28 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experiment 5 : Linear Speed : Elbow Joint Centre

```
Repeated Measures Analysis Summary                      C:\PDH\EXP5\ELBOW.DBF
-----------------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  6

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 14.285           s.d. = 1.6136
 2) NO BELT: mean = 14.17167      s.d. = 1.40695

 Mean Difference = 0.11333       s.d.(difference) = 0.92058

 95% C.I. about Mean Difference is (-0.85442, 1.08108)

Paired t-test
--------------
Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.30156 with 5 D.F.     p = 0.78 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

Experiment 5 : Linear Speed : Wrist Joint Centre

Repeated Measures Analysis Summary C:\PDH\EXP5\WRIST.DBF

Number of repeated measures is 2
Number of subjects read in 6

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 21.305 s.d. = 2.3626
2) NO BELT: mean = 21.09833 s.d. = 2.07078

Mean Difference = 0.20667 s.d.(difference) = 0.67221

95% C.I. about Mean Difference is (-0.49999, 0.91332)

Paired t-test

Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.75308 with 5 D.F. **p = 0.49** (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

Experiment 5 : Linear Speed : Finger Joint Centre

Repeated Measures Analysis Summary C:\PDH\EXP5\FINGER.DBF

Number of repeated measures is 2
Number of subjects read in 6

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 24.63667 s.d. = 2.75672
2) NO BELT: mean = 24.51833 s.d. = 2.66482

Mean Difference = 0.11833 s.d.(difference) = 0.86266

95% C.I. about Mean Difference is (-0.78853, 1.02519)

Paired t-test

Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 0.336 with 5 D.F. **p = 0.75** (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

Experiment 5 : Linear Speed : Grip of Javelin

Repeated Measures Analysis Summary C:\PDH\EXP5\GRIP.DBF

Number of repeated measures is 2
Number of subjects read in 6

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 25.75833 s.d. = 3.2609
2) NO BELT: mean = 25.30667 s.d. = 3.6901

Mean Difference = 0.45167 s.d.(difference) = 0.93277

95% C.I. about Mean Difference is (-0.5289, 1.43223)

Paired t-test

Hypotheses:
Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 1.1861 with 5 D.F. **p = 0.29** (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

Experiment 5 : Approach Velocity: Linear Hip Speed at BFC

```
Repeated Measures Analysis Summary             C:\PDH\EXP5\APPROA_V.DBF
-----------------------------------------------------------------------
Number of repeated measures is  2
Number of subjects read in  6

Means and standard deviations for  2  repeated measures:

 1) BELT: mean = 6.00          s.d. = 0.43
 2) NO BELT: mean = 5.91       s.d. = 0.37

 Mean Difference = 0.09       s.d.(difference) = 0.15

 95% C.I. about Mean Difference is (-0.07, 0.25)

Paired t-test
--------------
Hypotheses:

Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = 1.49 with 5 D.F.     p = 0.20 (two-sided)

Since p > 0.05, at the 0.05 significance level you do not have
enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to
the direction of your alternative hypothesis.
```

WINKS 4.21 : EXPERIMENT 5 : JAVELIN THROWING

Linear Speed (m s^{-1}) : (SHOULDER - HIP JOINT)

	BELT	NO BELT
Subject 1	1.66	1.52
Subject 2	1.78	1.90
Subject 3	1.48	1.44
Subject 4	2.35	1.56
Subject 5	2.91	2.59
Subject 6	2.17	1.59

Repeated Measures Analysis Summary

Number of repeated measures is 2
Number of subjects read in 6

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 2.06 s.d. = 0.53
2) NOBELT: mean = 1.77 s.d. = 0.43

Mean Difference = 0.29 s.d.(difference) = 0.34

95% C.I. about Mean Difference is (-0.07, 0.65)

Paired t-test

Hypotheses:

Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = **2.08** with 5 D.F. p = 0.09 (two-sided)
p = 0.05 (one-sided)

Since $p < 0.05$, at the 0.05 significance level you have evidence to reject the null hypothesis and conclude that the mean difference between the pairs is not 0 (one-sided).

WINKS 4.21 : EXPERIMENT 5 : JAVELIN THROWING

Time Between Peak Linear Speed (ms) : (SHOULDER - HIP JOINT)

	BELT	NO BELT
Subject 1	35	20
Subject 2	140	220
Subject 3	175	80
Subject 4	155	110
Subject 5	120	75
Subject 6	75	125

Repeated Measures Analysis Summary

Number of repeated measures is 2
Number of subjects read in 6

Means and standard deviations for 2 repeated measures:

1) BELT: mean = 117 s.d. = 53
2) NO BELT: mean = 105 s.d. = 67

Mean Difference = 12 s.d.(difference) = 65

95% C.I. about Mean Difference is (-57, 80)

Paired t-test

Hypotheses:

Ho: The mean difference between pairs is 0.
Ha: The mean difference between pairs is not 0.

Calculated t = **0.44** with 5 D.F. p = 0.68 (two-sided)
p = 0.34 (one-sided)

Since $p > 0.05$, at the 0.05 significance level you do not have enough evidence to reject the null hypothesis.
For a one-sided test, you must adjust the p-value according to the direction of your alternative hypothesis.

Javelin Throwing : Average (n=6)

	No Belt Condition				Belt Condition			
	Back Foot		Front Foot		Back Foot		Front Foot	
	Newtons	S.E.	Newtons	S.E.	Newtons	S.E.	Newtons	S.E.
Fz	2035	179	5069	420	2084	149	5015	340
Fy -ve	947	153	4065	300	958	172	4011	227
Fy +ve	321	64	253	40	346	62	307	84
Fx -ve	258	51	624	91	277	66	603	57
Fx+ve	431	108	553	51	475	109	587	60

Javelin Throwing : Average (n=6)

	No Belt Condition				Belt Condition			
	Back Foot		Front Foot		Back Foot		Front Foot	
	B.W.	S.E.	B.W.	S.E.	B.W.	S.E.	B.W.	S.E.
Fz	2.28	0.18	5.69	0.43	2.35	0.19	5.65	0.42
Fy -ve	1.05	0.15	4.58	0.34	1.07	0.18	4.53	0.31
Fy +ve	0.31	0.08	0.26	0.03	0.33	0.08	0.32	0.08
Fx -ve	0.30	0.08	0.71	0.03	0.32	0.08	0.67	0.08
Fx+ve	0.43	0.10	0.68	0.09	0.46	0.09	0.70	0.07

Javelin Throwing : Fz +ve Average Peak Forces

	No Belt Condition				Belt Condition			
	Back Foot		Front Foot		Back Foot		Front Foot	
	Fz +ve	B.W.	Fz +ve	B.W.	Fz +ve	B.W.	Fz +ve	B.W.
Subject 1	1642	2.10	5082	6.51	1737	2.22	5155	6.59
Subject 2	* **1546**	**1.80**	6011	7.00	* **1876**	**2.18**	6094	7.08
Subject 3	2281	2.89	3285	4.16	2489	3.16	3513	4.47
Subject 4	2361	2.25	6026	5.74	2302	2.15	5137	4.81
Subject 5	1768	1.95	5393	5.94	1670	1.84	5159	5.68
Subject 6	2613	2.71	* **4615**	**4.79**	2432	2.53	* **5030**	**5.24**
Average	**2035**	**2.28**	**5069**	**5.69**	**2084**	**2.35**	**5015**	**5.65**
S.D.	439	0.43	1029	1.06	365	0.45	834	1.02
S.E.	179	0.18	420	0.43	149	0.19	340	0.42

Average Peak Forces Fz : Difference : Belt - No Belt Conditions

	Back Foot		Front Foot	
	Newtons	B.W.	Newtons	B.W.
Subject 1	95	0.12	73	0.08
Subject 2	330	0.38	83	0.08
Subject 3	208	0.27	228	0.31
Subject 4	-59	-0.1	-889	-0.93
Subject 5	-98	-0.11	-234	-0.26
Subject 6	-181	-0.18	415	0.45
Average	**49**	**0.06**	**-54**	**-0.05**
S.D.	196	0.23	461	0.50
S.E.	80	0.09	188	0.20

Javelin Throwing : Fy +ve Average Peak Forces

	No Belt Condition					Belt Condition				
	Back Foot			Front Foot		Back Foot			Front Foot	
	Fy +ve	B.W.		Fy +ve	B.W.	Fy +ve	B.W.		Fy +ve	B.W.
Subject 1	438	0.56		107	0.14	461	0.59		78	0.10
Subject 2	111	0.13		206	0.24	168	0.20		202	0.23
Subject 3	341	0.12	*	**277**	**0.25**	388	0.12	*	**234**	**0.25**
Subject 4	527	0.50		408	0.39	520	0.49		384	0.36
Subject 5	173	0.19		259	0.29	156	0.17		268	0.30
Subject 6	335	0.35	*	**260**	**0.27**	382	0.40	*	**676**	**0.70**
Average	**321**	**0.31**		**253**	**0.26**	**346**	**0.33**		**307**	**0.32**
S.D.	157	0.19		98	0.08	151	0.19		206	0.20
S.E.	64	0.08		40	0.03	62	0.08		84	0.08

Average Peak Forces Fy +ve : Difference : Belt - No Belt Conditions

	Back Foot		Front Foot	
	Newtons	B.W.	Newtons	B.W.
Subject 1	23	0.03	-29	-0.04
Subject 2	57	0.07	-4	-0.01
Subject 3	47	0	-43	0.00
Subject 4	-7	-0.01	-24	-0.03
Subject 5	-17	-0.02	9	0.01
Subject 6	47	0.05	416	0.43
Average	**25**	**0.02**	**54**	**0.06**
S.D.	31	0.04	178	0.18
S.E.	13	0.01	73	0.07

Javelin Throwing : Fy -ve Average Peak Forces

	No Belt Condition				Belt Condition			
	Back Foot		**Front Foot**		**Back Foot**		**Front Foot**	
	Fy -ve	**B.W.**	**Fy -ve**	**B.W.**	**Fy -ve**	**B.W.**	**Fy -ve**	**B.W.**
Subject 1	587	0.75	4482	5.74	664	0.85	4438	5.67
Subject 2	1079	1.26	3728	4.34	1172	1.36	3879	4.51
Subject 3	* **1031**	**1.31**	* **2800**	**3.55**	* **1198**	**1.52**	* **3058**	**3.89**
Subject 4	1503	1.43	4336	4.13	1476	1.38	3856	3.61
Subject 5	459	0.51	4919	5.42	303	0.33	4628	5.10
Subject 6	1021	1.06	4124	4.28	934	0.97	4204	4.38
Average	**947**	**1.05**	**4065**	**4.58**	**958**	**1.07**	**4011**	**4.53**
S.D.	376	0.36	734	0.83	421	0.44	557	0.76
S.E.	153	0.15	300	0.34	172	0.18	227	0.31

Average Peak Forces Fy -ve : Difference : Belt - No Belt Conditions

	Back Foot		**Front Foot**	
	Newtons	B.W.	Newtons	B.W.
Subject 1	77	0.10	-44	-0.07
Subject 2	93	0.10	151	0.17
Subject 3	167	0.21	258	0.34
Subject 4	-27	-0.05	-480	-0.52
Subject 5	-156	-0.18	-291	-0.32
Subject 6	-87	-0.09	80	0.10
Average	**11**	**0.01**	**-54**	**-0.05**
S.D.	122	0.15	281	0.32
S.E.	50	0.06	115	0.13

Javelin Throwing : Fx +ve Average Peak Forces

		No Belt Condition					Belt Condition			
		Back Foot		Front Foot			Back Foot		Front Foot	
		Fx +ve	B.W.	Fx +ve	B.W.		Fx +ve	B.W.	Fx +ve	B.W.
Subject 1		337	0.43	334	0.43		426	0.54	341	0.44
Subject 2		148	0.17	586	0.68		282	0.34	658	0.76
Subject 3	*	**570**	**0.44**	524	1.04	*	**689**	**0.43**	509	0.88
Subject 4		846	0.81	533	0.51		865	0.81	575	0.54
Subject 5		177	0.20	682	0.75		135	0.15	695	0.77
Subject 6		507	0.53	659	0.68		453	0.47	746	0.78
Average		**431**	**0.43**	**553**	**0.68**		**475**	**0.46**	**587**	**0.70**
S.D.		265	0.23	125	0.21		266	0.22	147	0.17
S.E.		108	0.10	51	0.09		109	0.09	60	0.07

Average Peak Forces Fx +ve : Difference : Belt - No Belt Conditions

	Back Foot		Front Foot	
	Newtons	B.W.	Newtons	B.W.
Subject 1	89	0.11	7	0.01
Subject 2	134	0.17	72	0.08
Subject 3	119	-0.01	-15	-0.16
Subject 4	19	0	42	0.03
Subject 5	-42	-0.05	13	0.02
Subject 6	-54	-0.06	87	0.10
Average	**44**	**0.03**	**34**	**0.01**
S.D.	82	0.09	40	0.09
S.E.	33	0.04	16	0.04

Javelin Throwing : Fx -ve Average Peak Forces

	No Belt Condition				Belt Condition			
	Back Foot		Front Foot		Back Foot		Front Foot	
	Fx -ve	B.W.	Fx -ve	B.W.	Fx -ve	B.W.	Fx -ve	B.W.
Subject 1	327	0.42	510	0.65	368	0.47	458	0.59
Subject 2	* **169**	**0.20**	715	0.83	* **65**	**0.08**	735	0.85
Subject 3	360	0.46	* **623**	**0.79**	417	0.53	* **448**	**0.57**
Subject 4	174	0.17	405	0.39	232	0.22	702	0.66
Subject 5	102	0.11	472	0.52	124	0.14	528	0.58
Subject 6	413	0.43	1017	1.06	453	0.47	746	0.78
Average	**258**	**0.30**	**624**	**0.71**	**277**	**0.32**	**603**	**0.67**
S.D.	125	0.15	222	0.24	161	0.19	140	0.12
S.E.	51	0.06	91	0.10	66	0.08	57	0.05

Average Peak Forces Fx -ve : Difference : Belt - No Belt Conditions

	Back Foot		Front Foot	
	Newtons	B.W.	Newtons	B.W.
Subject 1	41	0.05	-52	-0.06
Subject 2	-104	-0.12	20	0.02
Subject 3	57	0.07	-175	-0.22
Subject 4	58	0.05	297	0.27
Subject 5	22	0.03	56	0.06
Subject 6	40	0.04	-271	-0.28
Average	**19**	**0.02**	**-21**	**-0.04**
S.D.	62	0.07	198	0.20
S.E.	25	0.03	81	0.08

Javelin Throwing : Time in Contact (ms)

	No Belt Condition		Belt Condition	
	Back Foot	**Front Foot**	**Back Foot**	**Front Foot**
Subject 1	195	468	226	437
Subject 2	302	* **469**	290	* **648**
Subject 3	* **291**	391	* **333**	380
Subject 4	264	404	266	368
Subject 5	250	386	270	385
Subject 6	303	451	297	471
Average	**268**	**428**	**280**	**448**
S.D.	41	39	36	105
S.E.	14	16	15	40

Average : Time in contact : Difference : Belt - No Belt Conditions

	Back Foot	**Front Foot**
Subject 1	31	-31
Subject 2	-12	179
Subject 3	42	-11
Subject 4	2	-36
Subject 5	20	-1
Subject 6	-6	20
Average	**13**	**20**
S.D.	22	81
S.E.	9	33

Javelin Throwing : Time to Peak Vertical Force (ms)

	No Belt Condition		Belt Condition	
	Back Foot	Front Foot	Back Foot	Front Foot
Subject 1	71	33	68	29
Subject 2	73	27	25	30
Subject 3	49	42	48	44
Subject 4	58	31	42	34
Subject 5	41	22	54	23
Subject 6	38	37	51	42
Average	**55**	**32**	**48**	**34**
S.D.	15	7	14	8
S.E.	6	3	6	3

P
P

Average Time to Peak Vertical Force : Difference : Belt - No Belt Conditions

	Back Foot	Front Foot
Subject 1	-3	-4
Subject 2	-48	3
Subject 3	-1	2
Subject 4	-16	3
Subject 5	13	1
Subject 6	13	5
Average	**-7**	**2**
S.D.	23	3
S.E.	9	1

Javelin Throwing : Loading Rates (Body Weight per second)

	No Belt Condition			Belt Condition	
	Back Foot	Front Foot		Back Foot	Front Foot
Subject 1	30.3	199		33.1	236
Subject 2	* **21.8**	268		* **114**	236
Subject 3	58.7	99.3		65.9	102
Subject 4	38.8	186		51.3	141
Subject 5	69.7	270		34.1	265
Subject 6	71.6	131		58.1	126
Average	**48.5**	**192**		**59.4**	**184**
S.D.	21.1	69.7		29.7	69.1
S.E.	8.61	28.4		12.1	28.2

Average Loading Rates : Difference : Belt - No Belt Conditions

	Back Foot	Front Foot
Subject 1	2.8	37
Subject 2	92.2	-32
Subject 3	7.20	2.7
Subject 4	12.5	-45
Subject 5	-35.6	-5
Subject 6	-13.5	-5
Average	**10.9**	**-7.88**
S.D.	43.5	28.6
S.E.	17.7	11.7

Javelin Throwing : Total Time in Contact (ms)

(Total Time = Back Foot Contact to Toe off Front Foot)

Overlap Time : Toe off (Back Foot) / Heel Contact (Front Foot)
+ Overlap - Gap

	No Belt Condition		Belt Condition	
	Total Time in Contact	**Overlap Time**	**Total Time in Contact**	**Overlap Time**
Subject 1	657	11	607	58
Subject 2	667	103	834	108
Subject 3	599	83	624	85
Subject 4	574	74	-	-
Subject 5	566	122	570	122
Subject 6	688	80	724	-8
Average	**625**	**78**	**672**	**73**
S.D.	52	38	96	46
S.E.	21	15	43	21

Average Differences : Total Time in contact : Overlap Time

(Belt - No Belt Conditions)

	Total Time in Contact	**Overlap Time**
Subject 1	-50	47
Subject 2	167	5
Subject 3	25	2
Subject 4	-	-
Subject 5	4	0
Subject 6	36	-88
Average	**-78**	**-7**
S.D.	254	44
S.E.	114	20

EMG Data : Mean

No Belt : Average 6 Subjects

	Quad	Hamstring	Calf	Abs	R. Back	L. Back
Subject 1	2806	3015	3007	2804	3112	3184
Subject 2	2866	3133	2682	-	-	-
Subject 3	3022	3236	3046	3083	3175	-
Subject 4	3118	3247	3058	3078	-	-
Subject 5	-	-	-	-	-	-
Subject 6	-	2911	2718	-	-	-
Average	**2953**	**3114**	**2902**	**2988**	**3143**	**3184**
S.E.	**71**	**70**	**79**	**113**	**32**	**-**

Belt : Average 6 Subjects

	Quad	Hamstring	Calf	Abs	R. Back	L. Back
Subject 1	2872	3096	3139	2863	3042	3087
Subject 2	2999	3023	2774	-	-	-
Subject 3	3004	3276	3005	2996	3160	-
Subject 4	3272	3179	3043	3050	-	-
Subject 5	-	-	-	-	-	-
Subject 6	-	2936	2812	-	-	-
Average	**3037**	**3102**	**2955**	**2970**	**3101**	**3087**
S.E.	**84**	**59**	**70**	**56**	**59**	**-**

Differences : Belt - No Belt

	Quad	Hamstring	Calf	Abs	R. Back	L. Back
Subject 1	66	81	132	59	-70	-97
Subject 2	133	-110	92	-	-	-
Subject 3	-18	40	-41	-87	-15	-
Subject 4	154	-68	-15	-28	-	-
Subject 5	-	-	-	-	-	-
Subject 6	-	25	94	-	-	-
Average	**84**	**-6**	**53**	**-19**	**-43**	**-96**
S.E.	**39**	**36**	**34**	**43**	**27**	**-**