

Low back pain and front foot hip joint kinematics in Western Province first league fast bowlers

by
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*Thesis submitted in fulfilment of the requirements for the degree of
MSc in Physiotherapy in the Faculty of Health Sciences, University of
Stellenbosch*



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March 2011

Declaration

By submitting this thesis electronically, I declare that the entirety of the work contained therein is my own, original work, that I am the authorship owner thereof (unless to the extent explicitly otherwise stated) and that I have not previously in its entirety or in part submitted it for obtaining any qualification.

Date: 6 March 2011

Abstract

Aim: The aim of the study was to improve understanding of the hip joint kinematics in cricket fast bowlers and to ascertain whether a relationship exists between hip joint biomechanical parameters, including kinematics, ROM characteristics and lumbar symptoms.

Study design: A descriptive cross-sectional study was conducted.

Participants: Sixteen adult male fast bowlers between the ages of 18 and 40 years old, playing first-club league, were featured in the study.

Main outcome measures: To obtain data with regards to the training history, as well as the nature of lumbar-spine symptoms experienced by the cricket fast bowlers, a newly designed questionnaire was compiled. For analysis of the front foot hip joint ROM and kinematics, the biomechanical equipment used included: a two-dimensional Canon MV950 Digital Video Camcorder, a Kodak EasyShare C310 camera and XSENS Motion Tracking equipment (Xsens Technologies B. V., Enschede, Netherlands).

Results: Eight of the sixteen bowlers in our study experienced LBP in the season with seven of these bowlers presenting with recent symptoms most of which are experienced after bowling a spell and described as “tightness” or a “stabbing pain” in the lower back. Intensity of LBP ranged between 1/10 to 8/10.

Front foot hip joint kinematics of fast bowlers showed highly individualised patterns of movement between different subjects. Medium amplitude movements in the flexion/extension as well as the rotation plane of movement showed a significant difference in bowlers with- and without LBP.

No significant differences between groups with LBP and without LBP were found in the three passive hip ROM measurements.

Conclusions: It has proved to be very difficult to improve the understanding of the front foot hip biomechanics in cricket fast bowlers due to the high inter-subject variability. Variability in movement patterns remains under-researched by sports biomechanics.

Although decreased hip mobility could alter mechanical forces transmitted to the lumbar spine and therefore predispose or be a causative factor in LBP development, this study found no significant relation between these parameters. The sample size was very small in this study which will influence the validity of results.

Our study confirmed the high incidence of LBP and preventative efforts for bowlers should therefore be strongly supported.

Abstrak

Doelwit: Die doelwit van die studie was om die heupgewrig kinematika van krieket snelboulers beter te verstaan en om vas te stel of daar 'n verwantskap bestaan tussen heupgewrig biomeganiese parameters, insluitende kinematika, omvang van beweging karakter en lumbale simptome.

Studie ontwerp: 'n Deursnee beskrywende studie is onderneem.

Deelnemers: Sestien volwasse manlike snelboulers tussen die ouderdomme van 18 en 40 jaar oud wat eerste liga speel maak deel uit van die studie.

Hoof uitkoms maatreëls: 'n Nuut ontwerpte vraelys is opgestel om data aangaande oefen geskiedenis sowel as aard van lumbale simptome wat deur krieket snelboulers ervaar word in te samel. Die biomeganiese apparaat wat gebruik is vir die analiese van die voorvoet heup omvang van beweging, sowel as die kinematika, sluit in: 'n twee dimensionele Canon MV950 Digitale Video Camcorder, 'n Kodak EasyShare C310 kamera en XSENS beweging volgende apparaat (Xsens Technologies B. V., Enschede, Netherlands).

Resultate: Agt van die sestien boulers in ons studie het lae rug pyn in die seisoen ervaar. Sewe van die boulers het gepresenteer met onlangse simptome waarvan die meeste na 'n bouler se bouleurt ervaar is en beskryf was as 'n "styfheid" of "steekpyn" in die lae rug. Die intensiteit van die lae rug pyn het gewissel tussen 1/10 en 8/10.

Voorvoet heup kinematika van snelboulers het hoogs individualistiese patrone van beweging getoon tussen verskillende deelnemers. Medium amplitude bewegings in die fleksie/ekstensie sowel as die rotasie plein van beweging het 'n beduidende verskil tussen boulers met- en sonder lae rug pyn getoon.

Geen beduidende verskille tussen die groep met- en sonder ruggpyn is gevind met die drie passiewe heup omvang van beweging meetings nie.

Gevolgtrekkings: Dit blyk baie moeilik te wees om die voorvoet heup biomeganika in krieket snelboulers beter te verstaan a.g.v. die hoë inter-deelnemer veranderlikheid. Veranderlikheid in bewegings patrone is nog nie genoeg nagevors deur sport biomeganici nie.

Alhoewel ingekorte heup mobiliteit meganiese kragte wat deur die lumbale werwelkolom gaan kan wysig, en sodoende die ontwikkeling van lae rug pyn kan predisponer of 'n oorsakende faktor kan wees, het hierdie studie nie 'n beduidende verwantskap tussen die parameters gevind nie. Die steekproef grootte was baie klein en dit sal die geldigheid van die resultate beïnvloed.

Ons studie het die hoë insidensie van lae rug pyn bevestig en pogings tot voorkomende maatreëls moet daarom ten sterkste ondersteun word.

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Acknowledgements

I want to acknowledge and thank my supervisors Prof Quinette Louw and Me Lynette Crouse as well as Susan Hilier from University of South Australia for all the assistance and hard work. My sincere thank you to the Dept of Mechanical Engineering at Stellenbosch University for invaluable guidance and labor, especially Prof Cornie Scheffer and Alex Busch. Furthermore Dr Martin Kidd for assistance regarding statistical matters, I thank you.

Mr Alex Busch, a post graduate student at US for helping to formulate a time-switch which captured the bowling trials with the XSENS equipment and assisted in technical aspects such as the set-up and attachment of the equipment and trouble shooting on testing days. Prof Cornie Scheffer from the Department Mechatronic Engineering at University of Stellenbosch, thank you for writing the computer program (See section on data processing 3.11 for method) for analysis and basic physical interpretation of the XSENS data and assisted in the primary analysis of the XSENS data.

I further want to thank WPCC for the use of their facility for allowing me to collect my data and test my subjects in their indoor facility.

Dr Kerith Aginsky, my research assistant, thank you for greeting the subjects on arrival, explaining the procedures and logistics as well as handing them their personal roster for the day (Appendix I). Furthermore the supervising the giving of consent (Appendix G-F) and administered the Lower Back Injury Questionnaire (Appendix C)

A heartfelt thank you to my husband, friends and family for supporting me in the organized chaos that is my life.

LIST OF TERMS

Back foot impact (BFI)

The start of the delivery stride, the bowler's weight is on the previously planted back foot with the body leaning away from the batsman. (Bartlett et al., 1996)

Ball

The cricket ball itself, made of cork wound with string, covered with leather.

or

The event of a bowling the ball towards the batsman; synonym for delivery. (DM's Explanation of Cricket)

Biomechanics

The British Association of Sport and Exercise Sciences (BASES) explains Sport and Exercise Biomechanics as an area of science concerned with the analysis of mechanics of human movement. In sport and exercise that definition is often extended to also consider the interaction between the performer and his or her equipment and environment. Biomechanics is traditionally described in terms of kinetic and kinematic parameters (Norkin & Levangie, 1992).

Delivery

A single action of bowling a cricket ball towards the batsman; synonym for ball. (DM's Explanation of Cricket)

Delivery stride

The bowling action between the back foot strike and ball release (Foster et al., 1989)

or

The delivery stride commences with the back foot strike. The weight is on this foot and the body is leaning away from the batsman. The delivery stride has three key events. Back foot strike, front foot strike and ball release. (MCC 1976)

Front foot impact (FFI)

As the delivery stride proceeds, the front (left) foot strikes the ground (right-handed bowler) (Bartlett et al., 1996)

Hip

The hip or coxofemoral joint in this study refers to the unmodified ovoid synovial joint with three degrees of freedom flexion/extension in the sagittal plane abduction/adduction in the frontal plane and medial/lateral rotation in the transverse plane,(Norkin & Levangie, 1992) consisting of the femur on the acetabulum.

Hip biomechanics

In this context the term is used to encompass both the kinematics and kinetics involving the hip joint

Innings

One side's turn to bat and score runs, completed when ten batsman are out. (abcofcricket.com)

Kinetics

A component of biomechanics including internal forces created by body structures to either produce movement (muscles) or counteracts other external forces (Norkin and Levangie, 1992).

Kinematics

A component of biomechanics including variables such as type of motion, the location of motion and range and direction of motion (Norkin and Levangie, 1992).

Low back injury:

The definition of injury employed in the epidemiological studies in cricket defines a lower-back injury as an injury to the lumbar spine that either prevents the player from being available for a match or which causes a player to be unable to play when required to in terms of the rules of cricket or by his team (Orchard et al., 2005).

Low back pain

Low back pain is pain, muscle tension, or stiffness localized below the costal margin and above the inferior gluteal folds, with or without leg pain ([sciatica](#)).

Over

The set number of balls bowled by a bowler. An over consists of 6 balls. The term “over” is also called by the umpire when the bowler has completed his. (abcofcricket.com)

Run Up

The run-up commences when the bowler walks or jogs over his marker, gradually increasing speed on his approach to the wicket, and ends as he leaps into the air at the start of the pre-delivery stride in preparation for the back foot to strike the ground, which marks the commencement of the delivery stride. The length of the run-up varies between bowlers and there is no universal agreement as to its optimal length. (Bartlett et al., 1996)

Spell

a series of alternate overs bowled by a single bowler, interrupted only by single overs from other bowlers: also a bowling spell or spell of bowling. (DM’s Explanation of Cricket)

Sport Technique

A specific sequence of movements (Dictionary of Sports Science, 1992).

a. The pattern and sequence of movements

The motion activity specified by biomechanical principles of human motion which utilize motor features of movement and body structure to obtain the best sport result (Bober, 1981).

b. Technique analysis vs. biomechanic analysis

Technique analysis is an identification of specific characteristics of technique which are studied with regard to their contribution to specific process and overall achievement (Dictionary of Sports Science, 1992).

Biomechanic analysis is the broader analysis that includes the understanding of the mechanisms operating in a given technique. (Lees, 2002).

LIST OF ABBREVIATIONS

ACL	Anterior cruciate ligament
ADL	Activities of daily living
ASIS	Anterior superior iliac spine
BFI	Back foot impact
BASES	British Association of Sport and Exercise Sciences
FFI	Front foot impact
GRF	Ground reaction force
HLR	Hip lateral rotation
LBP	Low back pain
MeSH	Medical subject heading
MVA	Motor vehicle accident
PGA	Professional Golf Association
RCT	Randomized controlled trial
ROM	Range of motion
SD	Standard deviation
SSISA	Sport Science Institute of South Africa
USA	United States of America
WPCU	Western Province Cricket Union
WPCC	Western Province Cricket Club
2D	Two dimensional
3D	Three dimensional

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Chapter 1: Introduction

Lower back injury, defined as “an injury that keeps a cricket player from losing playing hours” (Orchard et al., 2005), is probably the most common musculoskeletal condition among fast bowlers (Elliott & Khangure, 2002; Orchard et al., 2005). In Australia, close to 14% of fast bowlers are unavailable to play due to injury at any given time (Orchard & James, 2002). Approximately 30% of these injuries are sustained in the lower back, rendering affected bowlers unable to play (Orchard & James, 2002). In South Africa, national epidemiological studies have indicated similar lower back injury prevalence rates among adult male cricket players (Stretch, 1989; Stretch, 1992; Stretch, 2001; Stretch, 2003). Furthermore, 76% of South African fast bowlers showed a lifetime history of low back pain (LBP) in an epidemiological study by Harris (1993).

Pain can be a useful predictor of lower back injury in sports (Green et al., 2001) and more specifically, cricket (Elliot, 1992). Another precursor for the development of a lower back injury has been indicated in aetiological studies, namely radiological pathological changes to the lumbar spine of fast bowlers (Elliott et al., 1992; Elliott et al., 1993a; Elliott et al., 1993b; Foster et al., 1989), through the use of computer tomography (CT-scan). Pathologies which are a cause of concern to the healthcare professional include: bone stress reaction (Millson et al., 2004), stress fractures of the pars interarticularis, disc degeneration and chronic soft tissue changes of the lumbar spine of cricket fast bowlers (Elliott et al., 1993a; Elliott et al., 1993b; Foster et al., 1989; Payne et al., 1987). Although the pathological changes noted in these reports may account for the chronic nature of LBP among cricket fast bowlers, none of the

earlier studies pertaining to the lower back injuries of these sportsmen discussed the nature and severity of LBP experienced – indeed a dissociation between LBP as a symptom and radiological signs in the lumbar spine has been shown (Millson et al., 2004). Furthermore, it stands to reason that LBP would be a stronger precursor for a bowler to complain about and develop into a lower back injury, as defined by Orchard et al. (2005), than asymptomatic radiological signs. Questions which have a bearing on the area, type and severity of LBP and other lumbar symptoms, as well as the impact on usual daily functioning, including playing cricket, require further investigation (Steulcken et al., 2008).

An adequate description of the impact of a sports injury and a thorough understanding of risk factors are deemed to be crucial in preventative research programmes for sports-related injuries (Van Merchelen et al., 1992). The impact of lower back injury on fast bowlers in cricket specifically has been classified in terms of loss of player opportunities (Orchard & James, 2002; Portus et al., 2004; Stretch, 1992; Stretch, 2001; Stretch, 2003). Loss of play has repercussions, since detraining reduces fitness levels (Anderson et al., 2005), as well as the quality of the affected bowlers' technique, which in turn has been shown as one of the most common risk factors that may lead to problems relating to the further deterioration of the lumbar region (Bartlett et al., 1996; Burnett et al., 1995; Elliott et al., 1986; Elliott & Foster, 1984).

Three bowling techniques have been described in the published literature on biomechanics in cricket fast bowling, in order of prevalence of association with cases of lower back injury: the mixed bowling technique, the front-on technique, and the side-on technique (Bartlett et al., 1996; Elliott et al., 1986). The critical biomechanical risk factor for this increase in prevalence is postulated as the high degree of trunk counter-rotation involved in performing the mixed

bowling action. Current literature contains accounts of other identified biomechanical factors associated with an increased risk of lower back injury, such as increased knee extension (Nigg, 1983; Portus et al., 2004).

More research into the lower limb biomechanics illustrated that the lower back does not function independently to the rest of the kinetic chain (Kibler & Livingston, 2001). Due to the concomitant activity within the hip and lower back, it is not surprising that a relationship between abnormalities in hip biomechanical parameters may also be associated with symptoms in the lower back (Cibulka, 1999; Harris-Hayes et al., 2009; Leinonen et al., 2000; McClure et al., 1997; Mok et al., 2004). Such biomechanical alterations include: the increase or decrease in available range of hip range of motion (ROM) (Brier & Nyfield, 1995; Chesworth, 1994; Halbertsma et al., 2001; Murray et al., 2009; Van Dillen et al., 2008), muscular adaptations affecting the internal force generating capability, reduced muscle strength (Nadler et al., 2000); inappropriate timing, rate and force development of hip muscle activation patterns (Bruno & Bagust, 2006; Clark et al., 2002; Coorevits et al., 2005; Leinonen et al., 2000; Radebold et al., 2000; Vogt et al., 2003) and muscle inhibition (Nadler et al., 2002). The inadequate control exerted by these muscles may alter kinematics and increase the strain on the lumbar spine structures, thereby contributing to the development of lumbar problems (Coorevits et al., 2005; Leinonen et al., 2000; Nadler et al., 2002; Radebold et al., 2000; Vogt et al., 2003). Although a recent study was done into hip biomechanics of female fast bowlers (Steulcken et al., 2008), there is currently a lack of evidence into the hip biomechanical risk factors related to the development of LBP in their male counterparts. The aim of this project is thus to explore the

relationship between hip joint kinematic parameters and lumbar symptoms in male fast bowlers in cricket.

At the time the study was done, little information was available on kinematic parameters in the fast bowling action, specifically pertaining to the hip mechanics in relation to lower back injury. It was however a known fact that the moment of maximal ground reaction force, and therefore maximal force transmission through the lumbar spine structures, happened during front-foot impact (FFI) (Elliot, 2000; Ferdinands et al., 2009). As understanding biomechanical injury mechanisms is a crucial part of the actual prevention of problems of this nature (Bahr & Krosshaug, 2005), this study was executed to describe such a possible injury mechanism.

Chapter 2: Systematic review into hip biomechanics in relation to lower back injury in sportsmen

Currently, there is comprehensive literature available on the occurrence of lower back injury in cricket fast bowlers (Bartlett et al., 2003). A recent study by Steulcken et al. (2008) addressing hip joint musculoskeletal profiles related to the low back pain (LBP) experienced by bowlers in cricket, provide some further insight. No such studies however existed when this review was first undertaken. This chapter presents a systematic review of the published research into hip biomechanics in relation to lower back symptom development, including LBP in the wider population of sportsmen. Conducted between June 2007 and August 2010, this systematic review serves as background information to illustrate the available information reported in peer-reviewed literature regarding the definitions of LBP, and the different biomechanical parameters that have been related to these symptoms in sportsmen participating in different sports.

2.1 Introduction

LBP is one of the most common chronic musculoskeletal complaints amongst sportsmen. Hoskins et al. (2009) showed even more frequent and more severe LBP with increasing level of participation in Australian football codes. Cooke and Lutz (2000) provided corroborative data of the high rates of LBP (more than 30%) amongst sportsmen (Bono, 2004). A lifetime prevalence of up to 75% has been indicated in alpine ski instructors (Bahr et al., 2004; Peacock et al., 2005) and between 57.3% and 65.4% in endurance athletes (Bahr et al., 2004), compared to non-athletic controls who showed a LBP prevalence of 51%. The disabling effects of LBP among

sportsmen are expressed as loss of player opportunities in sports such as cricket (Bartlett et al., 1996), running (Woolf & Glaser, 2004), basketball (Herskowitz & Selesnick, 1993) and golf (Hosea & Gatt, 1996).

Some of the most common factors and mechanisms associated with LBP in sport (Van Merchelen et al., 1992) include: the type of sport, gender, training intensity, training frequency and technique (Bono, 2004). Sport biomechanical research for injury reduction or prevention requires that relationships are drawn between the kinetics of the movement or technique (Lees, 2002), and the injury type characteristics (Elliot, 1999).

Movement description is done by qualitative and quantitative methods for technique analysis. Qualitative methods include: subjective observation utilising phase analysis, temporal analysis and critical feature analysis. Quantitative technique analysis relies on the collection of biomechanical data. Most quantitative methods do not allow for establishing the characteristics of the whole skill (Lees, 2002), but provide objective means of looking at specific biomechanical variables that affect injury mechanisms. Artificial neural networks and 3-D computer simulation help to overcome these limitations, but most of the studies in this review report on very isolated biomechanical parameters that might contribute to injury development rather than the technique in its entirety. These parameters include: knee angular velocities (Reid et al., 2008), hip and knee range of motion (ROM) angles (Nigg, 1983; Portus et al., 2004), trunk counter-rotation (Elliott, 1984), ground reaction forces, isokinetics, passive ROM measurements and various muscle strength tests.

This systematic review was conducted to investigate whether hip joint biomechanical variables are associated with LBP in sportsmen, because such an association has been shown in the

general population (Bullock-Saxton et al., 1994; Janda 1992; Pierce & Lee, 1990; Vogt & Banzer, 1997; Vogt et al., 2003). Most studies focused on the relationship between LBP and hip ROM (Chesworth et al., 1994; Cibulka et al., 1998; Cibulka, 1999; Ellison et al., 1990). Some further studies reviewed hip kinematic parameters in relation to LBP (Porter & Wilkinson, 1997; Shum et al., 2007) because suboptimal functioning of the hip will alter lumbo-pelvic mechanics due to the close proximity of these segments in the kinetic chain (McGill, 1997).

This review investigates the different hip biomechanics variables measured in sportsmen in relation to lower back symptoms as well as the measurement tools utilised to analyse hip biomechanics and LBP in the existing literature. An understanding of the available information can provide an understanding of altered hip biomechanics as a possible predisposing factor to the aetiology of LBP development or as a result thereof in sport. Findings of such a review can be applied in future preventative injury intervention projects conducted in sports physiotherapy research. (Leinonen et al., 2000; Van Mechelen et al., 1992).

2.2 Review research questions

2.2.1 The following review questions apply to this systematic review:

- What measurement tools are utilised to measure LBP and hip biomechanical variables?
- How is LBP defined in published research into LBP among sportsmen?
- Which hip joint biomechanical variables are investigated in relation to LBP in sportsmen?
- Are hip joint biomechanical variables associated with LBP in adult male sportsmen?

2.3 Review method

2.3.1 Inclusion criteria

a. Type of study

All types of descriptive studies published in the English language into the influence of hip biomechanics as a risk factor in the development of LBP in sports, was included in this review.

Studies published between January 1995 and October 2010 was considered to ensure that current biomechanical technology had been used as instrumentation in the eligible studies (Elliot, 1999).

b. Type of participants

Studies including adult male participants, as well as mixed-gender studies from which data for males could be extracted, were included in this review. Men participating in sport have inherent biomechanical differences of the pelvic and hip complex compared to women (Ferber, 2003; Schache et al., 2000). Nadler et al. (2000) and Gombatto et al. (2006) also found a difference in relation to the development of lumbar spine symptoms. Studies including children under the age of 18 years old were excluded because of biomechanical differences in immature musculoskeletal structures compared to those of adults (Elliott et al., 1992; Elliot et al., 1993a; Elliot et al., 1993b; Hardcastle et al., 1992).

2.3.2 Exclusion criteria

Studies into the effect of surgical procedures or hip joint pathology were excluded from this review due to temporary or permanent disturbances in motor control. Case studies were also excluded.

2.3.3 Search strategy

Prior to undertaking the process of this systematic review in April 2007, a preliminary search was done in order to establish if a similar systematic review had been published. Databases searched included: PEDro, PubMed the Cochrane Library including reference databases such as CAPLUS and MEDLINE, the structured database REGISTRY and the reacting database CASREACT. These preliminary search findings illustrated that a similar review had not been published. After updating this review in 2010, a review on hip rotation and low back pain in golf was done (Murray, 2008) as well as a review of cross-sectional studies on relationship between hip and LBP in rotation related sports (Harris-Hayes et al., 2009).

Electronic databases available at the Stellenbosch University library were searched in order to identify eligible articles. The databases that were consulted, included:

- Cochrane Library
- CINAHL
- SCIRUS
- PEDro
- PUBMED
- SCIENCE DIRECT

2.3.4 Truncations use

Although search strategies in most databases were conducted in a similar fashion, each of these organised information bundles has a unique make-up of fields and sources. In order to best access the most relevant, and up to date information about the review topic within each bundle, different search strategies were developed for different databases. The factors that

necessitate this divergence include: the use of different terminology, the unique make-up and organisation of the database itself and the techniques utilised to combine concepts within the database.

2.3.5 Subject headings

In the databases PUBMED and CINAHL, the medical subject headings (MeSH-terms) were used. Single concepts were searched in all of these databases and combined concepts were searched using Boolean operators where available. Where indicated, possible truncation symbols were used to broaden the search in concepts with insufficient hits.

With Science Direct over 1 500 hits were retrieved using the key search word for all the text in the document. The keywords 'low back pain' and 'hip' searched, were also searched for the title and abstract, while the word 'sports' was subsequently searched for any text in the document to narrow the search and make it more specific. A similar approach was followed on CINAHL and PEDro as these databases also allow searching of this nature. The primary researcher's SCIRUS search was narrowed down by adding the word 'biomechanics'.

a. Search terms

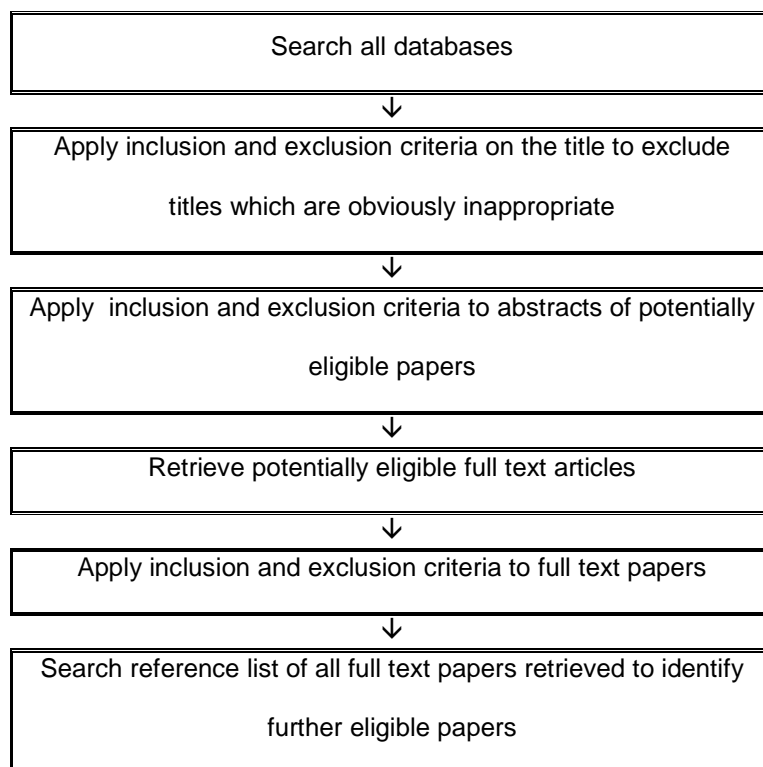
Table 2.1 presents the key words that were searched to source the articles on this topic.

Table 2.1 represents the key words searched in the relevant databases

Databases	Keywords searched
SPORTDiscus	low back pain, hip <i>and</i> sport
Cochrane library	hip, low back pain <i>and</i> sports.
PUBMED	hip, hip joint, low back pain, sports <i>and</i> sports medicine
SCIRUS	low back pain, hip <i>and</i> sports biomechanics
SCIENCE DIRECT	hip, low back pain <i>and</i> sports.
CINAHL	hip, low back pain <i>and</i> sports.
PEDro	hip, low back pain <i>and</i> sports
<i>American Journal of Sports Medicine</i>	low back pain, biomechanics <i>and</i> hip
<i>British Sports Medicine Journal</i>	low back pain, biomechanics <i>and</i> hip

2.3.6 Search strategy development

Figure 2.1 Flow chart for search strategy



The search strategy illustrated in Figure 2.1 was developed by the principal researcher to search for eligible papers.

2.4 Assessment of methodological quality

The principal researcher and an experienced reviewer appraised all the eligible publications using a generic critical appraisal tool (Downs & Black checklist, 1998). In order to determine the level of evidence, the hierarchy of evidence of “Sackett (2000) as cited by Coomarasamy et al., 2003” was used by the principal researcher.

2.4.1 Critical appraisal

The methodological quality of the sourced papers was appraised with an adapted checklist for measuring study quality by Downs and Black (1998). The questions contained in this checklist are presented in Table 2.2.

The checklist created by Downs and Black (Downs and Black, 1998) was assessed for face and content validity by three independent and experienced reviewers. It was shown to have a high internal consistency (KR-20:0.89) and the subscales, apart from external validity, were KR-20:0.54. Furthermore, the checklist showed a good quality Index for test-retest (r 0.88) and inter-rater (r 0.75) reliability and a high correlation was found for the Quality Index with an established instrument for assessing randomised studies (r 0.90).

In order to be consistent in the appraisal of the included literature, the Downs and Black checklist was adapted (Table 2.2) for this review. This was done in order to exclude the questions that applied only to the studies in which interventions took place, as seen in Table 2.3. Tools can be modified to suit the specific requirements of this study (Katrak et al., 2004).

Table 2.2 Appraisal questions from Downs and Black

Questions	
Reporting:	
1	Are the hypotheses/aim/objectives of the study clearly described?
2	Are the main outcomes to be measured clearly described in the Introduction or Methods section?
3	Are the characteristics of the patients included in the study clearly described?
4	Are the distributions of the principal confounders in each group of subjects to be compared clearly described?
5	Are the main findings of the study clearly described?
6	Does the study provide estimates of the random variability in the data for the main outcomes?
7	Have actual probability values been reported (e.g. 0.035 rather than <0.05) for the main outcomes except where the probability value is less than 0.001?
External Validity	
8	Were the subjects asked to participate in the study representative of the entire population from which they were recruited?
9	Were those subjects who were prepared to participate in the study representative of the entire population from which they were recruited?
Internal Validity-bias	
10	Was an attempt made to blind those measuring the main outcomes?
11	If any of the results of the study were based on "data dredging", was this made clear?
12	Were the statistical tests used to assess the main outcomes appropriate?
13	Were the main outcome measures used accurate (valid and reliable)?
Power	
14	Did the study have sufficient power to detect a clinically important effect where the probability value for a difference being due to chance is less than 5%?

Table 2.3 Deleted questions

Questions	
1	Are the interventions of interest clearly described?
2	Have all important adverse events that may be a consequence of the intervention been reported?
3	Have the characteristics of the patients lost to follow-up been described?
4	Were the staff, places, and facilities where the patients were treated, representative of the treatment the majority of patients receive?
5	Was an attempt made to blind study subjects to the intervention they have received?
6	<ul style="list-style-type: none">• In trials and cohort studies, do the analyses adjust for different lengths of follow-up of patients, or in case-control studies, is the time period between the intervention and outcome the same for cases and controls?
7	Was compliance with the interventions reliable?
8	<ul style="list-style-type: none">• Were the patients in different intervention groups (trials and cohort studies) or were the cases and controls (case control studies) recruited from the same population?
9	<ul style="list-style-type: none">• Were study subjects in different intervention groups (trial and cohort studies) or were the cases and controls (case-control studies) recruited over the same period of time?
10	<ul style="list-style-type: none">• Were the study subjects randomised to intervention groups?
11	Was the randomised intervention assignment concealed from both the parties and healthcare staff until recruitment was complete and irrevocable?
12	<ul style="list-style-type: none">• Was there adequate adjustment for confounding in the analyses from which the main findings were drawn?

2.4.2 Evidence hierarchy

In order to establish the level of evidence of the included literature and therefore the degree to which bias has been considered within the study designs of these publications, the hierarchy of evidence was appraised according to the system used by “Sackett (2000) as cited by Coomarasamy et al., 2003” (Table 2.4).

Table 2.4 Hierarchy of evidence “Sackett (2000) as cited by Coomarasamy et al., 2003”

Level	Study Type
1	Meta-analysis of randomised controlled clinical trials
2a	One randomised controlled clinical trial (RCT)
2b	One non-randomised, or non-controlled, or non-blinded clinical trial
3	Observational studies
4	Pre-post test clinical trials
5	Descriptive studies
6	Anecdotal evidence

2.5 Data capture

The collation and classification of articles was done using a *Microsoft Office Excel 2003* (computer software) database with the headings listed below. These headings were used to clarify and describe key elements of each study for comparison purposes.

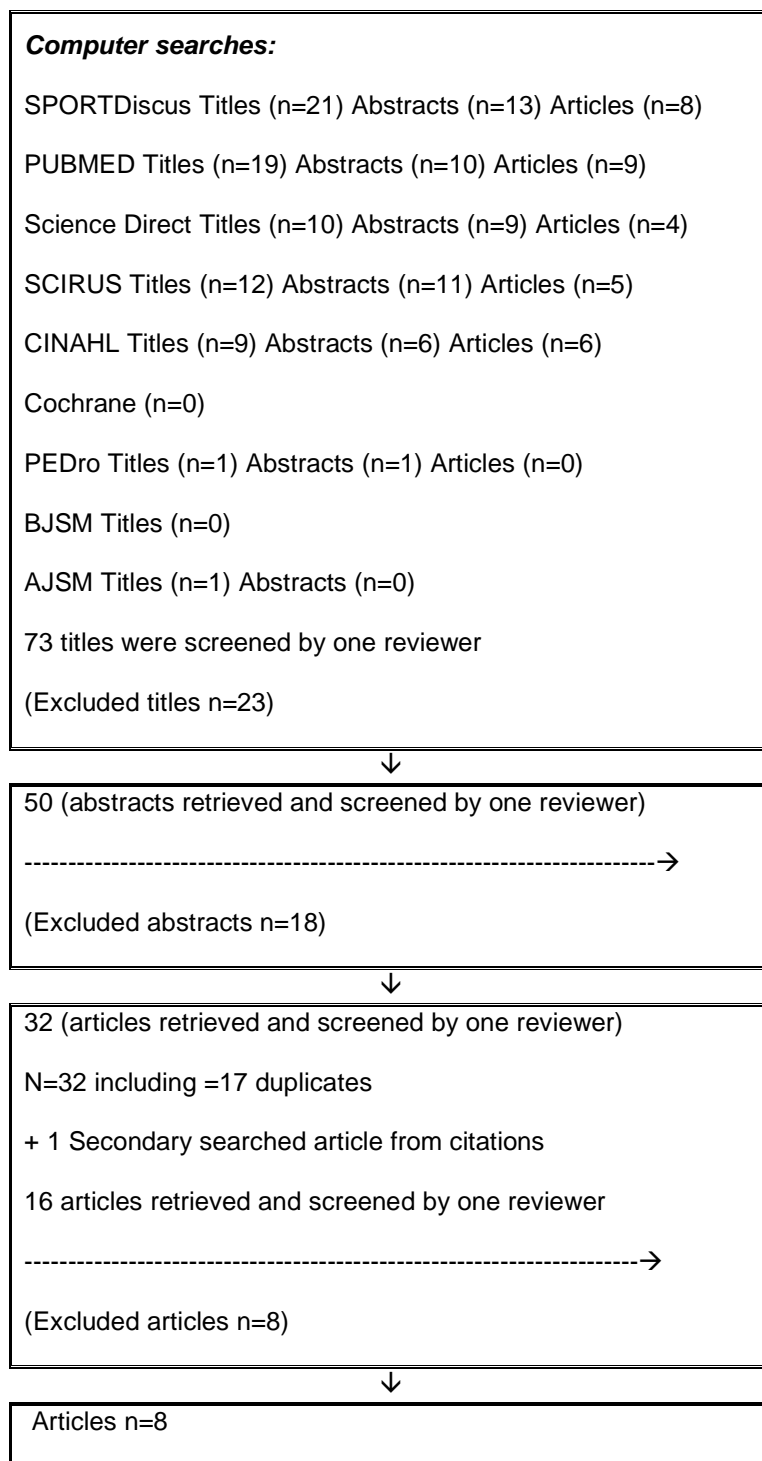
The following key elements were considered essential to describe studies in sufficient detail for analysis:

- Author
- Publication year
- Country
- Study design
- Sample size
- Male subjects
- Sample age range
- Sport types
- Level of play
- LBP def
- LBP assessment
- LBP findings
- Severity classification
- Measurement
- Tools
- Movement analysed
- Biomechanical parameters
- Reliability
- Validity
- Additional PE tests
- Statistical tests
- Main finding related to hip: Risk factor
- Other main findings
- Prevention implications
- Response rate

2.6 Results

The search findings are presented in Figure 2.2 and indicate that six papers were included in this study after exclusion criteria were applied to the papers originally sourced.

Figure 2.2 The review process



2.6.1 Studies included in the review

All of the studies were conducted in the USA, excluding Brier and Nyfield's (1995) study which omits the country in which their research was done, and that of Evans et al., (2005) which was undertaken in Australia. The participants in the studies are not all from the USA, although these might include touring professional sportsmen in Vad et al.'s (2004) study and international students in the studies by Nadler et al., (1998, 2000 and 2001) A summary of these studies is presented in Table 2.5.

Table 2.5 Summary of articles

Study	Country	Study design	Age	Sample size
Murray et al. 2009	United Kingdom	Observational case-control study	LBP group 56.4 +/- 8.4 Control group 54.3 +/- 14.4	43 male out of 64
Gombatto et al. 2006	USA	Cross sectional correlation	29.7+/-8.1	27 male out of 46
Evans et al. 2005	Australia	Longitudinal Prospective	18-35	14
Vad et al. 2004	USA	Cross-sectional, correlation	21-40	42
Nadler et al. 2001	USA	Prospective longitudinal	College students (Age not specified)	*100 male from total of 163
Nadler 2000	USA	Cohort	College students (Age not specified)	*140 male from total of 210
Nadler et al. 1998	USA	Prospective longitudinal	College students (Age not specified)	*170 male from total of 257
Brier & Nyfield 1995	USA	Retrospective and cross sectional Cross sectional, correlation	Older than 18+	Total 54 sedentary group, 33 runners and 21 cyclists not mentioned for male/female. Not indicated how many males
* Some of the studies included female subjects but discussed data was extracted to include only the male subjects.				

Table 2.6 Summary of articles continued

Study	Sports	Level of play
Murray et al. 2009	Golf	Amateur
Gombatto et al. 2006	Sport that placed repetitive rotational demands on the hip and lumbo-pelvic region	Minimum participation of twice a week in their sport.
Evans et al. 2005	Golf	Trainee professional golfers enrolled in Australia's division of PGA
Vad et al. 2004	Golf	Professional members of the PGA
Nadler et al. 2001	Specific sport not mentioned, just collegiate athletes	National Collegiate Athletics Association Division I
Nadler 2000	Specific sport not mentioned, just collegiate athletes	National Collegiate Athletics Association Division I
Nadler et al. 1998	Football, soccer, baseball, track, tennis, basketball, swimming	University representation
Brier & Nyfield 1995	Running and Cycling	Active runners >25miles per week. Active cyclists >30miles per week. Recreational or competitive with minimum of 25 miles a week for running and 30 miles a week for cycling

2.6.2 Critical appraisal

The studies were ranked on hierarchy of evidence and then critically appraised by two researchers.

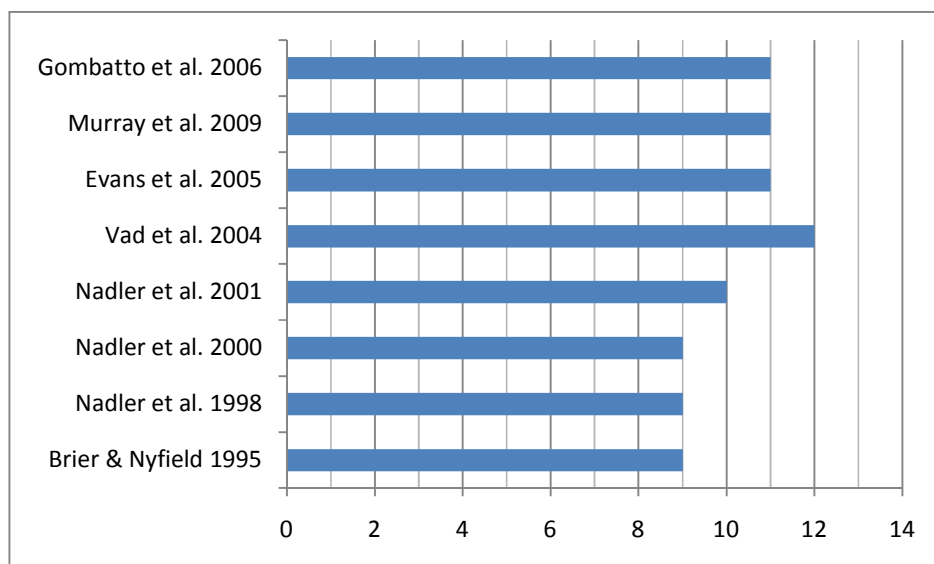
a. Hierarchy of evidence

All of the studies were observational and therefore ranked a level 3 on Sackett et al.'s hierarchy of evidence "Sackett (2000) as cited by Coomarasamy et al., 2003" (Table 2.4).

b. Methodological quality

The results for the adapted Downs and Black's checklist are presented in Figure 2.3. The score out of a maximum of 14 is shown with the two earlier studies by Nadler et al. (1998 and 2000) as well as Brier and Nyfield's study (1995) scored poorer than the remaining five studies.

Figure 2.3 Downs and Black scores out of 14



Most studies failed to score in the questions pertaining to study design. The poor methodological quality of Brier and Nyfield's (1995) study can be ascribed to a lack of

interpretation of the researchers' results. Furthermore, in four of the eight studies relevant outcome measures were ignored these were the 3 studies by Nadler et al., 1998, 2000 and 2001 as well as Brier and Nyfield (1995).

2.6.3 Population

The participants' ages ranged from 18 to 70 years old. Three of the studies, all by the same principal author, did not specifically report on the age of their subjects, but described their population as college students. Sporting codes included in the studies were running, cycling, football (presumably American Football), soccer, baseball, track, tennis, basketball, swimming, golf and two of the studies only mentioned collegiate athletes without specifically stating the sport. The scope for level of participation in the different sports included general recreation, on university level it ranged from recreational to national representation and memberships to professional associations (Table 2.5).

2.6.4 Aim of studies

The aims were clearly stated in all of the eligible papers. The study by Evans et al. (2005) was a preliminary investigation into predictors for LBP in young professional golfers. The study by Vad et al. (2004) aimed to determine a correlation between ROM deficits in the hip joint and lumbar spine with a history of LBP in golfers. Nadler et al. (2001) assessed whether athletes with hip muscle imbalance would have a better chance of developing a need for LBP treatment, following a study done in 2000 to determine the relationship of prior LBP on hip abduction and adduction strength. Nadler et al.'s 1998 prospective evaluation to test certain parameters, including hip flexor muscle tightness as predictive factors for LBP, precedes these two studies. Brier and Nyfield (1995) had a similar aim by comparing lumbo-pelvic inflexibility and LBP in

active runners and cyclists. Murray et al. (2009) looked at hip rotation ROM differences between golfers with and without low back pain. Gombatto et al. (2006) examined the relationship between movement pattern and LBP symptom reproduction in passive hip lateral ROM and an active hip lateral rotation (HLR) movement in prone as described by Sahrman (2002).

2.6.5 LBP and instrumentation

a. Definition of low back pain

All but one (Gombatto et al., 2006) of the studies relied on mere reporting of LBP without a specific measurement tool, including the studies of Nadler et al. (2000) and Vad et al. (2004) in which data was collected retrospectively. Gombatto et al. (2006) relied on both subjective report and so-called clinical test of movement and positions, but did not specify or report on these. Prospective LBP data collection relying on either self-report (Evans et al., 2005) or the report of the athletic trainer (Nadler et al., 1998, 2001) was done in the remaining studies. The definition of LBP differs from study to study as seen in Table 2.7.

Table 2.7 Definitions of low back pain

Study	Definition
Murray et al. 2009	Any pain or dysfunction of the lower back that impacted the golfer's ability to practice or perform during the study period and/or the last 12 months.
Gombatto et al. 2006	Chronic or recurrent LBP associated with their participation in sport with an increase in LBP during or after play.
Evans et al. 2005	Merely: Low back pain. Further mention of detailed instructions given for completing the questions on lower back pain was given prior to data

	collection.
Vad et al. 2004	Low back pain without radicular symptoms limiting their golf performance for greater than two weeks within the past year.
Nadler et al. 2001	LBP unrelated to blunt trauma requiring Rx as reported by athletic trainer.
Nadler, 2000	Lower-back pain during previous year that limited their ability to participate in sports activities.
Nadler et al. 1998	Low back pain requiring treatment according to athletic trainer.
Brier & Nyfield 1995	Merely: Low back pain.

Table 2.7 continued...

b. Severity classification

Brier and Nyfield (1995) included a severity classification for LBP according to frequency and extent of disability; and Evans et al. classified LBP as 'none, mild, moderate or severe'. None of the other studies classified severity.

2.6.6 Biomechanical hip variables and instrumentation

The different biomechanical parameters regarding the hip are presented in Table 2.8, together with the measurement tool and its reliability.

Table 2.8 Biomechanic variables

	Biomechanical variable	Study	Measurement tool	Reliability of tool
Hip ROM	Passive lateral rotation	Murray et al. 2009	Inclinometer	Intra-class correlation coefficients 0.83-0.99 (p<0.001)
		Gombatto et al. 2006	Inclinometer	Not mentioned
	Active lateral rotation	Murray et al. 2009,	Inclinometer	
		Gombatto et al. 2006	A six camera, three-dimensional, motion measurement system (EVaRT, Motion Analysis Corporation, Santa Rosa, CA)	Intra-class correlation coefficients 0.80-0.99 with typical error ranging from 0.8°-1.5°
	Internal Rotation (Active and Passive ROM)	Murray et al. 2009	Inclinometer	Intra-class correlation coefficients 0.83-0.99 (p<0.001)
		Vad et al. 2004	Goniometry	7% Margin of error
Flexion Abduction External Rotation with FABERE's*	Vad et al. 2004	Measuring tape	7% Margin of error	
Muscle length	Hip flexor muscle	Vad et al. 2004	Thomas in Evans et al. and Nadler et al. 1998 In Brier & Nyfield 1995 goniometry in prone and FABERE's in Vad et al. 2004	7% Margin of error Not mentioned in Nadler or Evans or Brier and Nyfield
		Nadler et al. 1998	Thomas Test	Not mentioned
		Evans et al. 2005	Thomas Test	Not mentioned
		Brier & Nyfield 1995	Goniometry in prone	Not mentioned
		Evans et al. 2005, Brier & Nyfield 1995	Active knee extension in Evans et al. Sit and reach in Brier & Nyfield	Excellent reliability in Evans et. al Not mentioned in Brier & Nyfield
	Hamstring			
Muscle strength	Maximum Isometric extension Maximum Isometric abduction	Nadler et al. 2001 and Nadler 2000	Commercial dynamometer with anchoring station	Anchoring station developed to improve
	Maximum extensor	Evans et al. 2005	Hand-held dynamometer (Powertrak)	Good, no values given
	Isometric abduction endurance component	Evans et al. 2005	Side bridge endurance (Abduction component)	Not mentioned
Pelvic obliquity	Functional Leg length discrepancy	Nadler et al. 1998	Wilson-Barstow test	Not mentioned

***FABERE's distance is a measurement of a combination of hip extension, internal rotation and adduction ROM. It is done with the ankle of the leg measured resting on the contra lateral knee in supine and is represented by the distance in cm from the knee to the horizontal.**

2.6.7 Relationship LBP and hip biomechanical factors

a. Hip flexor muscle length

Comparable parameters include the hip flexor muscle flexibility as measured by the Thomas test in two of the studies (Nadler et al., 1998; Evans et al., 2005), prone hip extension with goniometry in Brier and Nyfield (1995) and indirectly with FABERE's distance in Vad et al. (2004) as seen in Table 2.7. The difference in procedure and measuring tools as indicated in Table 2.7, complicated comparisons of the data between the studies. Therefore a mere report on the significance of the findings of the relationship between this parameter and LBP is given in Table 2.9.

Table 2.9 Hip flexor muscle length and LBP

Study	Statistical significance	Correlation	Statistical test
Evans et al. 2005	p=0.03	Significant	Pearson's product moment correlation coefficient
Vad et al. 2004	p<0.05	Significant in leading leg but not in other leg	Wilcoxon signed rank test
Nadler et al. 1998	p=0.52	Not significant	Chi-square analysis
Brier & Nyfield, 1995	Not mentioned	Not significant	Separate ANOVAs

The two studies which utilised the Thomas test, have contradictory findings to Evans et al. (2005), showing a significant correlation between LBP and hip flexor muscle tightness with a p-value of 0.03, and Nadler et al. (1998) finding no significant correlation with a p-value of 0.52.

Vad et al. (2004) supported Evans et al.'s (2005) finding of a significant correlation between the lead hip flexor muscle tightness and LBP in golfers. Brier and Nyfield's (1995) findings however supported the non-significant correlation of Nadler et al. (1998).

b. Hip abduction and extension strength

Abduction muscle strength (Nadler et al., 2001 and 2002) and hip extension strength (Evans et al., 2005; Nadler, 2000; Nadler et al., 2001) will be shown comparatively although measured with different dynamometers.

The dynamometer used in the two Nadler studies (1998, 2000) differed from the Powertrak hand-held dynamometer used in the Evans et al. (2005) study, but the testing procedures were similar and the results will therefore be compared.

The difference in strength between the dominant and non-dominant side of neither the abductors nor the extensors of the eight LBP cases in Nadler et al. (2001), was not found to be a significant predictor for LBP, with a p-value of 0.30 and 0.51 respectively. The study in the preceding work done by Nadler et al. in 2000, gave a similar result with respective p-values of 0.2 and 0.55.

The Evans et al. (2005) study showed similar results by reporting no significant correlation between hip extensor strength and LBP.

c. **Hip ROM**

Table 2.10 Hip medial ROM and LBP

Study	Lead hip	Statistical significance	Correlation	Statistical test
Murray et al., 2009	Passive ROM	p<0.001	significant	t-test
	Active	p<0.05	significant	t-test
Gombatto et al., 2006	Passive	p=0.85	not significant	t-test
	Active HLR test	p<0.01	significant	t-test
Vad et al., 2004	Passive	p<0.05	significant	Wilcoxon signed rank test

Vad et al. (2004) and Murray et al. (2009) investigated hip medial ROM and found a significant relationship between the leading leg's hip internal ROM and LBP in golfers. Non-leading hip ROM in both studies did not show noteworthy differences.

Passive lateral rotation in the studies by Murray et al. (2009) and Gombatto et al. (2006) showed no significant disparities between low back pain and unaffected controls, while the FABERE's distance, an indirect measure of lateral hip ROM in Vad et al.'s (2004) study, showed a significant variation between the groups.

Gombatto et al., (2006) further investigated active lateral rotation or HLR as a percentage of the maximum lumbo-pelvic rotation in the first 60% of movement, a kinematic dysfunction

described by Sahrman (2002). A gender difference indicated that male subjects had a higher report of symptom reproduction with the HLR test and an even larger (statistical significant) HLR percentage for the first 60% ($p < 0.01$).

2.7 Summary points

Although the population extracted from the studies in this review aged 18 years and older participated in more than 10 different sports, on levels of participation ranging from recreational to professional, most of the limited number ($N=8$) of studies meeting the criteria for this review were done in the USA, two of which by the same authors. These studies are therefore not representative of the wider population of adult sportsmen worldwide.

The variability in aims, definition, measurement tools and severity classification of lumbar pain, as well as the vast diversity in biomechanical variables together with its different measurement tools, made it difficult to discuss clear associations between lumbar pain and hip biomechanics.

Two studies (Vad et al., 2004; Murray et al., 2009) investigated hip ROM and both found a significant relationship between the leading leg's hip internal ROM and lower LBP in golfers. In another similar study (Van Dillen et al., 2008) which also featured women in the sample, the LBP group had significantly less left total hip rotation ROM than total right rotation ROM, where left constitutes the leading leg in right-handed golfers. This study did not however show a significant difference for medial ROM between groups with and without LBP.

High economic cost might be a reason for only one study utilising a measurement likely to be valid and reliable (Vad et al., 2004).

Measurement of LBP in all but one of the studies was done by mere reporting on LBP rather than utilising a valid and reliable tool.

Only one of the studies, Gombatto et al. (2002), introduced three-dimensional motion analyses to measure sport-specific biomechanical parameters associated with lower back pain. This motion analyses was not done in functional patterns, but rather as a movement in clinical testing.

Chapter 3: Methodology

3.1 Study aim and objectives

The aim of the study was to improve understanding of the hip joint kinematics in cricket fast bowlers and to ascertain whether a relationship exists between hip joint biomechanical parameters, including kinematics, ROM characteristics and lumbar symptoms.

The moment of maximum ground reaction force (GRF) in the fast bowling action is during front foot impact (Elliot, 2000; Ferdinands et al., 2009) in the delivery stride. The moment of greatest force translation to the lumbar spine is during this phase in bowling and therefore the principal researcher decided to describe the kinematics pertaining to the front foot kinematics.

3.1.1 The specific objectives of the study were to:

- ascertain the severity and nature of lumbar spine symptoms experienced by cricket fast bowlers and obtain information regarding their training and bowling history;
- evaluate 3-D front foot hip kinematics during the delivery stride;
- explore whether front foot hip joint kinematics during the delivery stride is associated with lumbar spine symptoms in fast bowlers; and
- compare hip ROM measures between bowlers with and without LBP.

3.2 Study design

A descriptive cross-sectional study was conducted.

3.3 Study population

The study population consisted of adult male cricket fast bowlers playing first-club league in the Western Province region.

3.3.1 Sampling method and sample description

Eleven first league cricket clubs were randomly selected from the 64 clubs listed in the Western Province region, using a computer randomisation table designed by a statistician. Generally, each club has about two to six fast bowlers and therefore approximately 11 clubs were required to obtain the target sample size of 30 players. Contact information of clubs in the Western Province region was obtained from the Western Province Cricket Union (WPCU) website (<http://www.cricket.co.za>). A letter, aimed at recruiting the relevant players, was sent to the 11 randomly selected clubs via e-mail. The letter (see Appendix A) informed the club manager or coach about the details of this research project and invited fast bowlers to participate in the research. The letter was followed up telephonically, at which time the names of the fast bowlers in the club were requested. The principal researcher obtained the contact details of the fast bowlers two weeks prior to each respective testing opportunity.

Of the 45 bowlers invited to participate in the study, 31 agreed to the testing, but only 16 kept their appointments. Although a sample size calculation was done and possible correlations could only be drawn with more subjects, most kinematic studies prior to this research project also used smaller sample sizes. Furthermore, the overwhelming data generated in these studies, plus very high inter-subject variability in movement analysis studies as presented by Bartlett at the ISBS China 2005 (Bartlett, 2005) and no prior studies describing hip joint

kinematics of fast bowlers, informed the decision to aim for fewer subjects and describe the data as accurately as possible.

a. The inclusion criteria were as follows:

- Adult fast bowlers between the ages of 18 and 40 years old; and
- Fast bowlers playing first-club league, which include players representing their club at provincial, franchise and national level, were featured in the study.

b. The exclusion criteria were as follows:

- Players who were ill at the time of data collection, hindering them from playing cricket, were excluded from the study in order to avoid aggravation of their condition;
- Players who were unavailable to play cricket due to any other musculoskeletal injury including severe or acute lumbar spine symptoms were excluded, since such injury might adversely influence the bowlers' technique; and
- Players younger than 18 were excluded from the study, due to biomechanical factors related to their immature spinal structure (Elliott et al., 1992; Elliot et al., 1993a; Elliot et al., 1993b; Hardcastle et al., 1992).

3.3.2 Subject invitation process

The 45 indentified bowlers were contacted telephonically by the principal researcher (see Appendix B) and invited to participate in the study, after obtaining contact information from the club representative. They were informed of the aim and objectives of the study and their availability during the testing period of March to June 2007 was discussed.

In order to motivate players to participate in this research project, a voucher for a free postural assessment, postural education and sports massage at the Sports Science Physiotherapy Centre was offered. A checklist to determine subject eligibility was compiled and is presented in points 14 - 16 in Appendix B. A convenient time for data collection was arranged with each of the eligible players.

When the expected number of bowlers was not obtained from this group, the next clubs on the randomised list were selected and the bowlers were contacted using the same protocol as explained above.

3.4 Setting

The study was conducted at the indoor practice nets of the Western Province Cricket Club (WPCC). Permission to use the facility was obtained from the club representative. The indoor facility comprised four practice nets with a synthetic surface and space for tables and chairs (Figure 3.1). The same net with its permanent creases, defining the area of delivery for the bowling station, was used for bowling testing. Subjects could enact the required bowling action with this crease encompassing the front foot impact area.

Figure 3.1 Indoor facility at WPCC



3.5 Instrumentation

To obtain data with regards to the training history, as well as the nature of lumbar-spine symptoms experienced by the cricket fast bowlers, a newly designed questionnaire (Appendix C) was compiled. For analysis of the front foot hip joint ROM and kinematics, the biomechanical equipment used included: a two-dimensional Canon MV950 Digital Video Camcorder, a Kodak EasyShare C310 camera and XSENS Motion Tracking equipment (Xsens Technologies B. V., Enschede, Netherlands). Permission to use the XSENS equipment was granted by Dr. C Sheffer from the Department Mechatronical Engineering at the University of Stellenbosch. The use of accelerometers such as the XSENS equipment is an inexpensive alternative to costly 3-D infrared camera systems for biomechanical analysis of sporting movement, outside restrictive laboratory situations (Thies et al., 2005).

3.5.1 Training and lumbar spine injury questionnaire

a. Questionnaire design

Previous literature was reviewed using the databases PUBMED, SPORTSDiscus and CINAHL. Searches were done for self-administered surveys into lower back symptoms in cricket and sports. The search produced injury surveillance in cricket from both South Africa and Australia. All these surveys were administered to health professionals who worked with teams and not self-report. In addition, the surveys were general injury surveys and not lower back symptom specific at the time of this review. It was clear that a new tool needed to be developed in order to describe lower back symptoms in fast bowlers in cricket. Retrospective data collection for

description of injury profiles was selected as this had been deemed appropriate by Murtaugh (2001).

Two medical doctors and two physiotherapists who regularly advise professional and amateur cricket players, were consulted by the researcher to determine the content of the lumbar spine questionnaire. Structural planning was based on a previously-validated questionnaire used to determine the prevalence and associated risk factors among a South African sporting population (Louw et al., 2006).

b. Questionnaire content and structure

The questionnaire (Appendix C) consists of six parts, as indicated in Table 3.1.

Table 3.1 Components of questionnaire

1	How to complete the questionnaire
2	A Demographic information
3	B Bowling history
4	C Training and conditioning
5	D Lower back symptoms (nature and severity)
6	E General health

c. Questionnaire face and content validity

In order to test the procedure of administration of the questionnaire, and to establish whether the questions could easily be interpreted by the bowlers, a pilot study was conducted prior to the main study. A sample of five fast bowlers was used to determine the above-mentioned

factors and the necessary changes were made to the content of two questions in the questionnaire: Section D 1.6 and 1.7.

Question 1.6 in the questionnaire was changed from asking subjects to report the location of the symptoms of LBP from a given list, to requesting that participants connect symptoms from a list on the left, to a body chart on the right, by drawing lines indicating area of symptoms. This was done to simplify the understanding of the question at hand and to aid appropriate responses.

Question 1.7 in the questionnaire was expanded to include three different questions instead of one. It was amended to include a further two questions regarding 'tightness' (a symptom regularly reported by fast bowlers in cricket) and 'any other symptoms' to group additional symptoms. The revised questionnaire was implemented without further testing.

3.5.2 Biomechanical instrumentation

a. XSENS motion technology

Data concerning front foot hip kinematics was obtained by means of the XSENS MTx miniature inertial 3DOF motion measurement system (Xsens Technologies B. V., Enschede, Netherlands).

Validation of XSENS

Published reports into the reliability and validity of the XSENS equipment demonstrated high accuracy and reliability in determining kinematics, in comparison to the VICON motion analysis system. The VICON system is currently considered the gold standard in motion analysis (Ehara et al., 1997; Luinge et al., 2007; Thies et al. , 2005).

The components of the XSENS system

This system consisted of the Xbus kit containing the Xbus Master which interconnects three MTx miniature inertial 3DOF Orientation Trackers with an Xbus cable. It was powered by rechargeable 1.2V AA type batteries.

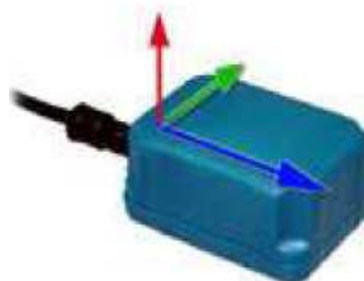
Xbus Master

The Xbus Master is a flat, box-shaped device that is strapped to the bowler's waist on the opposite side of the bowling arm. It delivers power to the MTx Motion Trackers and retrieves their synchronised data in relation to each other and the ground. It was sampled at 200Hz.

MTx Motion Analysis Trackers

A set of three complete miniature inertial measurement units (Figure 3.2) with three integrated dimensional magnetometers (3-D compass), as well as an embedded processor capable of outputting calibrated 3-D linear acceleration and the rate of turn and magnetic field (earth) data to the Xbus Master, were placed on specific anatomical landmarks as explained in section 3.10.9 (p 46-47) of this research project.

Figure 3.2 An XSENS tracker



b. Biomechanical software

The workstation consisted of a HP Compaq NX7000 personal laptop computer with a Pentium M 1.4 gigahertz processor and 512 MB RAM and data capture. Communications utilised the XSENS software and took place via Bluetooth wireless technology.

c. Anthropometry instrumentation

The principal researcher performed all the anthropometry measures (see section 3.10.5 on p. 40 for method) using a standard measuring tape and a measure stick. The anthropometric data captured on an anthropometric data capture sheet (Appendix D) was required in order to calculate the linear distance between the trackers by the mechanical engineers. This linear distance was wielded to compute angles representing the kinematics of the hip joint by the XSENS analyses software.

Accuracy of anthropometric data is condition-dependent and therefore the measurements were done just before the testing was conducted. Other factors like ethnicity and gender were not of any concern, since the data was merely utilised in order to attain the physical linear distance between trackers on the body in question.

d. 2-D Digital video camera and frame

A standard 2-D video camera, the Canon MV950 Digital Video Camcorder, was mounted on an overhead frame. This frame was used to film the delivery stride from overhead at the bowling station in order to classify the bowler's action. The system captured data at 30 frames per second.

e. Digital camera

A standard photographic Kodak EasyShare C310 4.0 mega pixel digital camera with a 35mm KODAK lens was mounted on a tripod with a fixed height, in relation to a standard plinth, on which the bowlers' hip ROM was photographed.

f. Dartfish kinematic analysis software

In order to analyse digital video and photographic data, Dartfish, a 2-D kinematic analysis system was used for goniometry. This system allows dynamic anthropometry and the measuring of angles in 2-D.

3.6 Pilot study

A pilot study was conducted with one subject. The aim of the pilot study was to assess the logistics and practicality of the testing procedures as described in sections 3.10. Following the pilot study, two adjustments were made. It was decided by the principal researcher to capture the two sets of bowling trials in succession, instead of two separate trials of six balls each, with other overs not captured in between these captured trials. This was done to allow for shorter testing sessions to accommodate bowlers' time constraints and for ethical considerations (to protect the bowlers against unnecessary injury risk).

3.6.1 Anthropometric pilot trial

A pilot trial was undertaken with one individual prior to data capture, in order to establish intra-tester reliability and to establish logistic practicality of the trial capture procedure.

The subject anthropometrics were measured five times using the protocol explained above. Good intra-tester reliability was established.

3.6.2 ROM pilot trial

A pilot trial was conducted with one individual prior to data capture, in order to establish intra-tester reliability and logistic practicality of the ROM trial capture procedure. Hip internal ROM measurement in prone has been shown more reliable than in supine (Cibulka et al., 1998). Although ROM measurements had been done in several studies which investigated hip involvement in LBP in sportsmen (Vad et al., 2004), most after-testing was done in this study (Harris-Hayes et al., 2009; Murray et al., 2009; Van Dillen, 2008).

For lateral rotation, most of the previous studies in sport utilised the FABERE’s distance, which is a combined test for lateral rotation abduction and extension of the hip. The principal researcher therefore decided to do a similar test in prone for the hip which has been previously shown to be valid and reliable (Ellison et al., 1990).

The subject was measured five times and good intra-tester reliability was established.

Table 3.2 Summary of pilot trial for internal rotation ROM



L=32.3°

L=31.3°

L=32.5°

L=33.3°

L=33.2°

R=27.3°

R=25.5°

R=25.6°

R=26.2°

R=26.7°

L=35.52° SD=2°

R=26.26° SD=1.8°

3.7 Data collection period

The trial was captured at the end of the domestic cricket season of 2006/7, from March to May 2007. The availability of the players and instrumentation and the fact that these months marked the end of the domestic cricket season, were the main considerations in opting for this period. Players could also report on the injury history of the entire season.

Data capturing commenced at 08h00 in the morning and a full session consisting of seven bowlers ended at 13h00.

3.8 Research team

The researcher required the assistance of two assistants on the day of data capture: an engineering consultant for assistance in biomechanical data capture and a research assistant who administered the questionnaire, supervised the completion of consent forms and explained the logistics of the day to each subject.

3.9 Preparation of the testing facility

Prior to the arrival of the first participants on the days of trial capture, the principal researcher and engineer prepared the practice nets for data capture. All the different stations were prepared and labelled station 'A - D' with an A4-size symbol for data collection. An equipment checklist (Appendix K) was completed to ensure that all the equipment was in order on the day preceding a typical testing day. The questionnaires were checked, including a page count, to ensure that they were complete and easily accessible.

3.9.1 Station A: Consent and questionnaire

A table and chair with the individual information sheets (Appendix I), consent forms (Appendix G), questionnaires (Appendix C), exercise hand-outs (Appendix L) and stationery including pens and pencils, were placed close to the entrance.

Figure 3.3 Consent and questionnaire station



3.9.2 Station B: Anthropometrics and ROM

A table with measuring stick, a standard measuring tape, reflective markers, double-sided tape, pair of scissors and the anthropometric data capture sheet (see Appendix D) on a clipboard, together with a pen and pencil, was placed in close proximity to station A. The electronic scale was placed adjacent to the table.

A portable plinth was positioned in order to test hip ROM with the 2-D Kodak EasyShare C310 4.0 mega pixel digital camera. The camera was placed on a tripod at the exact height of the plinth, at a fixed distance of 1m from the plinth or the hip rotation measurements. It was

placed at a fixed distance of 1,5m for the Thomas test which was used for the hip extension ROM.

Figure 3.4 Anthropometrics and ROM station



3.9.3 Station C: Warm-up

A second net was used as a warm-up area for the bowlers to follow the recommended warm-up routine (see section on data collection procedures 3.10 for method) in Appendix L. Copies of the documents were placed in this net, together with a cricket ball for sport-specific warm-up.

Figure 3.5 Warm-up station



3.9.4 Station D: Bowling

In order to film the delivery stride from above, the 2-D video camera was mounted on the frame and positioned in the net slightly left of the bowling crease. This position captured the front foot position relative to the gridlines and bowling crease in the delivery stride.

A bowling preparation point, which was in close proximity to the opening of the bowling net, was set in place. This consisted of a chair, a table containing the XSENS Xbus Master and belt, MTx miniature inertial 3DOF Orientation Trackers, double-sided tape, EAB plasters, scissors, a towel and liquid soap for skin preparation. The plaster and scissors were also placed on the table for tracker attachment. The laptop computer was placed on the same table in order to receive the blue tooth signal from the XBus transmitter (see Fig 3.2).

3.10 Data collection procedures

Trials for up to seven subjects were captured on any one testing day, but some of the testing of subjects overlapped between the different stations and implied the overlapping of duties of the principal researcher, engineer and research assistant.

Table 3.3 partially details the logistical arrangements required for a group of seven subjects in order to show the overlap in tasks of subjects on a testing day . See Appendix E for a full data collection day plan.

Table 3.3 Day logistics for seven subjects (partial)

1	2	3	4	5	6	7	Time
C							08h00
Q							08h04
Q							08h08
Q							08h12
Q							08h16
A							08h20
A							08h24
R							08h28
R							08h32
W	C						08h36
W	Q						08h40
Ⓢ	Q						08h44
P	Q						08h48
P	Q						08h52
Ⓢ	A						08h56
Ⓢ	A						09h00
Ⓢ	R						09h04
Ⓢ	R						09h08
Ⓢ	W	C					09h12
Ⓢ	W	Q					09h16
Ⓢ	Ⓢ	Q					09h20
Ⓢ	P	Q					09h24
	P	Q					09h28

Key to symbols:

1, 2, 3, 4: Bowlers to be tested

Black balls Ⓢ: Overs in the nets to simulate match conditions

Red balls Ⓢ: Overs to be filmed

A: Anthropometric measurements

W: Warm up

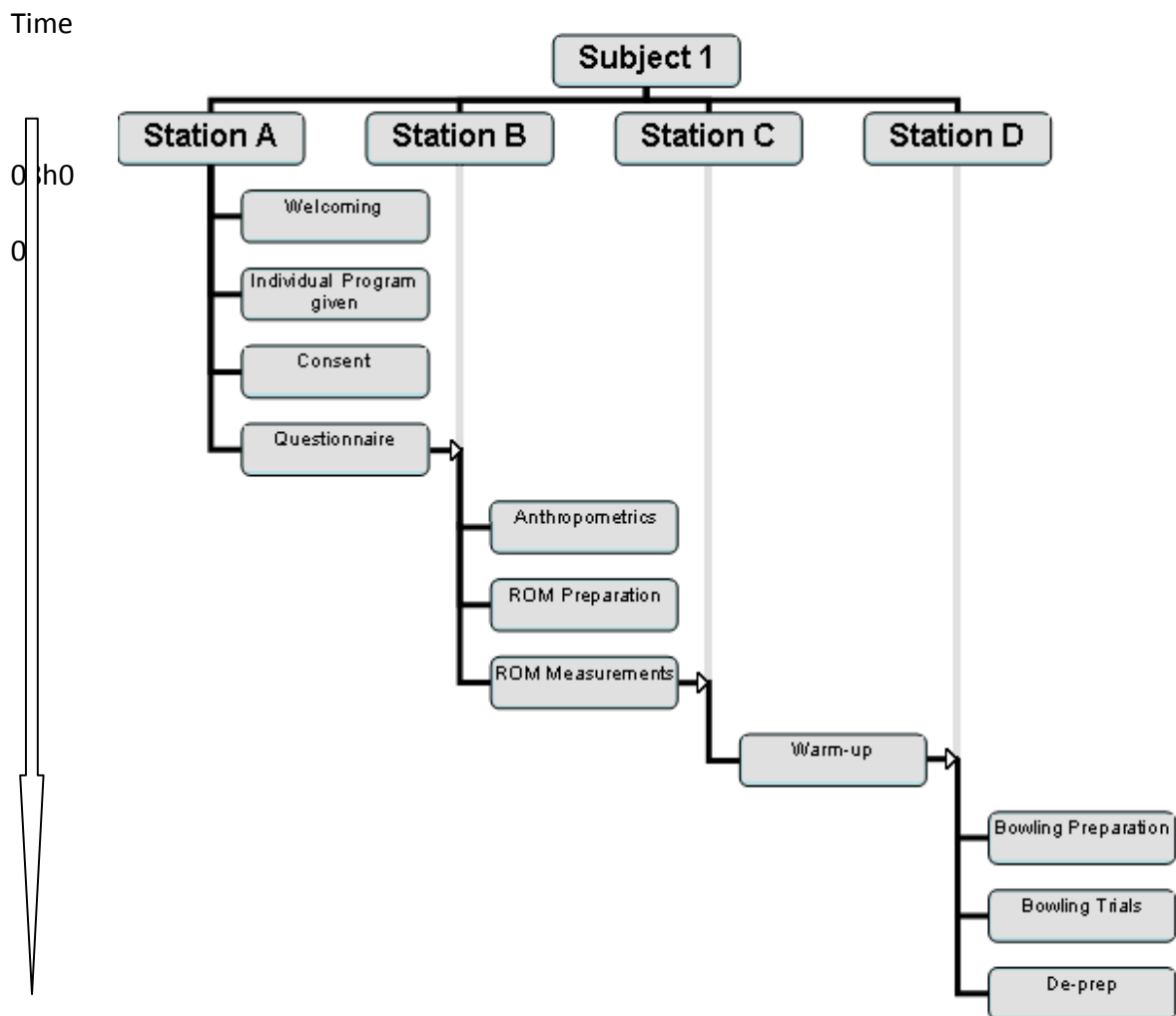
R: Hip Range of Motion

X: Fielding drills (Appendix I)

Q: Questionnaires administration

The diagram in Figure 3.6 maps the monitoring of one subject as he moves through the different stations in order to undergo the process of data collection of all the necessary data sets.

Figure 3.6 Logistics for one bowler



09h28

3.10.1 Welcoming of subject

On arrival each subject was greeted at the door, and guided to Station A by the research assistant as outlined in Appendix J. The research assistant explained the logistical arrangement for the testing, and provided the individual day programme in writing (Appendix I).

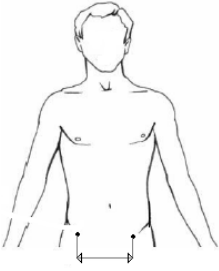
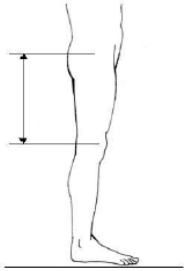
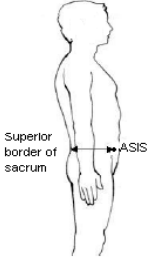
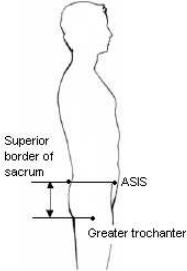
3.10.2 Informed consent and questionnaire

The subject was required to sign the letter of consent (Appendix H) pertaining to the trial before the trial capture commenced. The questionnaire was then administered by the research assistant according to standard procedures outlined in the assistant's duty list (Appendix J).

3.10.3 Anthropometric measures

The subject proceeded to station B, where the principal researcher took all anthropometric measurements presented in Table 3.4.

Table 3.4 Anthropometric measurements

 <p>Distance between ASIS</p>	 <p>Trochanteric thigh length</p>
 <p>Adjusted waist depth</p>	 <p>Distance between proximal border sacrum to ASIS and greater trochanter</p>

Subjects were measured in shorts without shirts, and all the measurements barring the low waist depth, were done in standing with the standard measuring tape. The adjusted waist depth measurement was taken in supine on the plinth. The distance from the ASIS to the plinth was measured with the measuring stick and as the superior border constitutes the weight-bearing area in contact with the plinth, it will represent the distance from the ASIS to the sacrum, but in the sagittal plane or the ASIS (called the low waist depth for easy reference).

The anthropometric measurements were captured on a data sheet (Appendix D) specifically drawn up for this study. These measurements were used to deduct the linear distance between the trackers required for the processing of XSENS data into hip kinematic information.

3.10.4 ROM measurements

All the ROM data collection was performed photographically on the plinth at station B.

a. Hip internal rotation ROM

The reflective markers were attached by the principal researcher to the following landmarks at station B in order to photograph the hip rotation ROM: The first two markers were placed on the tibial tuberosities and the next pair was used on the anterior aspect of each of the ankles, halfway between the medial and lateral malleoli.

Hip rotation ROM data was captured in prone with the hip in neutral in the sagittal plane. This position was selected because the hip is close to the neutral position in this plane during the front foot weight-bearing phase of fast bowling.

The subject was instructed to lie in prone. The camera was set on a 10-second auto-function to allow the principal researcher to passively flex the subject's knees to 90°, after medially rotating both hips to the point of first resistance and holding it manually, maintaining the 90° angle. The photograph was taken in this position.

b. Hip external ROM

The markers, as in section A, were used for the external rotation measurement. The same position, namely prone with 90° knee flexion, was used to measure the hip lateral rotation. The knee was rotated laterally by the principal researcher using the same protocol with the 10-second auto-function.

c. Thomas test

After rotation ROM data was captured, the markers' placement was changed for the Thomas test photographs as follows:

Three markers were used for each leg, one on the greater trochanter, one on the lateral joint line of the knee and one on the lateral malleolus. The Thomas test was filmed separately for each leg, with the hip flexor muscle length as measured by the Thomas test done after each marker placement.

Used in previous research regarding hip biomechanics in connection with LBP as explained in the literature review of this study (Evans et al., 2005; Nadler et al., 1998), the Thomas test is a valuable clinical test for hip extension ROM and has been found adequately reliable in previous research (Bartlett et al., 1985; Schache et al., 2000).

After the marker placement as explained in 3.10.5, the subject was instructed to stand at the foot-end of the plinth, then to rest just the ischium, explained as the edge of the buttocks, on the edge of the plinth. He was instructed to lie back (supine) while holding his left leg to his chest. The 10-second delay option on the camera was activated, upon which the researcher took that leg and positioned the subject's lower back into a flat back posture using the supporting surface of the plinth. A photograph was taken in this position to measure for the right leg hip flexor muscle length and the process was repeated for the left leg.

Figure 3.7 Thomas test



3.10.5 Warm-up

Next the subject proceeded to station C or second practice net where a 12-minute warm-up routine was performed, as indicated on the subject information sheet (Appendix L). The programme included:

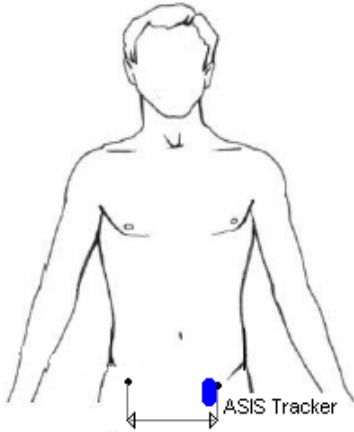
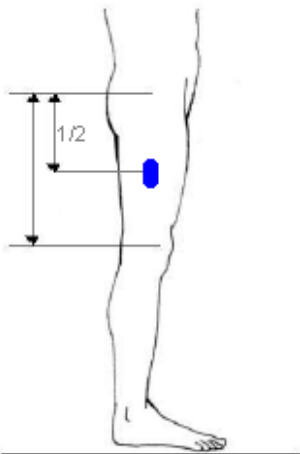
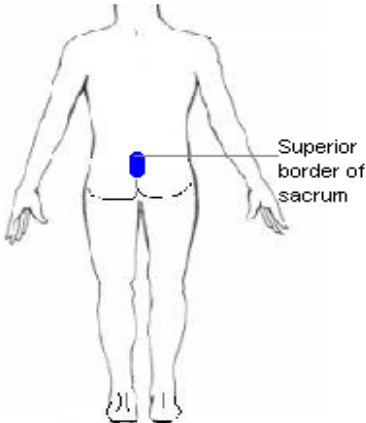
- running shuttles;
- both static and dynamic stretching; and
- the bowling action.

The first over was bowled as part of the warm-up and was not captured by the XSENS equipment and 2-D filming. Thereafter, the bowler returned to the bowling preparation station at station D in order to undergo preparation for his first bowling trial capture.

3.10.6 Bowling preparation

Subject preparation with XSENS Trackers.

Table 3.5 Location of trackers

 <p>Front foot ASIS Tracker for R-hand bowler</p>	 <p>Front foot thigh tracker for L-hand bowler</p>	 <p>Sacrum tracker</p>
---	--	--

The principal researcher prepared the appropriate areas (see Table 3.5 for tracker placement), by wiping excess sweat from the subject's skin in order to allow for the establishment of good contact between the tracking device and the skin.

Marker placement was based on recommendations from a study by Cappozza et al. (1996), which indicated that skin markers in VICON testing placed further away from the joint such as lateral thigh instead of on bony landmarks such as the greater trochanter, exhibit smaller skin

movement artifacts (movement of skin relative to underlying bone). Two markers were placed to define the proximal segment or pelvis, namely the ASIS and the sacrum.

The principal researcher, assisted by the mechanical engineer, applied the XSENS MTx miniature inertial 3DOF Orientation Trackers to the skin of the subject with double-sided tape and reinforced the cables with elastic adhesive bandages (Fig 3.8).

Figure 3.8 Sacral tracker



3.10.7 Subject preparation with Xbus Master

The Xbus Master was fastened around the bowler's waist with a belt supplied in the kit, facing away from the bowling arm in order not to influence the natural bowling style of the bowler.

3.10.8 Bowling trial

The trials were captured at station D by the engineer with the help of the principal researcher. The second over served as the first set of bowling trials captured with the biomechanical equipment whilst the third over served as the second.

a. Time frame

A 28-minute timeslot was granted per subject for two overs or 12 balls. This constituted the 12 trials and allowed for time eventualities, such as the detaching of trackers during the data capture of the 12 balls. One ball was allowed before the trial capture, to allow the bowler to become accustomed to the feel of the reflective markers and XBus, and enable him to ascertain his run-up length. The first practice delivery further helped the bowlers to familiarise themselves with the environment and testing procedure.

All bowlers were given the following standard instructions by the principle researcher:

- “Please mark your run-up now and use your one delivery to ascertain this. This will also provide you with the opportunity to familiarise yourself with the feel of the trackers and the cameras will give us information in order to classify your technique as either front-on, side-on or mixed.”
- “There are three trackers that will capture information on the movements and communicate via Bluetooth to the computer information regarding your bowling action.”
- “Before you start your run-up, stand still on your mark facing the wickets so the computer can get a neutral measurement.” (This was done in order to find the neutral position for the hip joint from the basic anatomic position in the data and served as the calibration for the system.)

- “Run up and bowl when the engineer verbally prompts you on the track, using the white lines as the bowling and popping crease on command of the engineer, as the equipment enables capture of data.”

This procedure was repeated 12 times per bowler during one data capturing session.

b. XSENS data capture

XSENS software has a start-stop feature which starts and ends data capture. It was controlled by the engineer on the laptop, while the research assistant controlled the stopwatch in order to have a frame of reference for data analysis of the biomechanic data of the bowling trial. This time switch was derived using a three-point timeframe with a standard stopwatch with a laps-feature.

The manual time switch was activated at: 1) the onset of data collection by the XSENS when ‘start’ was pressed before the bowler started his run-up, 2) at back foot impact (BFI), and 3) at completion of the trial capturing when the ‘stop’ button was pressed. These time frames were used in order to provide a reference point for the delivery stride’s onset at BFI in the analysis of XSENS data. Data was therefore captured by the XSENS equipment for a few seconds before, and then over the full duration of the delivery stride in each trial.

The trial number, as well as the time for the three lap times of which the first would be the starting point, was noted on the timesheet for XSENS data capture (Appendix N).

The Xbus Master transmitted synchronised data retrieved from the MTx Motion Trackers via a wireless Bluetooth link to the laptop computer within a 15m range. Data files were saved in the database linked with the system where the initial processing was done at a later stage.

c. Kinematic data assessment

Between deliveries, all captured trials were checked to ensure that the trial was successfully communicated from the trackers to the Xbus and then via Bluetooth technology to the laptop computer. If a trial communication was unsuccessful, an extra trial was captured before debriefing of the subject to ensure 12 successful trials for each subject. The timesheet for XSENS data capture (Appendix O) allowed for these additional trials.

3.10.9 De-preparation of subjects

Upon completion of the trial, the XSENS trackers were removed, and the bowlers were instructed to cool down as instructed in their individual information sheets (Appendix I).

The cool down included running slow shuttles and both static and dynamic stretching.

The participant was given an opportunity to ask questions regarding the research project and received a voucher for a free massage and structured stretching programme compiled by the physiotherapists at the Sports Science Institute of South Africa (SSISA).

3.11 Data processing

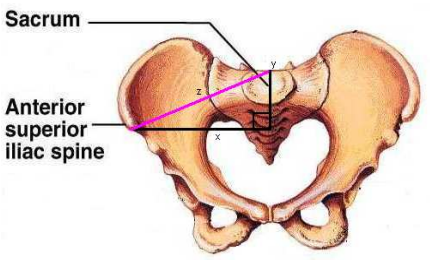
3.11.1 Questionnaire data

The questionnaire data was captured in *Microsoft Excel 2003 version X* (computer software) on a datasheet designed by a statistician.

3.11.2 Anthropometric data

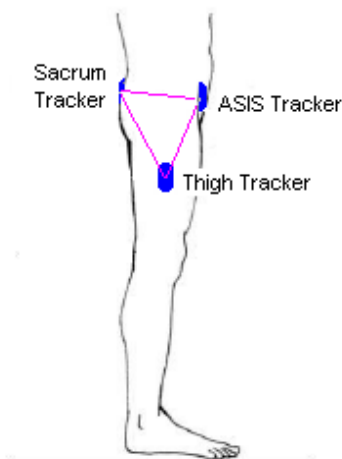
The measurements were used by engineers in order to calculate the linear distance between trackers by using simple Pythagoras theorems as seen in Table 3.6 and Figure 3.9.

Table 3.6 Example of a formula to calculate linear distances between trackers using anthropometric measurements

Linear distance from:	Formula	Anthropometrics	
z =ASIS tracker to Sacrum tracker	$z^2 = y^2 + x^2$	x =1/2 L ASIS to R ASIS y =Adjusted waist depth	

The mathematical model recorded in writing, as used by the XSENS software program, utilised these distances for motion analysis.

Figure 3.9 Linear distances between trackers



3.11.3 Biomechanical data

a. ROM data

Photographic data, captured with the 2-D camera, was analysed with Dartfish software in order to obtain the angles for the hip ROM (see Table 3.5 for processed photographs). Data collected was captured in *Microsoft Excel 2003 version X* (computer software) on a datasheet designed by a statistician.

Bilateral differences in hip ROM were tested using the Wilcoxon signed-rank test with the significance level set at $P < 0.05$.

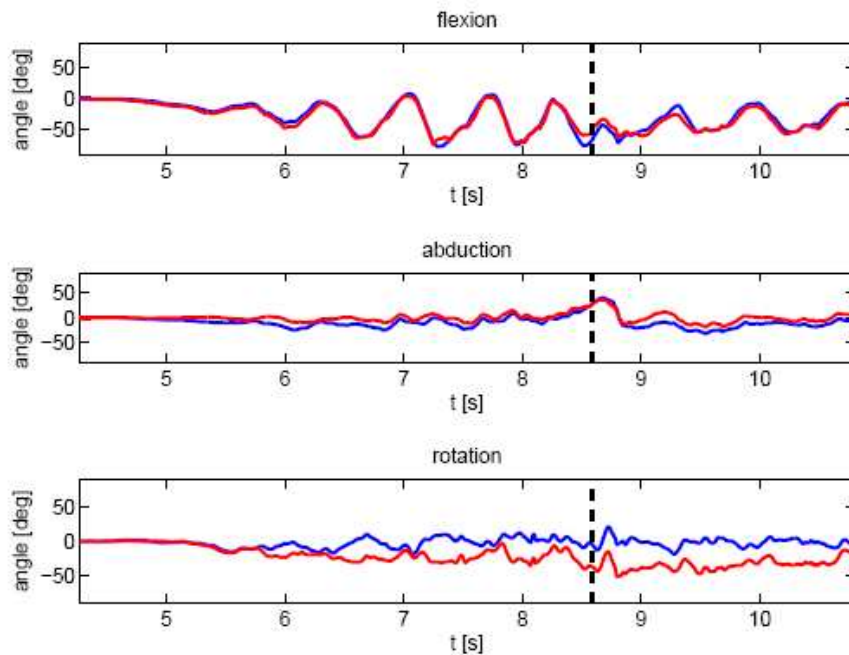
b. XSENS hip kinematic data

The data as captured above was subsequently exported to Matlab and *Microsoft Excel version 2003 (computer software)*. Initial analysis was done by the engineers providing the raw data in spreadsheets and graphs. Figure 3.15 illustrates an example of the graphs plotted after data processing. After deriving a joint coordinates system and bone-embedded anatomical frame (Hagemeister et al., 2005; Capozzo et al., 1996), the kinematic parameters derived from these measurements after initial analysis, included hip joint flexion and extension angles, hip joint adduction and abduction, hip joint internal and external rotation.

The two different colours in the graphs of Figure 3.10 represent the two different trackers on the pelvis that embody the segment in the hip joint. The sacrum was chosen as the ASIS tracker was tilted by the impaction unto the abdomen in the first part of the delivery stride and produced a faulty representation. Data for hip movement was analysed by using the sacrum and femur trackers.

From the above data, only the data representing the one second before and one second after BFI for each run of every bowler, was extracted and plotted in an Excel graph in order to decide on ways to best present data.

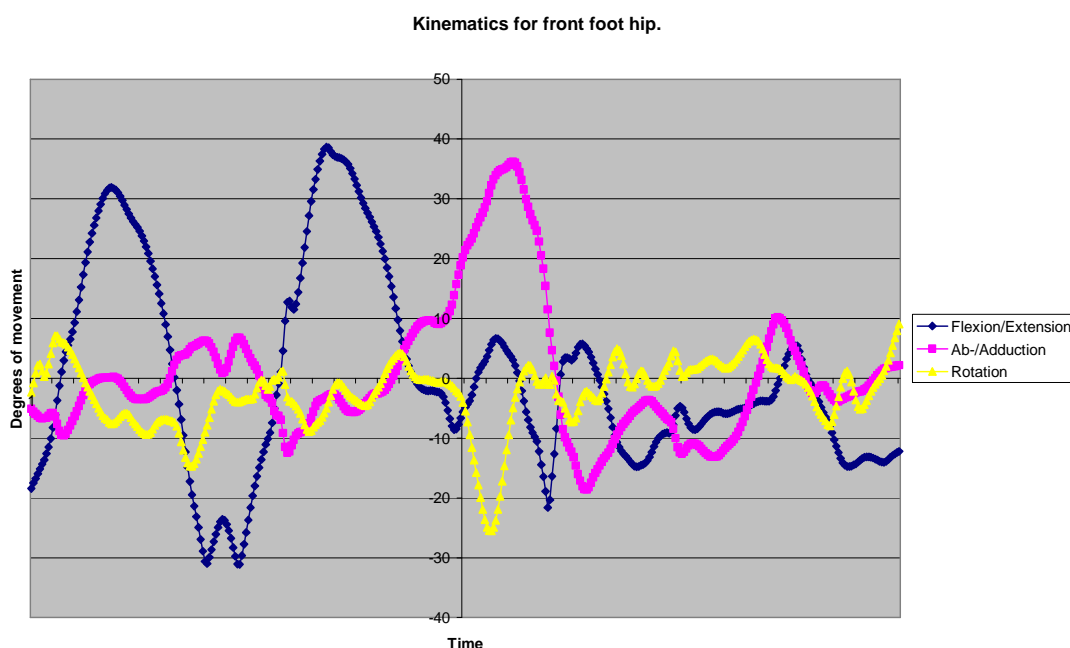
Fig 3.10 Example of raw data format



The average movement for each bowler during the second before and after BFI was analysed by the consultant engineers and was plotted for each run of every bowler in order to view the intra-subject variability. The kinematics as seen in Figure 3.11, in spite of a definite consistency in different balls bowled by the same bowler, did not conform to any pattern whatsoever between different bowlers. It was therefore apparent that a high variability existed between different bowlers. In order to quantify the extent of variability, the average movement for each bowler was calculated by using frequency domain averaging. In frequency domain averaging, the time histories of the signals are converted to the frequency domain, and the mathematical

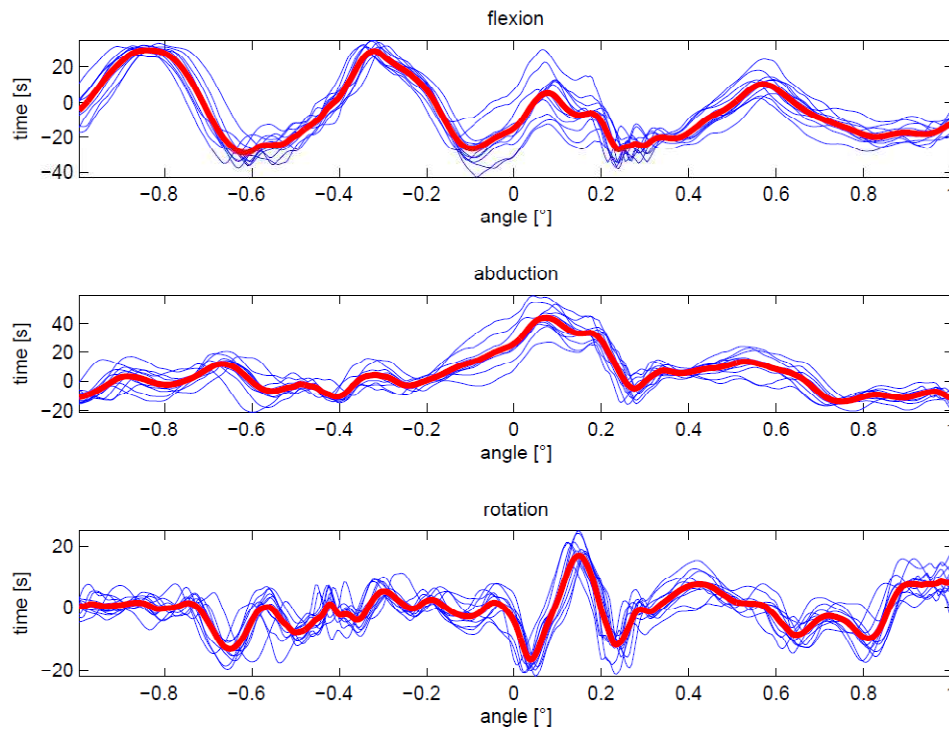
average is taken of all the signals. This mathematical average is then converted back to the time domain in order to yield an averaged signal. Due to the fact that the time domain signals are not synchronised, time domain averaging is impossible, necessitating averaging of this nature. In the frequency domain, the signals do not have to be synchronised in order to calculate an average.

Figure 3.11 Kinematics for front foot hip



Following calculation, the data average was presented with the method of rain-flow counting – an analysis style often used to determine the number of cycles in a time history signal. It is used for example, in mechanical fatigue tests (Amzallag et al., 1994), to deduce the number of cycles within certain ranges that a component can withstand before failure. In this study, the algorithm was also useful for ascertaining the number of cycles within certain ranges that each bowler performed during his bowling action.

Figure 3.12 Kinematics for front foot hip for all trials in one bowler.



The linear correlation coefficient was calculated for each movement plane, utilising the data of each bowler, with the purpose of presenting the intra-subject variability results in graphs as seen in Figure 3.12. Also see Appendix H for average and trials for all bowlers.

c. 2-D video data

The data captured during the filming process was exported to Dartfish, in which the front foot position was determined relative to the bowling crease and captured in *Microsoft Excel 2003 version X* (computer software) in a datasheet designed specifically by a statistician. The data in question was not analysed further for the purposes of this research project.

3.12 Statistical analysis

The statistical analysis of the data is mostly of a descriptive nature, therefore descriptive tools as standard deviations and histograms were used, depending on the type of data. Mann-Whitney U was used to test the difference concerning hip ROM between the LBP and no LBP groups and is presented in section 4.4. The significance level was set at $P \leq 0.05$ and statistical analysis was done in *Microsoft Excel version 2007* (computer software).

3.13 Ethical considerations

The approval of the Committee for Human Research at Stellenbosch University was obtained before the commencement of this research project. The study was conducted according to internationally-accepted ethical standards and guidelines. The letter of acceptance is attached to this thesis (Appendix N)

Written informed consent (Appendix F & G) was obtained from each participating fast bowler prior to the execution of the pilot and main study. A bowler had the right to withdraw from the study at any time by notifying the researcher.

Chapter 4: Results

4.1 Bowlers' profiles

Sixteen of the 45 cricket bowlers who were contacted agreed to participate in the study (N=16).

The profiles of the bowlers are discussed in this section.

4.1.1 Demographic information and sample description

The mean age of the 16 subjects was 25.30 years (SD=5.77), ranging from 19 to 42 years. The highest level of play for 14 of the subjects was club level, while two played at national level.

Fourteen of the subjects were right-handed bowlers.

4.1.2 Warm-up

The information pertaining to warm-up history is reported in Table 4.1.

Table 4.1 Warm-up history of subjects (n=16)

Modalities of warm-up	Nr of bowlers					
	Before innings	4 overs	3-4 overs	2-3 overs	1-2 overs	1 over
Stretching	14					
Running	12					
Bowling simulation	11					
Timing of warm-up session before the start of bowling spell	10	10	1	4	3	2

Information pertaining to warm-up illustrates that the bowlers applied stretching, running and bowling simulation prior to a bowling spell. Bowlers were able to request more than one warm-

up session before their bowling spell. Responses from the bowlers show that more than half of the subjects performed warm-up before the innings and four overs before their spell.

4.1.3 Bowling history

The bowling history profile of bowlers is described in Table 4.2.

Table 4.2 Bowling history of subjects

Years of Bowling: N=16	Mean Age	SD	Range
Age at which cricketer started playing cricket	9.86 years	4.51	5-22 years
Age at which cricketer started bowling	10.06 years	4.49	6-23 years
Duration up to date of bowling career	10.00 years	6.46	7-30 years

4.1.4 Training history

No cricket specific-training pertaining to batting and fielding was reported by the subjects during the season.

In-season training history is reported in Table 4.3, whilst the pre-season training is reported in Table 4.4.

Table 4.3 Number of bowlers reporting on type training in season (n=13)

	Number of bowlers						Total
	1 Day / week	2 Days /week	3 Days /week	4 Days /week	5 Days /week	6 Days /week	
Weight training (n=10):							
Free weights	-	6	2	-	-	-	8
Body weight	2	1	1	1	-	-	5
Theraband	2	2	1	-	-	-	5
(Time spent on training varies from 30 minutes to longer than 1h15 minutes)							
Cardiovascular training (n=13)							
Cycling	1	4	1	-	-	-	6
Running	-	8	2	2	-	-	12
Swimming	1	-	-	-	-	-	1
Cross training with other sports	-	-	-	-	-	-	-
(Time spent on training varies from 15 minutes to longer than 1h15 minutes)							
Core stability training (n=6)							
Unsupervised exercises	1	4	-	1	-	-	6
Supervised exercises	-	-	1	1	-	-	2
(Time spent on training varies from 15 minutes to longer than 45 minutes)							

Table 4.4 Number of bowlers reporting on type of training pre-season (n=8)

	Number of bowlers training given number of days in one calendar week.						Total
	1 Day / week	2 Days / week	3 Days / week	4 Days / week	5 Days / week	6 Days / week	
Weight training in pre-season (N=6):							
Free weights	-	2	2	-	1	-	5
Body weight	-	1	1	-	-	-	2
Theraband	-	-	-	-	-	-	
(Time spent on training varies from 30 minutes to longer than 1h15 minutes)							
Cardiovascular training (N=8)							
Cycling	-	1	1	1	-	-	3
Running	1	6	1	-	-	-	8
Swimming	1	1	-	-	-	-	2
Cross training with other sports	1	-	1	-	-	-	2
(Time spent on training varies from 30 minutes to longer than 1h15 minutes)							
Core stability training (N=3)							
Unsupervised exercises	-	2	-	-	-	-	2
Supervised exercises	-	1	-	-	-	-	1
(Time spent on training varies from 15 minutes to longer than 45 minutes)							

4.2 Injury profiles

4.2.1 Lower back symptoms

The presence of symptoms is indicated per bowler in Table 4.5.

Table 4.5: Bowler symptom profile

Bowler's number	Symptoms in season	Recent symptoms
1	No	No
2	No	No
3	No	No
4	Yes	Yes
5	No	No
6	No	No
7	Yes	Yes
8	Yes	Yes
9	Yes	Yes
10	Yes	No
11	No	No
12	No	No
13	Yes	Yes
14	Yes	Yes
15	Yes	No

Eight of the 15 subjects experienced pain in the lower back while or after playing cricket during the season. Of these eight subjects, three were unable to play for a few days (less than a week) and another subject was unable to play for a few weeks (less than a month). The remaining four reported no loss in playing time. This loss of play hours constitutes either competition or training. Four subjects reported lower back symptoms related to cricket activities within the first two weeks of the cricket season.

a. Effect on ADL

None of the subjects indicated an impact on their ability to perform tasks at work or home due to symptoms, but three indicated a negative impact on recreational activities other than cricket.

b. Medical consultation

Four of the eight subjects consulted a health professional due to lower back symptoms. Two consulted a chiropractor and another one consulted a physiotherapist. The remaining subject failed to indicate which health professional he had consulted. Two had special investigations namely X-rays, while the others did not report any special investigations. Two of the four subjects who had consulted a health professional, recalled being given a diagnosis for their lower back problem, but not the diagnosis.

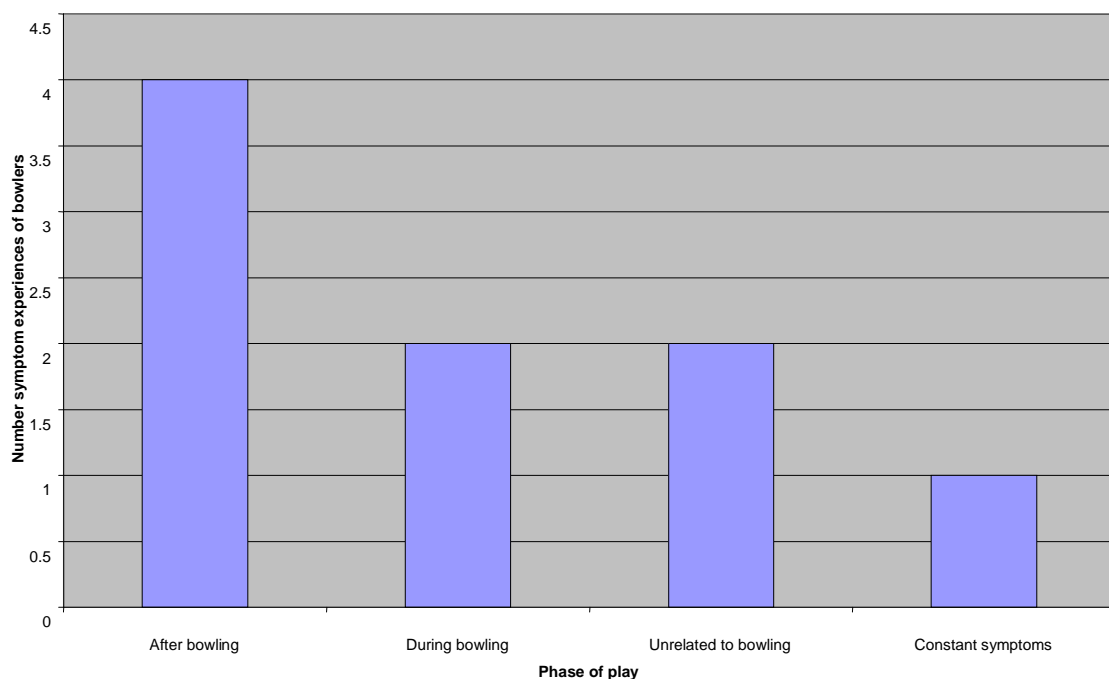
Four subjects received treatment for LBP. The subjects could report more than one treatment modality. Three reported massage as the treatment modality and two were treated with electrotherapy modalities. At least one was treated using only electrotherapy as modality.

4.2.2 Recent symptom profile

Seven of the 16 subjects reported a total of nine lower back pain experiences associated with playing cricket during the past week before the trial capture. Figure 4.1 represents the phase of play in which the symptoms were experienced by the seven subjects (each subject could nominate more than one pain experience).

Four of the subjects who experienced symptoms associated with bowling, reported post-play lumbar symptoms. One subject reported symptoms in each of the following phases of bowling: Back-foot impact, ball release, follow through, after delivery, after over (in the field) and after a spell (in the field). None of the subjects reported pain during the run-up phase.

Figure 4.1 Phase of play associated with symptom experiences developed

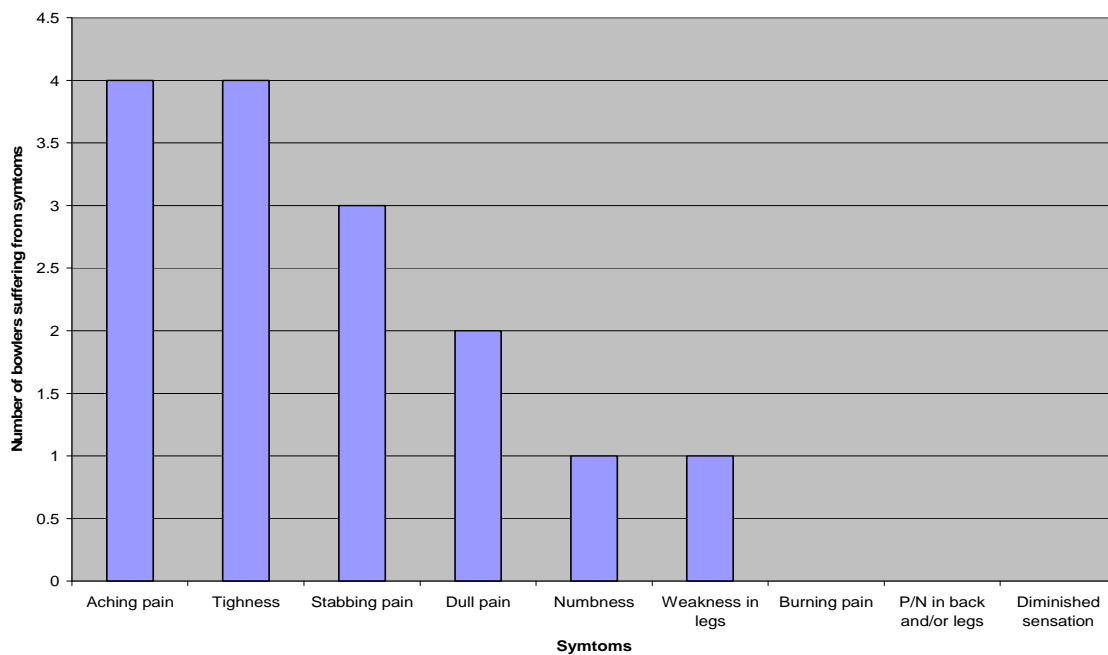


a. Onset of symptoms

Five of the seven subjects who experienced recent (in the last week before the trail capture) lower back symptoms, reported a gradual onset while the remaining two reported a sudden onset of symptoms. In-season onset of symptoms was reported by 86% of the bowlers, with all but one reporting onset during play (two while bowling and three while fielding). One subject reported out of season onset. None of the subjects reported onset of symptoms in the pre-season.

b. Nature of symptoms

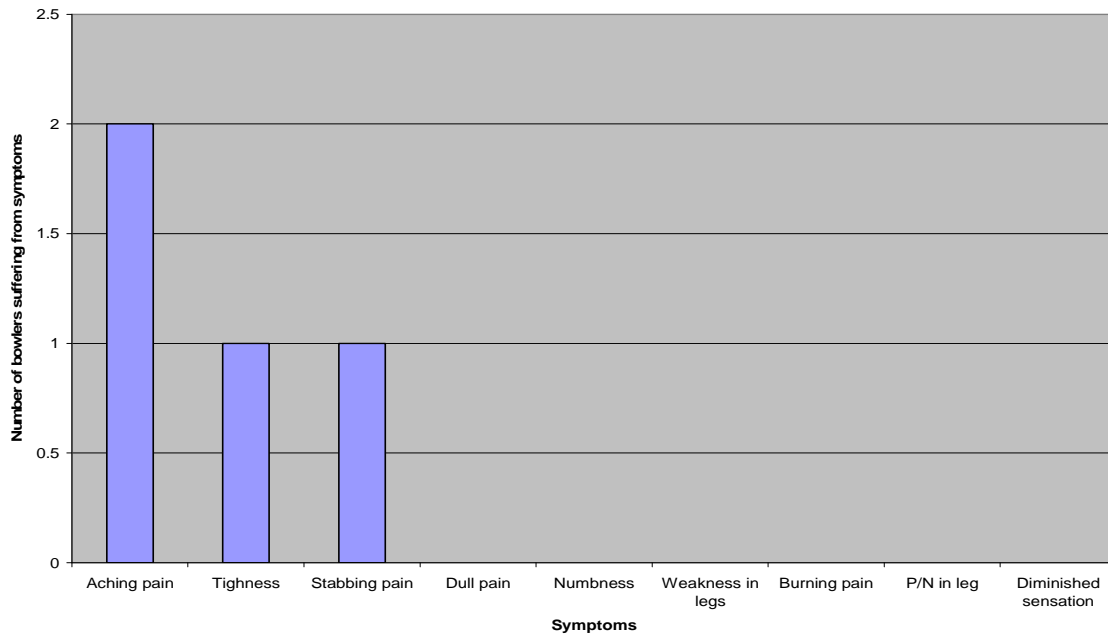
Figure 4.2 Symptoms in lower back area experienced by the seven bowlers reporting recent LBP



Twenty-three symptoms were experienced by the seven subjects who reported recent symptoms. The relevant symptoms experienced and body area in which the symptom was

experienced, are indicated in the figures below. Fifteen of these symptoms were experienced in the lower back area as seen in Figure 4.2.

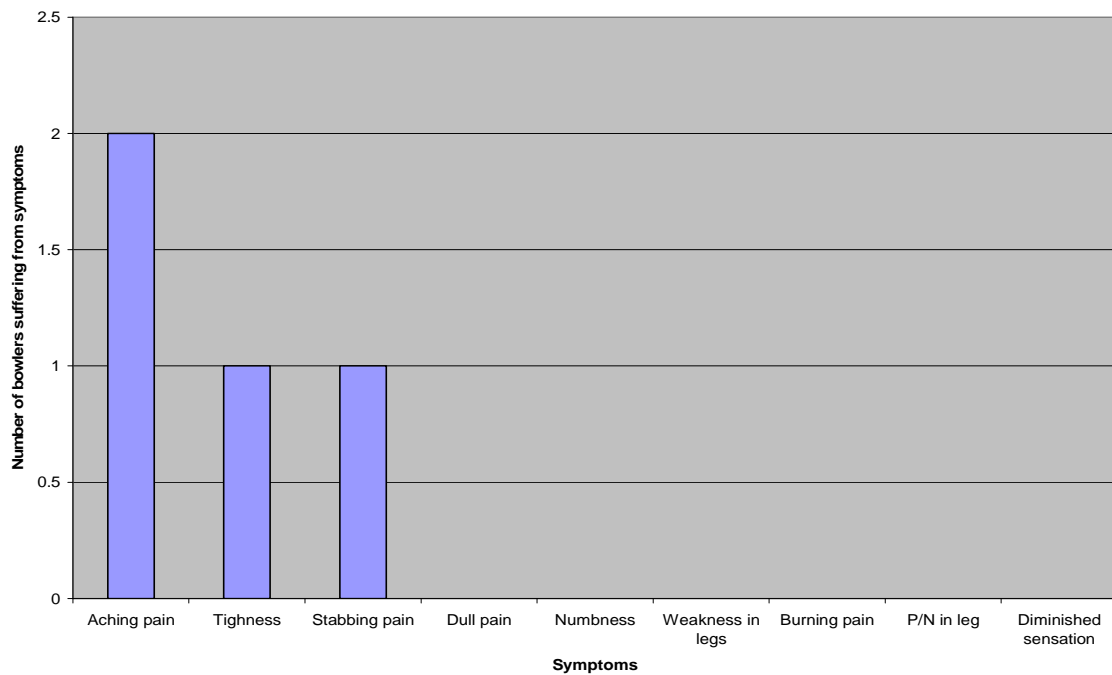
Figure 4.3 Symptoms in left posterior area of thigh experienced by the seven bowlers reporting recent LBP



Four of the 23 symptoms reported were experienced in the posterior aspect of the left thigh as seen in Figure 4.3.

No symptoms were indicated in the left foot, posterior aspect of the leg or the anterior aspect of the left thigh. For the right leg, one bowler indicated pain in the anterior aspect of the thigh and symptoms for the posterior aspect are presented in Figure 4.4. No symptoms were experienced in the lower leg or foot on the right.

Figure 4.4 Symptoms in right posterior thigh area experienced by the seven bowlers reporting recent LBP



c. Intensity of symptoms

Subjects were asked to grade the intensity of the symptoms on a subjective scale of 0 - 10 with a visual line diagram, where '0' reflected no symptoms and '10' indicated the worst pain that the subjects had ever experienced.

Table 4.6 Intensity of recent symptoms

Symptoms	Intensity of symptoms	Number of bowlers reporting intensity
Lower back pain (N=7)	7/10	1
	5/10	1
	4/10	3
	3/10	1
	2/10	1
Tightness in lower back (N=8)	2/10-8/10	8
Pins and Needles (P/N) in back and legs (N=4)	1/10	1
	3/10	2
	5/10	1

4.2.3 General health

None of the subjects disclosed previous trauma such as a motor vehicle accident (MVA) prior to taking part in this study. One subject indicated an incident six months earlier without elaborating.

Fifteen bowlers indicated not suffering from arthritic conditions or diabetes, while one did not answer these two questions.

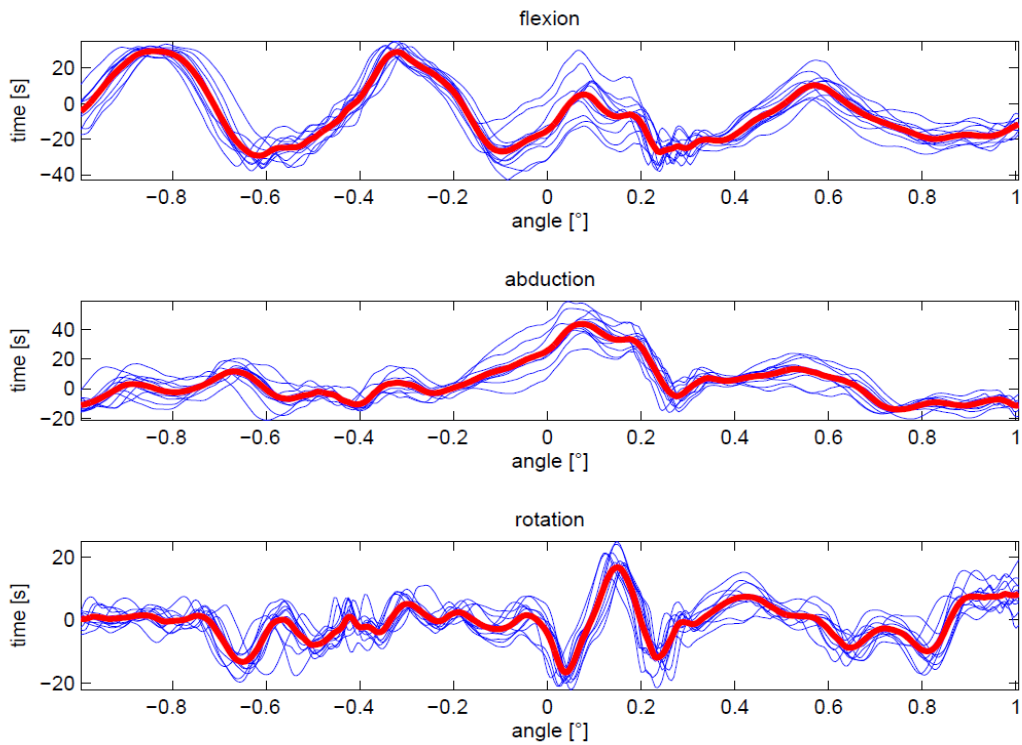
4.3 Movement analysis


The principal researcher's study reports on the kinematics regarding the levers of the thigh and the pelvic area as two independent levers. Therefore, only the gross movements of these two levers around the hip joint area were discussed. Direction of movement was shown, but this does not represent true hip joint movement, as the hip joint centre was not calculated. Therefore to assume true hip joint movement, errors associated with hip joint centre displacement will be shown (Della Croce et al., 1999; Seidel et al., 1995).


For each of the 15 subjects' twelve balls bowled, a graph was done plotting the kinematics over the one second before and one second after BFI (this time encompasses the last second of the run-up and the delivery stride) for the movement planes, sagittal, frontal and axial, therefore flexion/extension, ab-/adduction and rotation of the hip (refer to Appendix H). In previous sports biomechanic research, one trial was chosen as a 'representative trial' for the subjects' movement pattern, but has been shown ineffective (Bauer & Schöllhorn, 1997). Therefore, the average movement for each subject was calculated using frequency domain averaging.

In frequency domain averaging, the time histories of the signals are converted to the frequency domain, and the mathematical average is then taken of all the signals. This mathematical average is converted back to the time domain in order to yield an averaged signal. The reasoning behind opting for this kind of averaging is that the time domain signals are not synchronised, making time domain averaging impossible. In the frequency domain, the signals do not have to be synchronised in order to calculate an average.

Figure 4.5 Kinematics for runs and average



Frequency domain average 

All the other runs 

4.3.1 Intra-subject correlation

The bowling pattern of an individual subject shows a relatively consistent and repeated pattern with linear correlation coefficients as shown in Table 4.7 below.

A linear correlation coefficient between 0.82 - 0.97* for flexion/extension plane, 0.89 - 0.98* for ab-/adduction plane and a slightly lower 0.74 - 0.94* for rotation plane is shown in Table 4.7 above.

*Subject six was not included in the discussion due to much lower intra-subject correlation with coefficients of 0.59, 0.77 and 0.65 for the three planes irrespectively.

Table 4.7 Linear correlation coefficients for patterns between deliveries for each individual bowler

Bowler		Correlation for flexion/extension	Correlation for Ab-/Adduction	Correlation for Rotation
Bowler 1	-	0.93	0.93	0.84
Bowler 2	-	0.97	0.98	0.87
Bowler 3	-	0.85	0.94	0.77
Bowler 4	P	0.86	0.93	0.76
Bowler 5	-	0.92	0.95	0.74
Bowler 6	-	0.59	0.77	0.65
Bowler 7	P	0.92	0.96	0.80
Bowler 8	P	0.91	0.96	0.91
Bowler 9	P	0.90	0.95	0.91
Bowler 10	P	0.95	0.94	0.84
Bowler 11	-	0.96	0.97	0.94
Bowler 12	-	0.92	0.95	0.84
Bowler 13	P	0.92	0.97	0.84
Bowler 14	P	0.82	0.89	0.90
Bowler 15	P	0.85	0.90	0.93

4.3.2 Inter-subject correlation

If consistency across subjects was viewed on the graphs for averages in Appendix H, it showed very little consistency and therefore highly individualised patterns of movement between different subjects. A rain-flow analysis was done on the average bowling pattern of each of the 15 subjects. The amplitudes were broken up into small, medium and large amplitudes and the cycles were then counted and presented in histograms for each subject in Appendix M.

A few of the runs were omitted in the calculation of the averages due to a problem with the signal sampling. These runs were:

Table 4.8 Runs omitted from average calculation due to signal sampling problem

Bowler	Run omitted
Bowler 4	1
	12
Bowler 6	2
	5
	11
Bowler 7	1
	4
	5
	11
Bowler 9	2
Bowler 14	1
	6

The method of rain-flow counting is often used to determine the number of cycles in a time history signal. It is used for example, in mechanical fatigue tests to determine the number of cycles within certain ranges that a component can withstand before failure. In this study, the algorithm is also useful to determine the number of cycles within certain ranges that each bowler performs during his bowling action to illustrate the innate differences in bowling styles.

a. Flexion/extension plane of movement

Amplitudes were classified as being either small (S) (0 - 2.5), medium (M) (5 - 25) or large (L) (25 - 50) for flexion by grouping angles for flexion.

Between one and a half and eight small amplitudes were counted for the eight subjects with symptoms, while between one and three medium and 0-0.5 large amplitudes were counted in the flexion/extension movement plane as seen in Figure 4.6.

Between one and a half and 10 small amplitudes, (more than in the subjects with symptoms) were counted for the seven subjects without symptoms, while between one and a half and three medium and 0-0.5 large amplitudes were counted in the flexion extension movement plane. Appendix L contains tables and graphs showing the minimum and maximum as well as the mean amplitude count for the bowlers for each category of S, M or L amplitudes with and without LBP for the flexion/extension plane.

Table 4.9 A comparison of LBP and kinematics in the flexion/extension plane, represented as total number of amplitudes of movement between bowlers with and without LBP in the season

Variable	LBP (n=8)	No LBP (n=7)	Statistical significance (two tailed p value)
Total number of amplitudes	6.250±2.171	6.642±2.358	p=0.862
Small amplitudes	4.625±2.356	4.429±2.668	p=0.862
Medium amplitudes	1.438±0.320	2.143±0.690	p=0.049*
Large amplitudes	0.1875±0.259	0.071±0.190	P=0.452

*Significantly different p≤0.05

Medium amplitude movements in the flexion/extension plane, show a statistical significance in LBP bowlers compared to bowlers without LBP.

b. Ab-/adduction plane of movement

Amplitudes were classified as being either small (S) (0 - 7.5), medium (M) (7.5 - 20) or large (L) (20 - 85) for flexion by grouping angles for ab-/adduction.

Between four and seven small amplitudes were counted for the eight subjects with symptoms, while between zero and one medium and 0-0.5 large amplitudes were counted in the ab-/adduction movement plane.

Between three and nine small amplitudes were counted for the seven subjects without symptoms, while between zero and one and a half medium and all subjects with half large amplitudes were counted in the ab-/adduction movement plane. Appendix L contains tables and graphs showing the minimum and maximum as well as the mean amplitude count for the bowlers for each category of S, M or L amplitudes with and without LBP for the ab/adduction plane.

Table 4.10 A comparison of LBP and kinematics in the ab-/adduction plane, represented as total number of amplitudes of movement between bowlers with and without LBP in the season

Variable	LBP (n=8)	No LBP (n=7)	Statistical significance (two tailed p value)
Total number of amplitudes	6.313±0.998	5.857±2.0354	p=0.247
Small amplitudes	5.188±1.100	4.643±2.0354	p=0.183
Medium amplitudes	0.688±0.458	0.714±0.488	p=0.954
Large amplitudes	0.438±0.177	0.5±0	p=0.685

(Significance level $p \leq 0.05$, no significant differences)

c. Rotation plane of movement

Amplitudes were classified as being either small (S) (0-4), medium (M) (4-15) or large (L) (15-60) for flexion by grouping angles for rotation.

Between three and six and a half small amplitudes were counted for the eight subjects with symptoms, while between one and two and a half medium and zero and one large amplitudes were counted in the rotation movement plane.

Between four and nine and a half amplitudes were counted for the subjects without symptoms in the rotation plane compared to the three and six and a half small amplitudes for the subjects with symptoms, while between one and three medium and 0-0.5 large amplitudes were counted in the rotation movement plane. Appendix L contains tables and graphs showing the minimum and maximum, as well as the mean amplitude count for the bowlers for each category of S, M or L amplitudes with and without LBP for the rotation plane.

Table 4.11 A comparison of LBP and kinematics in the rotation plane, represented as total number of amplitudes of movement between bowlers with and without LBP in the season

Variable	LBP (n=8)	No LBP (n=7)	Statistical significance (two tailed p value)
Total number of amplitudes	6.938±1.568	8.500±1.979	p=0.1862
Small amplitudes	4.813±1.438	5.571±2.009	p=0.452
Medium amplitudes	1.625±0.518	2.286±0.636	p=0.049*
Large amplitudes	0.5±0.378	0.286±0.267	p=0.297

*Significantly different p≤0.05

Medium amplitude movements in the rotation plane show a statistical significance in LBP bowlers compared to bowlers without LBP.

4.4 ROM analysis

No significant differences between groups with LBP and without LBP were found in the three passive hip ROM measurements.

Table 4.12 A comparison of LBP and hip range of motion between bowlers with and without LBP in the season

Variable	LBP (n=8)	No LBP (n=7)	Statistical significance (Two tailed p value)
Hip medial rotation (front foot side)	37.9±6.9	33.7±9.3	p=0.248
Hip medial rotation (back foot side)	30.5±8.4	31.5±10.3	p=0.916
Hip lateral rotation (front foot side)	50.3±5.8	58.3±11.1	p=0.165
Hip lateral rotation (back foot side)	53.5±7.4	56.6±11.6	p=0.643
Total hip rotation (front foot side)	88.2±8.8	92.2±17.6	p=0.817
Total hip rotation (back foot side)	84.0±4.4	88.6±13.1	p=0.908
Hip extension (front foot side)	13.3±6.7	14.8±5.9	p=0.524
Hip extension (back foot side)	11.7±4.5	14.3±4.6	p=0.093

Range of motion in degrees (Significance level $p \leq 0.05$, no significant differences)

Chapter 5: Discussion

This study describes the three dimensional front foot hip kinematics and how it relates to lower back injuries in adult male fast bowlers, playing first league cricket in the Western Province region. This is the first study presenting three-dimensional data of hip kinematics in fast bowlers, utilising a portable device (XSENS) that transmits its data via 3G technologies. At the onset of the study, no published studies had been done on hip joint kinematics in cricket, despite calls to improve the scientific research into sport injury mechanisms (Bartlett, 2003).

The descriptive cross-sectional study in question further discusses the severity and nature of lower back injuries experienced by cricket fast bowlers, as well as their training and bowling history.

5.1 Kinematics

It has proved to be very difficult to improve the understanding of the front foot hip biomechanics in cricket fast bowlers. In this study, describing front foot kinematics of fast bowlers in cricket was limited to describing intra- and inter-subject correlation and to a superficial discussion of the possible trends in frequency and amplitude size of movement in the three anatomical planes.

5.1.1 Intra-subject correlation

The findings demonstrated relatively good intra-subject correlation (Section 4.3.1) in the laboratory setting of this study. The controlled environment of the indoor facility in which the

testing took place (Section 3.6) meant no changing weather conditions. Furthermore, clear instructions were given to enable subjects to complete the task in this study (Section 3.10). In addition, the 12 trials of each subject were also captured consecutively without other activities in between trials and there was no contending batsman at the crease. The demand for functional variability and adaptation to changing informal constraints, which exists in the performance environment (Davids et al., 2003; Thies et al., 2005) as shown in other skilled movement patterns (Arutyunyan et al., 1968; Scholz et al., 2000), was therefore lowered in this study.

There is still limited insight into the relationship between consistency of performance and injury occurrence. Thus, more future research into the variability of movement is required.

5.1.2 Inter-subject correlation

Performance enhancement research and implementation of strategies to improve sporting outcomes has become an important subject in sport (Baudouin & Hawkins, 2004). This is probably due to the increase of professionalism in sport. Sports performance studies (Brisson & Alain, 1996) aim to utilise existing knowledge in kinematics pertaining to sporting techniques, in order to train proper techniques for performance enhancement in the sport (McGill, 2001; Portus et al., 2004). This particular frontier in sports performance science has become progressively more popular due to advances in technology and the implementation of concepts derived from dynamical systems theory in the last few years (Davids et al., 2003). The drive by researchers to understand 'common optimal movement patterns' in sports performance remains challenging (Bennett, 2003). Kinetic variability of the lumbar spine has been noted by

researchers (Ferdinands et al., 2009). Movement of the proximal body segment, the lumbar spine, will influence the movement in the other joints of the kinetic chain (Atwater, 1979; Elliott, 2000). Thus, differences in hip kinematic patterns can be expected in bowlers performing the same task (Temprado et al., 1997). It could be reasoned that hip ROM, as well as certain kinematic parameters in the hip, will also influence the more proximal lumbar spine's kinematic variability (Burnett et al., 1998; Elliott, 1999) in the same way in the closed chain action of cricket fast bowling.

Variability in movement patterns remains under-researched by sports biomechanics (Bartlett et al., 2007). The findings of this study demonstrated poor inter-subject correlation in kinematic patterns of the hip between different fast bowlers participating in the study (Section 4.3.2). The highest variability existed in the small amplitude movements as seen in Tables 4.7 - 4.9, representing the finer motor control that influences individual bowling technique and timing. Therefore, the hip kinematics between cricket bowlers was very variable. Movement seems to be distinct and it is influenced by factors such as individual cognitive motor control patterns, personal attributes and environmental aspects (Davids et al., 2003). The profile of the fast bowlers in this study differed with respect to age when subjects started playing cricket, training methods and styles, bowling load and warm-up strategies (Section 4.1). These factors may explain the inter-subject variation noted between the players.

The findings of published research into three-dimensional motion analyses of sporting activities demonstrated similar results in their findings with respect to the variation in performance between subjects (Winter, 1984). In cricket, Portus et al. (2000) demonstrated significant variation in fast bowling kinematics. Portus et al. (2000) also hypothesised that specific

techniques may be associated with lower back injury among fast bowlers in cricket. This guided researchers to classify three fast bowling styles according to the hip and shoulder separation angles (Elliott et al., 1986). The mixed action is described as an action with higher counter rotation angles between hip and shoulder girdle in the coronal plane ($>40^\circ$) during the delivery stride. This action is associated with lower back injury (Burnett et al., 1998; Foster et al., 1989; McIntosh, 2005). Although this revelation sheds some light on the kinematics in relation to lower back injury, further research is needed to improve an understanding of the biomechanical causal patterns.

5.2 Lower back pain

An objective of this study was to ascertain the severity and nature of lower back injuries experienced by cricket fast bowlers. About 50% of the bowlers in this study reported LBP. Although the number of bowlers included in this study was very small, this finding concurs with published research into the prevalence of lower back injuries which render about 30% of bowlers unable to play cricket due to LBP (Orchard & James, 2002). Foster et al. (1989) also found a LBP prevalence of 38% in lower back injuries among young Australian fast bowlers.

Sports injuries are often defined as injuries or symptoms that result in a loss of playing time (Orchard, 2000). Therefore, loss of playing should be considered in order to understand the severity of the injury. In this study, one quarter of the bowlers reported a loss of playing time which was related to bowling. This finding is in accordance with a study which involved adult cricket players (Orchard et al., 2006). About 30% of the sample in an Australian study by Orchard et al., (2003) reported that they were unable to play cricket. The proportion of players

who are unable to play cricket due to lower back injuries is alarming and further purports the notion that research into the causal mechanisms of lower back pain among cricket players are needed (Ferdinands et al., 2009).

None of the bowlers in this study reported activities of daily living (ADL) disability due to lower back injuries associated with cricket fast bowling (Section 4.2.1a). This finding is not surprising, as published research illustrates that lower back injury sufferers who are physically fit report no or little ADL limitations compared to sedentary individuals (Kuijjer & van der Molen, 2007). Similar results were indicated in a study into women fast bowlers (Stuelcken et al., 2008). Adaptation due to physical exercise or work has shown to strengthen spinal structures (Portus, 1987; Sward et al., 1990) and therefore may be an underlying reason why physically fit people do not struggle with ADL's. In the Stuelcken et al. (2008) study, where about 14 of the 26 bowlers included in the study reported a history of LBP, nine of the bowlers had functional limitations due to LBP. Although it is reassuring that a small proportion of bowlers suffering from LBP experienced functional limitations in performing ADLs, this proportion may increase as the severity and frequency of lower back signs and symptoms intensifies. Furthermore, ADL is not an accurate measure of functional limitation for bowlers to ascertain whether they are unable to compete or perform on the field of play. Therefore, LBP preventative efforts for bowlers should be strongly supported.

5.3 Kinematics of the hip in relation to lumbar spine symptoms

In this study, the front foot kinematics of the hip is described with respect to the direction, frequency and size of movement of two levers – the femur and the pelvic-sacral unit relative to

each other (Section 4.3). This is the first time that the rain-flow analysis is used in biomechanical research, although it has been found to be a useful method for comparing movement data patterns (Amzallag et al., 1994).

Although the movements are broken up into different amplitude sizes in order to simplify the description of movement, a trend of more movement amplitudes in bowlers without symptoms than those with symptoms in the lower back, exists. Previous research done into motor learning also indicated that more skilled performers can unfreeze the joint biomechanical degrees of freedom and therefore produce more complex movements compared to unskilled performers who tend to simplify movement by freezing a certain link, or joint in the kinetic chain (Newell & Vaillancourt, 2001). The performance might become less skilled when influenced by pain or injury. Work by Davids et al. (1999) on anterior cruciate ligament (ACL) postural strategies also showed less movement, or postural sway in ACL-deficient subjects than controls. Both these studies therefore link well with this study's finding of more movement in unaffected subjects.

5.3.1 Hip flexion and extension

In the sagittal plane, bowlers without LBP had more amplitude during the bowling action, especially in medium amplitude movements (statistically significant), compared to bowlers with LBP (Table 4.9). Although this is a very small sample and definitive conclusions cannot be reached, this trend might suggest that the pelvic tilt movement, that constitutes hip flexion/extension, might be under-utilised by the bowlers with LBP. The limited flexion and extension movement may be due to loss of perception of this movement. This study indicates

that movement is lost due to under-utilisation and eventual passive ROM loss in bowlers with LBP compared to those without LBP as seen in Table 4.12. Small precision movements have been associated with higher skill levels of sportsmen (Scholz et al 2000). This could suggest that these small corrective movements in subjects with LBP might be inhibited due to delayed feedforward proprioception loss similar to ACL postural sway studies (Davids et al., 1999).

The findings related to limited flexion and extension movements noted among low back pain, may also indicate muscle inhibition (Yerus et al., 2002), delayed firing (Leinonin et al., 2000) and/or poor endurance of the gluteus maximus (Steulcken et al., 2008).

5.3.2 Hip adduction and abduction

The amplitude count in the frontal plane of movement was higher for the bowlers without symptoms than the bowlers with symptoms (see Figure 4.7). This difference could be an indication of poor neuromuscular control of hip abduction in sporting movements which require high speed involvement of the hip abductors in causing LBP (Johnson, 1999). Hip abductors, together with the quadrates lumborum muscle, are crucial for postural stability in mid-stance of gait. The same stability with increased demands will be needed for the front foot impact phase of bowling. Therefore, if the movement patterns are disturbed it could leave the lumbar spine vulnerable to the development of lumbar symptoms. No statistically significant differences were found in comparing the kinematics in this plane between bowlers with and without LBP.

5.3.3 Hip internal and external rotation

The frequency of small and medial (statistically significant) amplitude movements in the rotation plane of movement was higher in bowlers without symptoms than those with pain (Table 4.9). This could be an indication of poor neuromuscular control, hip muscle imbalance and reduced proprioception in the lumbar spine. These differences in the kinematics could be due to compensation mechanisms to protect the lumbar spine structures. One of the reasons could be limited ROM, preventing movement over the injured site. This could be due to muscle spasm or co-contraction of opposing muscle groups (Lundt et al., 1991). A component of abduction muscle in the study by Johnson included the rotation component and therefore will also alter kinematics in this plane (Johnson, 1999).

Motion analysis studies have illustrated that back pain is related to changes in the kinematics and coordination of the lumbar spine and hips (Esola et al., 1996; Shum et al., 2005). A study by Dennis et al. (2008) stressed the importance of further investigation into hip joint kinematics.

5.4 Hip ROM in relation to lumbar spine symptom

Although decreased hip mobility could alter mechanical forces transmitted to the lumbar spine and therefore predispose or be a causative factor in LBP development, this study found no significant relation between these parameters. The sample size was very small in this study which will influence the validity of results (Table 4.12). Although previous studies found that limitation in hip ROM correlates with LBP symptoms, Harris Hayes et al. (1999) presented a few confounders such as: activity demand, LBP classification and gender that might explain other studies with contradicting findings (Ellison et al., 1990). These factors postulate that people

who place repetitive demands on hip rotation have a limitation in ROM and will increase their chance of developing LBP.

5.4.1 Hip extension ROM

Anterior hip capsule tightness leads to decreased hip extension and this has been linked with gluteus maximus weakness due to an inhibitory athrokinetic reflex (Yerus et al., 2002). Mackay and Keech (1988) hypothesised that anterior hip tightness can cause anterior rotation of the pelvis and increased lumbar lordosis on the lumbar spine. This study indeed shows (Table 4.12) a decrease in passive hip extension ROM in bowlers with LBP compared to those without, even if it is not statistically significant. This might be a causative factor for LBP experienced by cricketers. Steulcken et al. (2008) demonstrated a lower lifetime incidence of LBP for women fast bowlers compared to their male counterparts. This may be related to the larger hip range of movement among females (Steulcken et al., 2008). It may be hypothesised that the gluteus maximus of the female fast bowlers in Steulcken et al.'s study might be less influenced by the inhibitory athrokinetic reflex due to anterior tightness as shown in the Yerys et al. (2002) study. It could therefore be suggested that male fast bowlers are more likely to sustain lower back injuries compared to women bowlers due to less passive hip extension ROM (Steulcken et al., 2008). In contrast, Nadler and Malanga (2000) indicated that injury surveys across a wide range of sport in the USA, demonstrated that female athletes are twice as vulnerable to develop LBP compared to men. Further research is thus warranted to explore this gender issue in cricket. The gluteus maximus must further stabilise the hip on the pelvis in weight-bearing movements such as fast bowling (Nadler et al., 2002). Imbalances between left and right hip extensors have

also been demonstrated in relation to LBP by the research of Hewett et al. (1996) and Nadler et al. (2000). If the front foot of fast bowlers is the non-dominant side of the bowler, weakness will greatly influence LBP development, if taking into account that front foot impact constitutes the period of highest force transmitted through the kinetic chain (Ferdinands et al., 2009). However, further research into this area is needed to determine cause-effect in dynamic three-dimensional kinematic studies, as most of the studies utilise very specific and isolated biomechanics parameters (Nadler & Malanga, 2000).

Running forms a major part of the bowling action, since the largest part of the bowling action is spent in the run-up phase. Although this part does not constitute the instance of highest impact forces on the lumbar spine, injuries to the lumbo-pelvic-hip complex constitute around 14% of all injuries sustained to runners (Benell & Crossley, 1996). Anterior pelvic tilt or increased lumbar lordosis will be evident in bowlers as has been shown in runners (Schache et al., 2000), as limited hip extensor ROM increases repetitive forces on the vertebral facets and other posterior structures in the lumbar spine. This is therefore a further parameter that cannot be overlooked when examining the sagittal plane movement pertaining to hip extension ROM deficits.

It will be worthwhile to investigate hip extension ROM with a bigger sample size to increase the validity of this study results, as it could be of value to the prevention and treatment of LBP in cricket fast bowlers.

5.4.2 Hip rotation ROM

Hip rotation ROM on the ipsilateral leg (front foot) is regarded to be a predisposing factor for injury in male fast bowlers (Dennis et al., 2008). This study shows a statistically non-significant decreased total hip rotation on the front foot side (Table 4.9) with medial rotation increased and lateral decreased. Results on this matter are therefore inconclusive. Stuelcken et al. (2008) postulated that decreased hip mobility in male fast bowlers compared to their female counterparts, might be a factor dictating a higher lifetime incidence of LBP in male fast bowlers. Investigating hip rotation ROM with a bigger sample size to increase the validity of these study results, could be of significant value to the prevention and treatment of LBP in cricket fast bowlers.

5.5 The XSENS equipment

The XSENS system also has the capability to synchronise analog voltage recording measurements, for example ground reaction forces (GRF) with a force plate or Electromyography (EMG), to further investigate torque forces as well as muscle recruitment patterns. However, these functions were not used in the current study.

Chapter 6: Conclusion, limitations and recommendations

The prevalence of low back pain(LBP) among South African cricket players is high (Stretch, 2003).

This is the first study which utilised a portable, wireless motion analysis system to analyse the hip kinematics during the bowling action in cricket fast bowlers. The findings of this study demonstrate good intra-subject correlation of the foot-hip kinematics during the bowling action, but poor inter-subject correlation. In addition, the findings of the study in question also provide data which may indicate that there is a correlation between front foot hip kinematics and LBP. These findings provide an impetus for further research by sports scientists to improve understanding of the association between the biomechanical risk factors and LBP experienced by cricket fast bowlers.

6.1 Limitations and recommendations

6.1.2 The facility

Difficulties with booking the WPPC were encountered during the study due to lack of funding. A double-booking was made by the club on the second testing opportunity and seven bowlers had to be cancelled on short notice. Of these seven bowlers, three did not arrive for their next testing opportunity and two could not reschedule another convenient testing date. Five of the bowlers were therefore lost to the study, adding to the sample bias as discussed in the previous section. Another week in March set out for testing had to be cancelled due to other bookings in

the facility. No bookings were made with bowlers for these testing dates, but valuable time was lost that the researcher and engineer had set aside for this purpose.

6.1.2 Demographic information and sample description

The random selection of the clubs and consequent contacting of all the first league fast bowlers provided a sample of convenience and may have introduced a certain degree of bias. It provided subjects from similar lifestyle and socio-economic backgrounds who were not necessarily representative of the entire population. The availability and trustworthiness of bowlers posed a major barrier to the execution of this study. Random selection should therefore be attempted in future studies to reduce selection bias.

6.1.3 Instrumentation

The reliability and validity of the measurement tool used to assess the severity and nature of the lumbar spine symptoms was not validated due to the scope of this project. No radiological information or medical records were obtained to provide insight into the nature and severity of LBP symptoms. Therefore, lumbar symptoms were self-reported and collected by a retrospective design, creating the potential for recall bias.

In larger, future studies, the questionnaire should be validated for the local cricket population and findings from lumbar investigations should be considered.

The data obtained by the XSENS system only allowed the analysis of frequency and size of amplitudes of the movement cycle. Although the system is advantageous as it is portable and wireless, further development of the system is required. Further research, employing a more widely used biomechanical system may be beneficial to continuing studies, as it will enable the

analyses of movement patterns of the hip joint in degrees of movement. The clinical application of the findings may then also be enhanced.

6.1.4 Kinematic analysis

The hip joint centre was not calculated in this study. Therefore, some of the difficulty to describe true hip joint kinematics, rather than the limited kinematic parameters pertaining to direction as described in section 6.1.3, was not possible. It follows that the difficulty in analysing the kinematic data can partly be due to error propagation (Cappozzo, 1991; Kadaba et al., 1990).

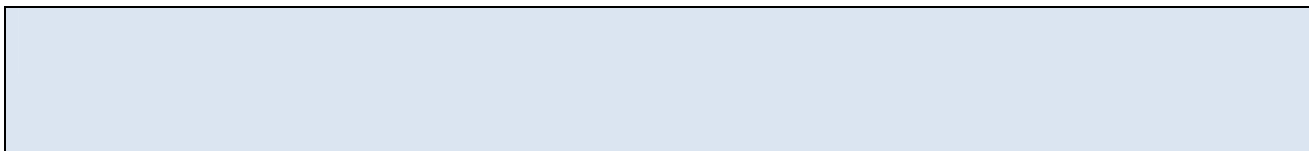
The manual time-switch utilised in the study did not provide sufficient data to determine bowling phases, as it only provided a point of reference for the onset of the delivery stride. Although kinematic measures elsewhere in the kinetic chain have been used in cricket to determine phases of movement as seen in the study of Aginsky (2010), this study lacked positional orientation of the rest of the kinetic chain. With only the hip kinematics measures, the researcher was unable to precisely determine the bowling phases that followed BFI and FFI. Proposed anatomical landmarks, as well as anatomical systems of axes, have also been proposed by Capozzo et al. (1995). The experimental protocol described by these authors for a standardised representation of kinematic data might be useful in future research in this field.

6.1.5 Statistical analysis

Although a statistical significance was found in the kinematic patterns in the flexion/extension plane of movement and no other statistical significant comparisons were made in ROM or

kinematic parameters between the LBP and no LBP group, the small sample size will influence the validity of the results due to sample bias.

APPENDIX A



Island View 52
Lapaloma Avenue
Big Bay
Cape Town
7441
March 15, 2007

To Whom It May Concern:

CRICKET RESEARCH PROJECT

I am currently a postgraduate master's student registered with the Department of Physiotherapy at Stellenbosch University. My research project will be conducted in the field of biomechanics in cricket. I have been involved as a health care professional with cricketers from school- to international level for four years now.

My reasons for this study stems primarily out of my passion for this sport and a shared frustration from working with fast bowlers in the rehabilitation of lower-back injury. As you are, no doubt, well aware, lower-back injury in fast bowlers is of major concern to all of those of us who are involved with the sport of cricket. The impact of these injuries is apparent in the unavailability of affected players for matches, as well as in their need to retire early from the sport. As researchers in this field, we aim to provide appropriate solutions for this dilemma.

The target group of this study is fast bowlers of the Western Province First League. My results will, accordingly, represent this group of cricketers and, therefore, should benefit this group in term of the findings that I make. Benefits to bowlers to emerge from being part of this study stand to include:

- having a physiotherapist with experience in the field of cricket look at possible risk factors in individual's actions relating to potential lower-back injury; and
- gaining access to a hand-out with a pre-season lower back exercise programme based on previous research for every participant involved in this study, which will enable him to strengthen his back and so reduce the chance of his being injured in the coming season. The programme will include back care instruction, as well as appropriate stretches and exercises; and
- a free posture analysis and sport massage at Sports Science Physiotherapy Centre
- being of wider benefit to the population as a whole by investigating these parameters, knowledge will be gained regarding the underlying factors that might cause injury to the lower

back. Such knowledge will facilitate the devising of future lower- back injury prevention programmes in the field of cricket.

- Ultimately, we may then lose fewer outstanding fast bowlers due to lower-back problems.

Your club has been randomly selected to form part of this study to be conducted at your cricket club at the second half of the 2006/2007 season during March and April of this year. All the fast bowlers in your club are therefore invited to participate in this research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the researcher any questions about this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is entirely voluntary and you are free to decline to participate. If you say no, this will not affect you negatively in any way. Bowlers are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the Committee for Human Research at Stellenbosch University and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

WHAT IS THIS RESEARCH STUDY ALL ABOUT?

- 30 fast bowlers will participate in this study.
- The aim of the study is to describe the mechanical actions at work within the body during the delivery stride in relation to lower back problems in fast bowlers, thereby contributing to further understanding of the causes of these lower back injuries.
- The procedure for this study will include completing a questionnaire, measuring hip movements with a camera and, filming of the bowlers from an over-head two-dimensional video camera while collecting information about hip movements via a three-dimensional tracking system attached to the hip and leg.
- All the participants in the study will undergo the same testing procedure.

WHAT WILL YOUR RESPONSIBILITIES BE?

- Provide contact information for all the fast bowlers aged 18years and older who have bowled in the first and second league for your club in this season. (see attached form)
- Send ASAP please

WHAT WILL BOWLERS RESPONSIBILITIES BE?

- You will be asked to complete a questionnaire to provide information about your lower-back symptoms, your bowling and your training. This will take approximately 28minutes.
- You will be requested to follow a warm-up routine of 12 minutes.
- Some hip measurements will be taken with a camera taking approx 12 minutes.
- You will then be instructed to bowl a spell consisting of seven consecutive overs in just less than 80 minutes. Two of these overs will be filmed and tracked with the research equipment.
- The rest of the overs will be bowled in the practice net with four-minute active resting periods in between each over. You will complete a fielding drill, explained in writing in these rest periods in order to simulate match conditions in the laboratory environment.

WHO WILL HAVE ACCESS TO YOUR TEST RESULTS?

- The information collected will be treated as confidential and results will possibly be published in a journal. It will be included in a thesis and possibly in a professional journal without disclosing the identities of the participants.

ARE THERE IN RISKS INVOLVED IN YOUR TAKING PART IN THIS RESEARCH?

- You will encounter a similar risk of injury as with bowling a six over spell. The risk is reduced because of the laboratory environment.

WILL YOU BE PAID TO TAKE PART IN THIS STUDY AND ARE THERE ANY COSTS INVOLVED?

Players will not be paid to take part in the study but your transport costs will be covered for each study visit. There will be no costs involved for them, if they do take part.

IS THERE ANY THING ELSE THAT YOU SHOULD KNOW OR DO?

Please complete the form attached to this letter if you agree to participate in this project.

I shall phone you within the coming week to make an appointment with you regarding the gathering of this information.

I shall be responsible for the rest of the work to be done for the project, starting with setting up an appointment with each player for his testing to be done at club

Thank you so much for assisting me in this matter. Should you require feedback and results emanating from this research, please contact me at the e-mail address that I provide below.

Sincerely,

Merike Hopkins

(merikehop@yahoo.com)

APPENDIX B

INVITATION PHONECALL SUBJECT

Fast Bowler Name:					
Age:		First League:	Yes	No	
Telephone(H)		Telephone(W)		Cell	

1 Good morning/afternoon (Name) you have been elected to participate in a cricket study conducted through Stellenbosch University at the Western Province Cricket Club

2 Are the following contact information correct and the best way to get hold of you?

Yes No

3 Can you also provide me with you address an e-mail address?

Yes No

4 Have you been informed of this study by your club?

Yes No

5 Can I provide you with further information on- and advantaged of partaking in this study?

Yes No

6 Advantages of participating in the study:

- having a physiotherapist with experience in the field of cricket look at possible risk factors in your individual bowling action and muscle contraction patterns, relating to potential lower-back injury;

- being of wider benefit to fast bowlers in general by investigating these parameters, knowledge will be gained regarding the underlying factors that might cause injury to the lower back. Such knowledge will facilitate the devising of future lower- back injury prevention programmes in the field of cricket. Ultimately, we may then lose fewer outstanding fast bowlers due to lower-back problems. and
- Gaining access to a pre-season lower back exercise programme based on previous research, which will enable you to strengthen your back and so reduce the chance of being injured in the coming season. The programme will include back care instruction, as well as appropriate stretches and exercise

7 The study will take place in February and March of this year. You will be required to attend one of the testing opportunities which will take approximately 2 hours on one weekday during this time. Study opportunities start at 11h00, 18h00, 19h34 or 20h06. Will you be available over this time?

Yes No

What would be expected of you?

8 You would be expected to bowl seven overs of which two will be filmed and analyzed.

9 A questionnaire will be filled out after completing you last ball.

10 Can I count on you to form part of this study?

Yes No

11 Have you represented your club in the first league this season?

Yes No

12 What is your birth date?

13 Are you a registered cricket player with the Western Province Cricket Union?

Yes No

14 Are you suffering from an illness that prevents you from playing cricket currently?

Yes No

15 Are you suffering from any injury that prevents you from playing cricket currently?

Yes No

16 Are you suffering from pain or discomfort in your lower back that prevents you from playing cricket currently?

Yes No

17 Can we make a provisional appointment for this time? (This is necessary to organize transport for you and to book the laboratory in advance.)

Yes No

18 Please be so kind to inform me of any problems with you keeping this appointment as soon as possible.

19 Can I provide you with my contact information, should you have any queries.

Yes No

20 My telephone number is 083 450 0398

21 My e-mail address Merikehop@yahoo.com

22 I will send you more information on the study and a copy of your time schedule for your appointment date.

23 I will phone again to confirm this appointment a week prior to your appointment!

24 Please dress appropriately for bowling. Shoes etc.

25 Thank you for your time and cooperation in this matter.

APPENDIX C

Lower Back Questionnaire

Please fill out the questionnaire to the best of your ability

(Feel free to direct questions at the researcher that is present)

A Personal information:

Club:	
Name:	
Occupation:	
Telephone (w)	
Telephone (h)	
Cell Phone	
Age:	



(Mark relevant block with X e.g.)

1. What is your highest level of playing cricket currently?

Club

Provincial

National

2. Indicate whether you are a right- or left hand bowler.

Right

Left

B Bowling history:

At what age did you start to play cricket?

 Years



How many years have you been a fast bowler?

Years

Do you currently keep a log book on bowling?

Yes

No

(If Yes please complete the rest of question 3)

On average, how many days do you bowl per week in-season?

(Include practice and competitions)

Every day

6 days a week

5 days a week

4 days a week

3 days a week

2 days a week

1 day a week



How many balls do you bowl on average in a training session?

- 0-18 balls/ 0-3 overs
- 19-36 balls/ 3-6 overs
- 37-54 balls/ 6-9 overs
- 55-72 balls/ 9-12 overs
- 72 or more balls

3.3 How many overs do you bowl on average spell in a match?

- 0-2 overs
- 3-4 overs
- 5-6 overs
- 7-8 overs
- 9-10 overs
- 11-12 overs
- More than 12

4. Do you warm up before bowling spells?

Yes

No

(If Yes, please complete question 4.)

Which of the following components is included in your bowling warm-up routine?

Running

Stretching

Bowling simulation

How long before your bowling spell starts do you start warming up?

Before innings

3-4 overs

2-3 overs

1-2 overs

In over before first delivery



C. Conditioning and other Training History.

1 How often do you do specific cricket training with or without the team?

	Days per week						
	1	2	3	4	5	6	7
Batting	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Fielding	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Bowling	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

2 Do you do any other type of training currently in season?

Please indicate

- Yes
- No

(If Yes please complete question 2.)



2.1 Is weight training included in your routine?

Yes

No

(If Yes, please complete question 2.1.)

2.1.1 What type of weight training do you do, and how often?

	Days per week						
	1	2	3	4	5	6	7
Free weights	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Body weight	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Theraband	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



2.1.2 How long is a training session?

- 15-30 minutes
- 30-45 minutes
- 1 hour - 1 hour 15 min
- 1 hour 15 minutes +

2.2 Is cardio vascular training included in your routine?

- Yes
- No

(If Yes, please complete question 2.2.)

2.2.1 What type of cardio-vascular training is included in your weekly training routine?

	Days per week						
	1	2	3	4	5	6	7
Cycling	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Running	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Swimming	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Other sport	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



2.2.2 How long is a training session?

- 15-30 minutes
- 30-45 minutes
- 1 hour - 1 hour 15 min
- 1 hour 15 minutes +

2.3 Do you do core training as part of your training routine?

- Yes
- No

(If Yes, please complete question 2.3.)

2.3.1 How often do you do core training?

		Days per week						
		1	2	3	4	5	6	7
By myself		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Supervised		<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>



2.3.2 How long is a training session?

- 15-30 minutes
- 30-45 minutes
- 1 hour - 1 hour 15 min
- 1 hour 15 minutes +

3 Did you do any other type of training in pre-season?

- Yes
- No

(If Yes, please continue to question 3.)

3.1 Was weight training included in pre-season routine?

- Yes
- No

(If Yes, please complete question 3.1.)

3.1.1 What type of weight training did you do, and how often?

		Days per week						
		1	2	3	4	5	6	7
Free weights								
Body weight								
Theraband								

3.1.2 How long is a training session?

- 15-30 minutes
- 30-45 minutes
- 1 hour - 1 hour 15 min
- 1 hour 15 minutes +

3.2 Was cardio training included in your routine?

- Yes
- No

(If Yes, please complete question 3.2.)



3.2.1 What type of cardio-vascular training was included in your weekly training routine?

	1	2	3	4	5	6	7
Cycling							
Running							
Swimming							
Other sport							

3.2.2 How long is a training session?

- 15-30 minutes
- 30-45 minutes
- 1 hour - 1 hour 15 min
- 1 hour 15 minutes +





3.3 Did you do core training as part of your training routine?

Yes

No

(If Yes, please complete question 3.3.)

3.3.1 How and how often did you do core training?

	Days per week						
	1	2	3	4	5	6	7
By myself	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Supervised	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

3.3.2 How long is a training session?

15-30 minutes

30-45 minutes

1 hour - 1 hour 15 min

1 hour 15 minutes +



D. Lower Back Symptoms

1 Have you experienced any discomfort or pain in the lower back associated with playing cricket in the past week?

Yes

No

(If Yes, please complete question 1.)

1.1 When did you experience symptoms during or after bowling?

During bowling

After Bowling

All the time (constant)

On and off (unrelated to bowling)





1.2 At which stage of the bowling action do you experience these symptoms?

- Run-up
- In back foot impact phase
- Ball release
- Follow through
- After delivery
- After over in the field
- After spell in the field
- After match

1.3 Was there a gradual onset of these symptoms or is there a specific incident when you first felt it?

- Gradual
- Sudden



1.4 In what time of year did you sustain this injury?

- In season
- Pre-season
- Out of season

1.5 Did you sustain this first injury playing cricket?

- Yes
- No

(If Yes, please complete question 1.5)

1.5.1 Was the specific incident was it associated with a specific
phase of play?

- Bowling
- Batting
- Fielding

1.5.2 If no to the above, did the symptoms prevent you from losing overs or spells that would otherwise be demanded of you?

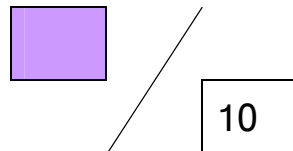
- Not finish an over (Balls lost)
- Not finish a spell (Overs lost)
- Not bowling at all (Spell lost)

1.6 Please indicate symptoms by connecting relevant symptom to the area felt on the body chart below.

Stabbing Pain	
Achy Feel	
Numbness	
Burning Pain	
Dull Pain	
Pins and Needles in back	
Diminished sensation in skin	
Pins and Needles in legs	
Weakness in legs	
Tightness	

1.7 If you had to grade the symptoms out of 10. Where 0 is no symptoms and 10 is worst pain you ever felt

0-----10.



2 Have you experienced symptoms in the lower back while or after playing cricket any time during this season?

- Yes
- No

(If Yes, please complete question 2.)

2.1 How many episodes of onset of lower back symptoms have you had in this season?

- 1 episodes of onset
- 2 episodes of onset
- 3 episodes of onset



2.2 Did you rest due to this injury from any practice or matches?

Yes

No

(If Yes, please complete question 2.2.)

2.2.1 How long did you rest from cricket activities?

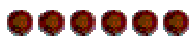
Few days (less than a week)

Few weeks (less than a month)

Few months (not entire season)

Whole season

More than one season



3 Have you experienced symptoms in the lower back while or after playing cricket in the first two weeks of this season?

Yes

No

4 Did the lower back symptoms impact on your life in the following ways? Please indicate?

Unable to perform duties at work

Unable to perform duties at home

Unable to participate in sports or recreation

5 Did you see a health professional for the lower back symptoms

Yes

No

(If Yes, please complete question 5.)

5.1 Please indicate which health-care professional did you see?

- General Practitioner or Sports Physician
- Chiropractor
- Orthopedic surgeon
- Physiotherapist
- Other, Please indicate

5.2 Was any special tests done?

- Yes
- No

(If Yes, please complete question 5.2)

5.2.1 Which tests were done?

- X-Rays
 - MRI-Scan
 - Blood Tests
 - Bone Scan
-

5.3 Was a diagnoses made?

Yes

No

(If Yes please

5.4 Did you receive any treatment?

Yes

No

(If Yes, please complete question 5.4)

5.4.1 If yes, what type of treatment did you receive?

Physiotherapy with machines

Medication

Rehabilitation exercises

Surgery

Massage

Other (Please specify)



E General Health Investigation:

**1 Do you have a history of trauma to the back? E.g. fall or
Motor vehicle accident?**

Yes

No

(If Yes, please complete question 1.)

1.1 How long ago was this incident?

1-2 Weeks

2-4 Weeks

1-2 Months

2-3 Months

3-6 Months

6-12 Months

1-2 Years

2 Years +



1.2 Please state the diagnoses of this traumatic injury if known

2 Do you have any arthritic conditions?

Yes

No

3 Do you suffer from Diabetes?

Yes

No

(Thank you for your time!)

APPENDIX D

ANTHROPOMETRIC MEASURES

Parameter	Measurement
Body mass	kg
Height	cm
ASIS breadth	cm
Thigh length	cm
Mid-thigh circumference	cm
Calf length	cm
Calf circumference	cm
Knee diameter	cm
Foot length	cm
Malleolus height	cm
Malleolus width	cm
Foot breadth	cm

APPENDIX E

1	2	3	4	Time
A				16h44
A				16h48
A				16h52
A				16h56
A				17h00
A				17h04
A				17h08
Q				17h12
Q	A			17h16
Q	A			17h20
Q	A			17h24
Q	A			17h28
Q	A			17h32
Q	A			17h36
Q	A			17h40
W	Q			17h44
W	Q			17h48
W	Q			17h52
W	Q			17h56
①	Q			18h00
X	Q			18h04
②	Q			18h08
②	Q			18h12
②	W			18h16
②	W			18h20
②	W			18h24
②	W			18h28
②	①			18h32
X	X			18h36
③	②			18h40
X	②			18h44
④	②	A		18h48
X	②	A		18h52
⑤	②	A		18h56
X	②	A		19h00
⑥	②	A		19h04
X	X	A		19h08
⑦	③	A		19h12
⑦	X	O	A	19h16
⑦	④	O	A	19h20
⑦	X	Q	A	19h24
⑦	⑤	O	A	19h28
⑦	X	Q	A	19h32
⑦	⑥	O	A	19h36
	X	Q	A	19h40
	⑦	Q	Q	19h44
	⑦	W	Q	19h48
	⑦	W	Q	19h52
	⑦	W	Q	19h56
	⑦	W	Q	20h00
	⑦	①	Q	20h04
	⑦	X	O	20h08
		②	O	20h12
		②	W	20h16
		②	W	20h20
		②	W	20h24
		②	W	20h28
		②	W	20h32
		②	①	20h36
		X	X	20h40
		③	②	20h44
		X	②	20h48
		④	②	20h52
		X	②	20h56
		⑤	②	21H00
		X	②	21H04
		⑥	②	21H08
		X	X	21H12
		⑦	③	21H16
		⑦	X	21H20
		⑦	④	21H24
		⑦	X	21H28
		⑦	⑤	21H32
		⑦	X	21H36
		⑦	⑥	21H40
			X	21H44

			⑤	21H48
			⑤	21H52
			⑤	21H56
			⑤	22h00
			⑤	22h04
			⑤	22h08
			⑤	22h12

Key to symbols:

1, 2, 3, 4: Bowlers to be tested.

Black balls ⑤: Overs in the nets to simulate match conditions.

Red balls ⑤: Overs to be filmed and EMG.

A: Antropometric measurements, Weight and Height

W: Warm up.

X: Fielding drills done by the bowlers between overs

Q: Questionnaires to be filled out.

APPENDIX F

DEELNEMER INFORMASIE BILJET EN TOESTEMMINGS VORM

TITEL VAN DIE NAVORSINGS PROJEK:

'n Beskrywing van Lae-rug Besering en Voorvoet Heupgewrig Kinematika
Gedurende die Boulaksie van Krieket Snelboulers.

VERWYSINGS NOMMER:

HOOF NAVORSER: Merike Hopkins

ADRES: Via Firenze 24
Parklands
Kaapstad

KONTAK NOMMER: 083 450 0398

U word uitgenooi om deel te neem aan 'n navorsings projek. Neem asseblief u tyd om deur die inligting te lees wat die fynere details van hierdie projek verskaf. Moenie skroom om enige vrae aan die navorsers te rig oor enigeiets wat u nie ten volle verstaan met betrekking tot hierdie projek nie. Dit is baie belangrik dat u geheel en al tevrede is dat u ten volle verstaan wat die navorsing behels en dat u weet hoe u betrokke kan wees. Verder is u deelname **heeltemal vrywillig** en is u welkom om die uitnodiging tot deelname van die hand te wys. As u nee sou sê sal daar nie teen u gediskrimineer word nie en dit sal u ook nie op geen manier negatief beïnvloed nie. U sal ook op enige stadium gedurende die studie toegelaat word om te ontrek, selfs al het u ingestem tot deelname.

Hierdie studie is goedgekeur deur die **Komitee vir Mensnavorsing van Stellenbosch Universiteit** en sal in ooreenstemming met die etiese riglyne en beginsels van die internasionale Deklarasie van Helsinki, Suid Afrikaanse Riglyne vir Goeie Kliniese Praktijk en die Mediese Navorsingsraad (MNR) Etiese Riglyne vir Navorsing uitgevoer word.

Waaroor gaan hierdie navorsings-studie?

- *Die doel van hierdie studie is om die meganiese aksies wat in die liggaam plaasvind gedurende die aflewering-tree in verhouding tot lae-rug probleme van snelboulers te beskryf. Hiermee poog ons om by te dra tot 'n verdere begrip vir die oorsake van lae-rug beserings.*
- *Hierdie studie sal by die Sport Science Instituut van Suid Afrika uitgevoer word. 30 Snelboulers sal deelneem aan die studie.*
- *Die procedure vir die studie sluit die invul van 'n vraelys en die verfilming van die boulers met 'n hoë-spoed driedimensionele kamera-sisteem in.*
- *Al die deelnemers aan die studie gaan dieselfde toetsprosedure ondergaan.*

Hoekom word jy uitgenooi om deel te neem?

- *Jou klub is ewekansig vanuit 'n volledige lys van die Westelike Provinsie klubs gekies om deel uit te maak van hierdie studie.*
- *Omdat jou klub gekies is, word al die snelboulers in jou klub uitgenooi om deel te neem.*

Wat gaan jou verantwoordelikhede wees?

- *Daar sal van jou gevra word om 'n opwarmings-roetine van 12 minute te volg.*
- *Daarna gaan jy die instruksie kry om 'n sewe opeenvolgende beurte in ongeveer een en 'n half uur te boul. Twee van hierdie beurte sal verfilm word deur die kameras.*
- *Die res van die beurte sal met aktiewe rusperiodes tussen elkeen in die oefennette geboul word. Om wedstrydkondisies na te boots, sal daar van jou verwag word om 'n veldwerk oefening te doen wat skriftelik aan jou verduidelik sal word.*
- *Hierna sal jy gevra word om 'n vralys te voltooi om sodoende inligting aangaande jou lae-rug simptome, jou boulerie en oefenry te bekom. Dit behoort jou omtrent 28 minute te neem.*

Sal jy voordeel trek deur deel te neem aan hierdie navorsing?

- *Jy sal 'n fisioterapeut met ondervinding in die terrein van krieket hê wat uitkyk vir moontlike risiko faktore in jou individuele boul-aksie en spiersametrekkings patrone wat in verhouding mag staan tot potensiële lae-rug beserings;*
- *Jy sal toegang hê tot 'n pamflet met 'n voor-seisoense lae-rug oefenprogram gebaseer op vorige navorsing. Dit sal jou in staat stel om jou rug te versterk en sodoende jou kans om 'n besering op te doen in die komende*

seisoen verminder. Die program sal rugsorg instruksies, asook geskikte strekke en oefeninge insluit; en

- Jy sal indirek voordeel trek deur 'n wyer voordeel vir snelboulers in die algemeen. Deur hierdie parameters te ondersoek, sal kennis aangaande onderliggende faktore wat tot lae-rug besering mag lei, verkry word. Sulke kennis mag toekomstige lae-rug besering-voorkoming-programme in die veld van krieket fasiliteer.

Is daar enige risiko's betrokke as jy deelneem aan hierdie navorsing?

- *Jy sal 'n soortgelyke risiko van besering teekom as wanneer jy sewe beurte boul. Die risiko is egter minder omdat jy in 'n gekontroleerde labratorium omgewing is.*

Wie het toegang tot jou toetsresultate?

- Die ingesamelde inligting sal konfidensieël hanteer word en die resultate sal mootlik in 'n professionele joernaal gepubliseer word. Dit sal ook in 'n tesis ingesluit wees sonder om die identiteite van die deelnemers te onthul.

Wat gebeur in die onwaarskynlike aangeleentheid van 'n besering as 'n direkte gevolg van jou deelname aan die navorsings-studie?

- *In die onwaarskynlike aangeleentheid van skade aan die persoon as gevolg van nalatigheid aan die kant van die navorser is daar dekking onder die Univeriteit van Stellenbosch met Alexander Forbes Group (Edms) Bpk.*
- *Hierdie toestemming vrywaar die navorser van enige verantwoordelikheid vir beserings wat opgedoen word a.g.v. nalatigheid aan jou kant..*
- *In die onwaarskynlike aangeleentheid waar 'n geringe muskulo-skeletale besering opgedoen is gedurende toetsing, sal die navorser wat self 'n gekwalifiseerde fisioterapeut is, 'n eerste evaluering doen en die toestand eenmalig behandel. Sy sal dan as verdere behandeling geindikeerd is, die nodige verwyssing doen.*
- *Geen vorige beserings sal behandeling ontvang nie.*

Word jy betaal om aan hierdie studie deel te neem en is daar enige kostes betrokke?

Jy word nie betaal om deel te neem aan die studie nie, maar jou vervoerkostes sal gedek word vir jou besoek. Daar sal geen kostes betrokke wees as jy deelneem nie.

Is daar enigeiets anders wat jy moet weet of doen?

- Indien jy aan 'n kondisie lei wat deur fisiese oefening beïnvloed kan word, moet jy moet jou huisdokter of gewone dokter in kennis stel van jou deelname aan hierdie navorsingstudie.
- Indien jy enige verdure vrae het kan jy my, Merike Hopkins kontak by 083 450 0398.
- Jy kan die Komitee vir Mensnavorsing skakel by 021-938 9207 as jy enige kommer of klagtes het wat nie voldoende deur die navorser aangespreek is nie.
- Jy sal 'n kopie van hierdie inligting en toestemming vorm ontvang vir jou eie rekords.

Verklaring deur deelnemer

Deur hieronder te teken stem ek (naam)..... in om deel te neem aan 'n navorsings studie getiteld: 'n Beskrywing van Lae-rug Besering en Voorvoet Heupgewrig Kinematika Gedurende die Boulaksie van Krieket Snelboulers. Ek verklaar dat:

- Ek die informasie en toestemmings vorm, en die geskrewe taal, wat ek vlot kan praat en waarmee ek gemaklik is, gelees het, of dat dit aan my voorgelees is.
- Ek 'n kans gehad het om vrae te vra en dat al my vrae voldoende geantwoord is.
- Ek verstaan dat deelname aan hierdie studie **vrywillig** is en dat nie gedwing word om deel te neem nie.
- Ek mag op enige tydstip kies om die studie te verlaat en dat ek nie gepeenaliseer sal word of dat daar 'n vooroordeel sal wees teenoor my as gevolg hiervan nie.
- Ek mag verder ook voor die einde van die studie gevra word om die studie te verlaat, indien die navorser voel dat dit in my voordeel sal strek, of as ek nie die instruksies van die studie-plan soos ingestem volg nie.

Geteken te (SSISA) op (*datum*)
2006.

.....
Handtekening van deelnemer

.....
Handtekening van getuie

Verklaring van navorser

Ek (*naam*) verklaar dat:

- Ek die inligting in hierdie dokument verduidelik het aan.....
- Ek hom aangemoedig het om vrae te vrae en dat ek voldoende tyd geneem het om dit te beantwoord.

- Ek tevrede is dat hy al die aspekte van die navorsing wat hierbo bespreek word, voldoende verstaan.
- Ek nie 'n vertaler gebruik het nie.

Geteken te (SSISA) op (*datum*)
2006.

.....
Handtekening van navorser

.....
Handtekening van getuie

APPENDIX G

PARTICIPANT INFORMATION LEAFLET AND CONSENT FORM

TITLE OF THE RESEARCH PROJECT:

A Description of Lower-back Injury and Front-foot Hip Joint Kinematics
During the Bowling Action of Cricket Fast Bowlers

REFERENCE NUMBER:

PRINCIPAL INVESTIGATOR: Merike Hopkins

ADDRESS: Via Firenze 24
Parklands
Cape Town

CONTACT NUMBER: **083 450 0398**

You are being invited to take part in a research project. Please take some time to read the information presented here, which will explain the details of this project. Please ask the researcher any questions about this project that you do not fully understand. It is very important that you are fully satisfied that you clearly understand what this research entails and how you could be involved. Also, your participation is **entirely voluntary** and you are free to decline to participate. If you say no, this will not affect you negatively in any way. You are also free to withdraw from the study at any point, even if you do agree to take part.

This study has been approved by the **Committee for Human Research at Stellenbosch University** and will be conducted according to the ethical guidelines and principles of the international Declaration of Helsinki, South African Guidelines for Good Clinical Practice and the Medical Research Council (MRC) Ethical Guidelines for Research.

What is this research study all about?

- *The aim of the study is to describe the mechanical actions at work within the body during the delivery stride in relation to lower back problems in fast bowlers, thereby contributing to further understanding of the causes of these lower back injuries.*

- *The study will be conducted at your cricket club. 30 fast bowlers will participate in this study.*
- *The procedure for this study will include completing a questionnaire, measuring hip movements with a camera and, filming of the bowlers from an over-head two-dimensional video camera while collecting information about hip movements via a three-dimensional tracking system attached to the hip and leg.*
- *All the participants in the study will undergo the same testing procedure.*

Why have you been invited to participate?

- *Your club has been randomly selected from a list of all the clubs in the Western Province to form part of this study*
- *Since your club has been selected, all of the fast bowlers in your club will be invited to participate*

What will your responsibilities be?

- *You will be asked to complete a questionnaire to provide information about your lower-back symptoms, your bowling and your training. This will take approximately 28minutes.*
- *You will be requested to follow a warm-up routine of 12 minutes.*
- *Some hip measurements will be taken with a camera taking approx 12 minutes.*
- *You will then be instructed to bowl a spell consisting of seven consecutive overs in just less than 80 minutes. Two of these overs will be filmed and tracked with the research equipment.*
- *The rest of the overs will be bowled in the practice net with four-minute active resting periods in between each over. You will complete a fielding drill, explained in writing in these rest periods in order to simulate match conditions in the laboratory environment.*

Will you benefit from taking part in this research?

- *You will have a physiotherapist with experience in the field of cricket look at possible risk factors in your individual bowling action that might relate to potential lower-back injury;*
- *You will gain access to a handout with a pre-season lower back exercise programme based on previous research, which will enable you to strengthen your back and so reduce the chance of being injured in the coming season. The programme will include back care instruction, as well as appropriate stretches and exercises; and*
- *You will benefit indirectly because of a wider benefit to fast bowlers in general. By investigating these parameters, knowledge will be gained regarding the*

underlying factors that might cause injury to the lower back. Such knowledge will facilitate the devising of future lower- back injury prevention programmes in the field of cricket.

Are there in risks involved in your taking part in this research?

- *You will encounter a similar risk of injury as with bowling a seven over spell. The risk is reduced because of the laboratory environment.*

Who will have access to your test results?

- The information collected will be treated as confidential and results will possibly be published in a journal. It will be included in a thesis and possibly in a professional journal without disclosing the identities of the participants.

What will happen in the unlikely event of some form injury occurring as a direct result of your taking part in this research study?

- *In the unlikely event of damage to the person as a direct result of negligence on the part of the researcher, their will be cover under the University of Stellenbosch with Alexander Forbes Group (Pty) Ltd.*
- *With this I give consent and indemnify the researcher from the responsibility for any injuries I sustain as a result negligence on my part.*
- *In the unlikely event of a sustaining a minor musculo-skeletal injury during testing the researcher, a qualified physiotherapist, will conduct an initial assessment and treat the condition once, after which the subject will be referred for further treatment if indicated.*
- *No previous injuries will be treated.*

Will you be paid to take part in this study and are there any costs involved?

You will not be paid to take part in the study but your transport costs will be covered for each study visit. There will be no costs involved for you, if you do take part.

Is there any thing else that you should know or do?

- You should inform your family practitioner or usual doctor that you are taking part in a research study if you suffer from a condition that might be influenced by physical activity.
- You can contact me Merike Hopkins at 083 450 0398 if you have any further queries.
- You can contact the Committee for Human Research at 021-938 9207 if you have any concerns or complaints that have not been adequately addressed by the researcher
- You will receive a copy of this information and consent form for your own records.

Declaration by participant

By signing below, I agree to take part in a genetic research study entitled: A Description of Lower-back Injury and Front-foot Hip Joint Kinematics Involved in the Bowling Action of Fast Bowlers Playing First League Club Cricket in the Western Province

I declare that:

- I have read or had read to me this information and consent form and it is written in a language with which I am fluent and comfortable.
- I have had a chance to ask questions and all my questions have been adequately answered.
- I understand that taking part in this study is **voluntary** and I have not been pressurised to take part.
- I may choose to leave the study at any time and will not be penalised or prejudiced in any way.
- I may be asked to leave the study before it has finished, if the study doctor or researcher feels it is in my best interests, or if I do not follow the study plan, as agreed to.

Signed at (SSISA) on (date)
2007.

.....
Signature of participant

.....
Signature of witness

Declaration by investigator

I (name) declare that:

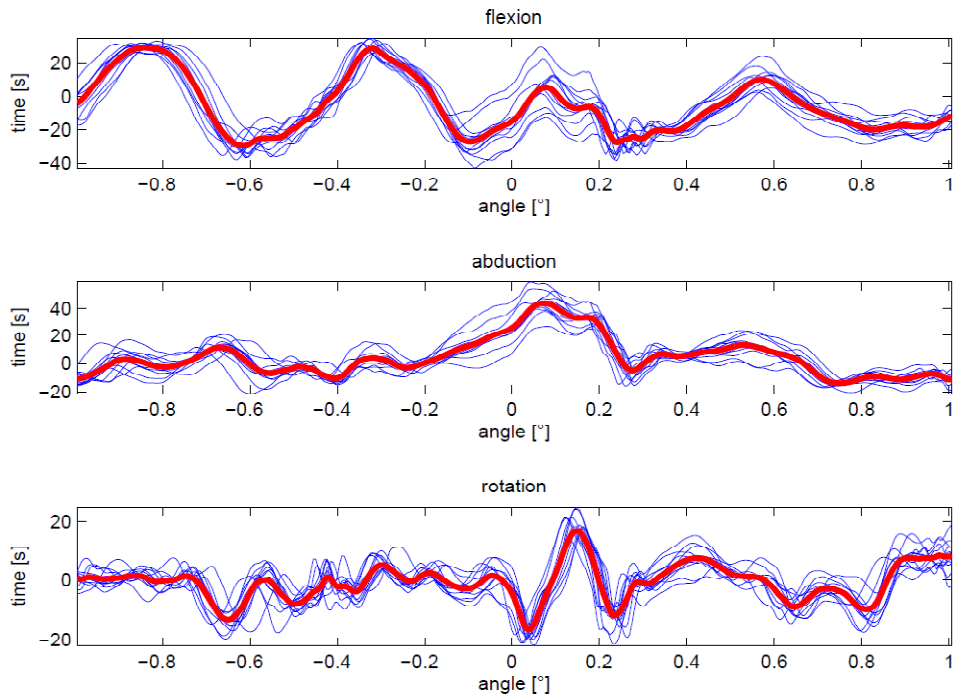
- I explained the information in this document to
- I encouraged him/her to ask questions and took adequate time to answer them.
- I am satisfied that he/she adequately understands all aspects of the research, as discussed above
- I did not use a translator.

Signed at (place) on (date) 2007.

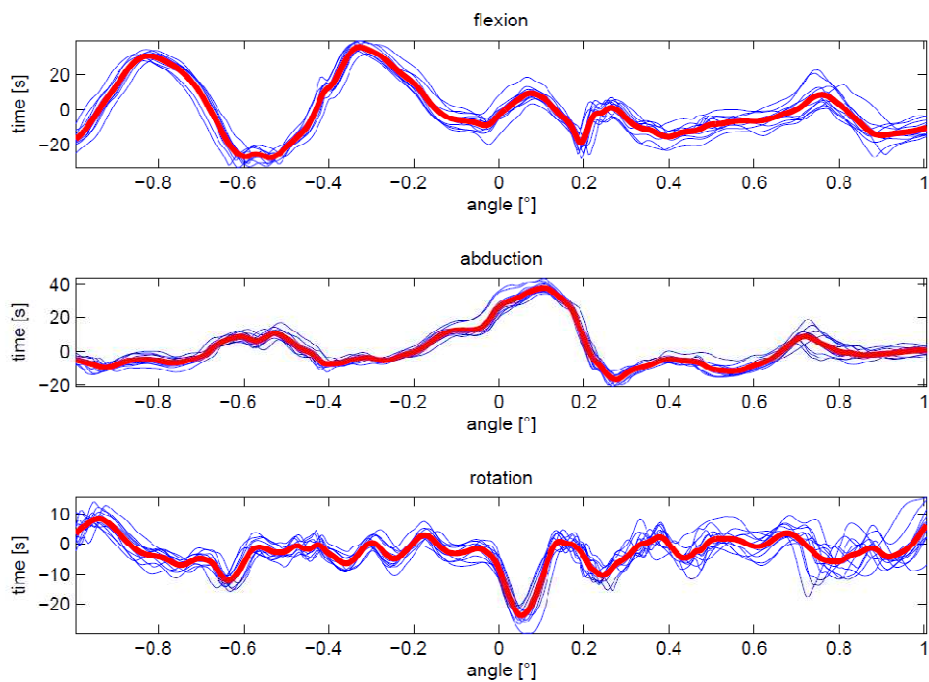
.....
Signature of investigator

.....
Signature of witness

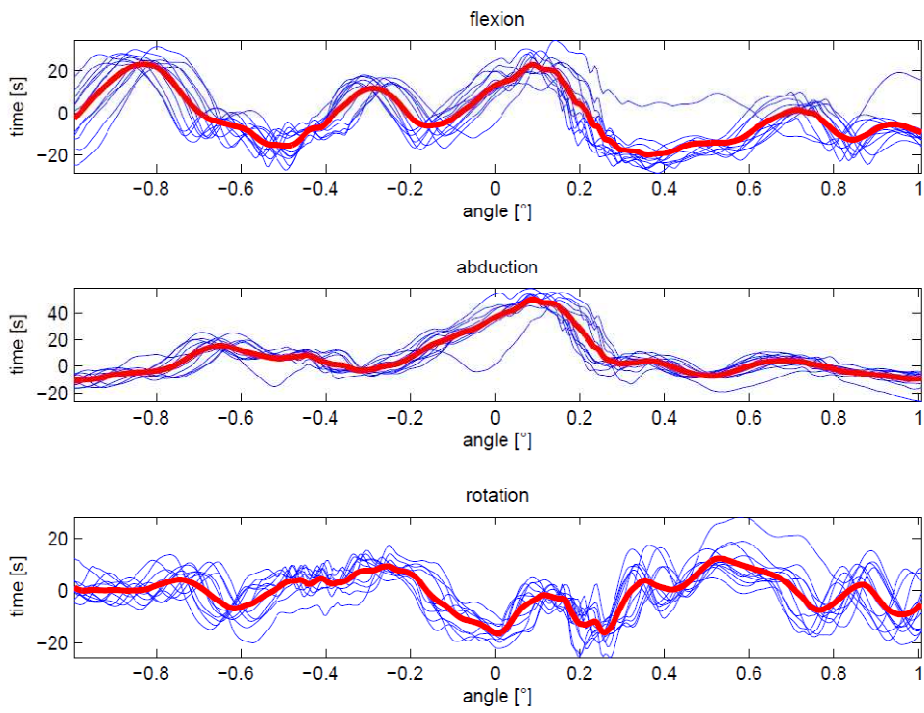
APPENDIX H



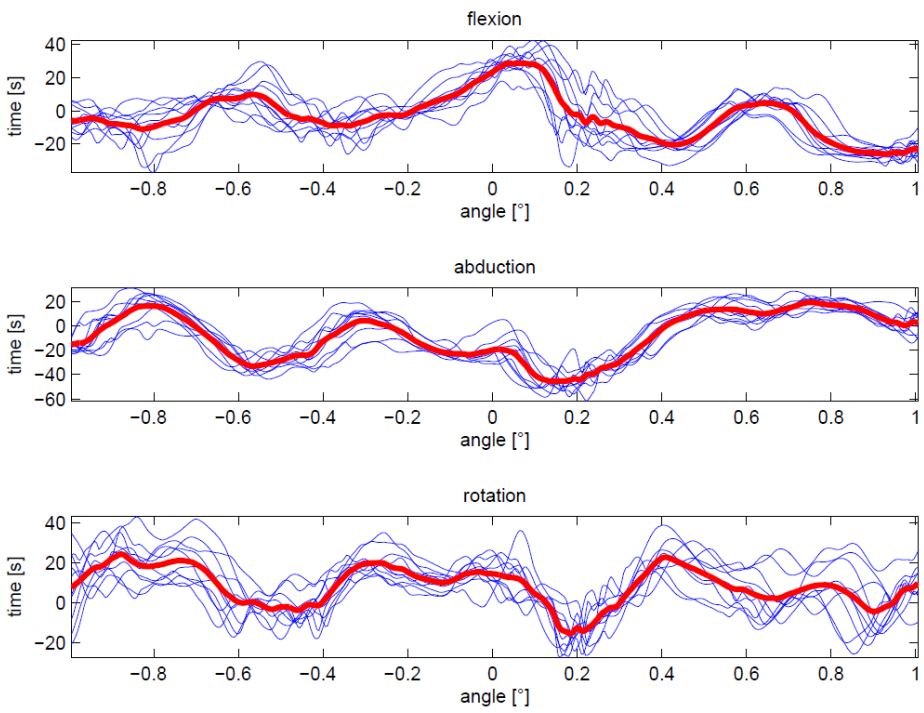
Bowler 1



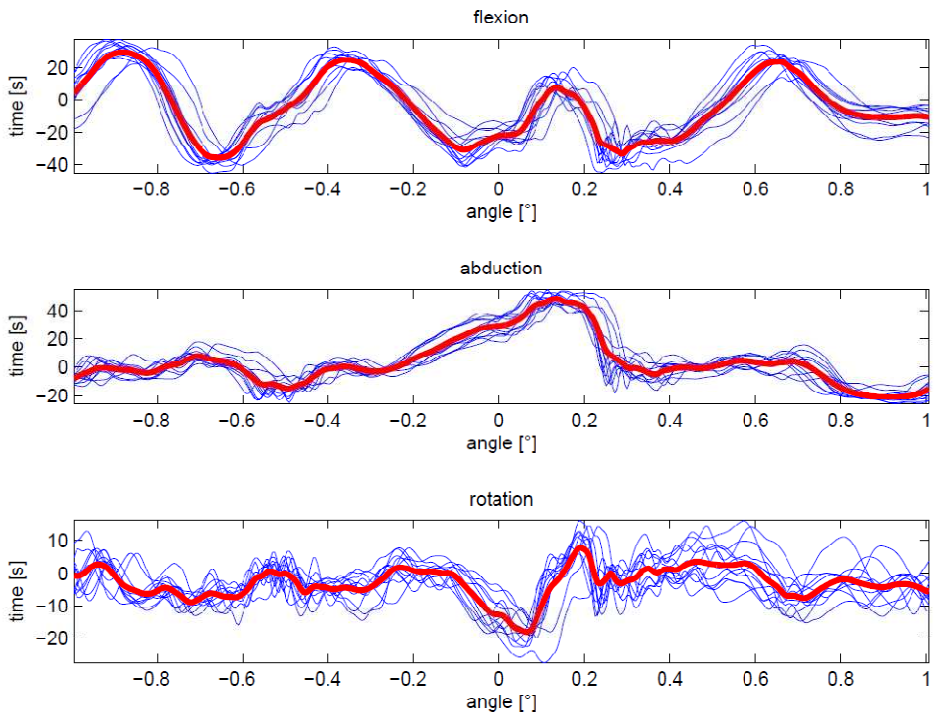
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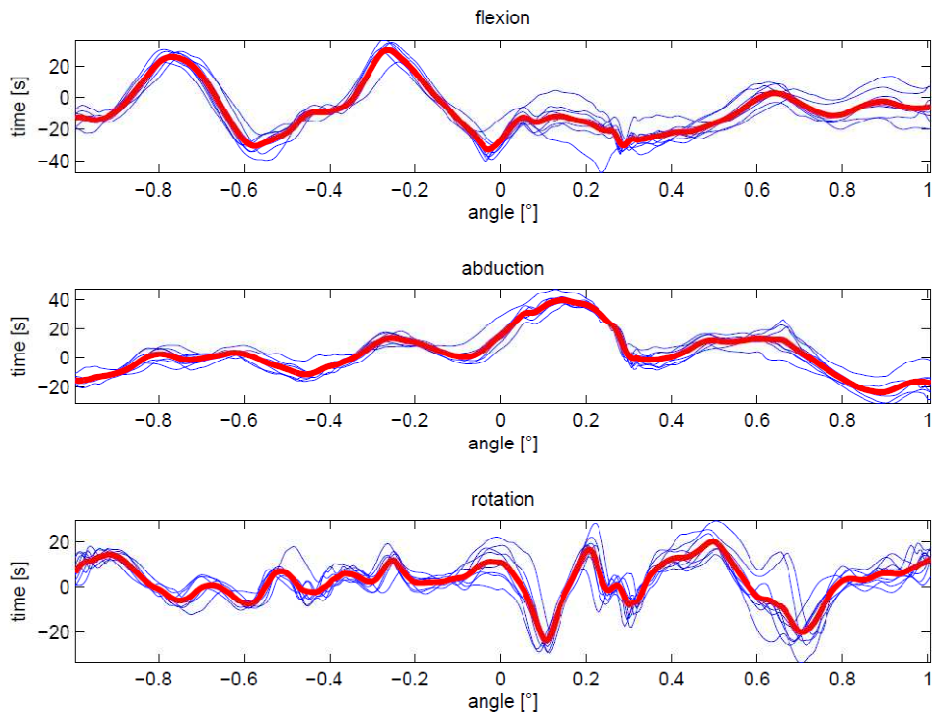
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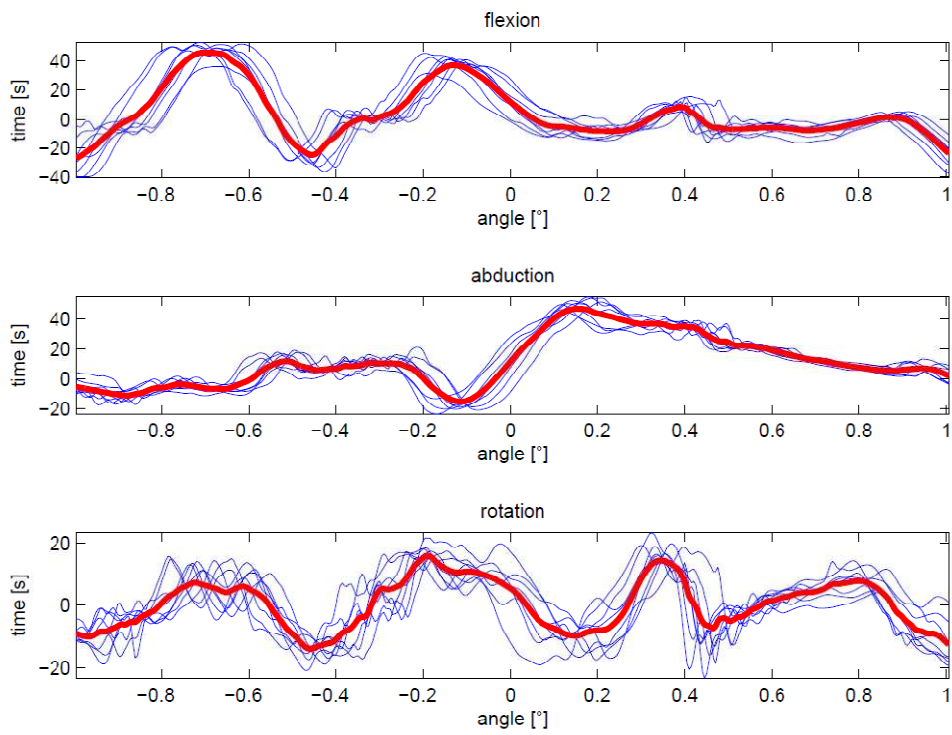
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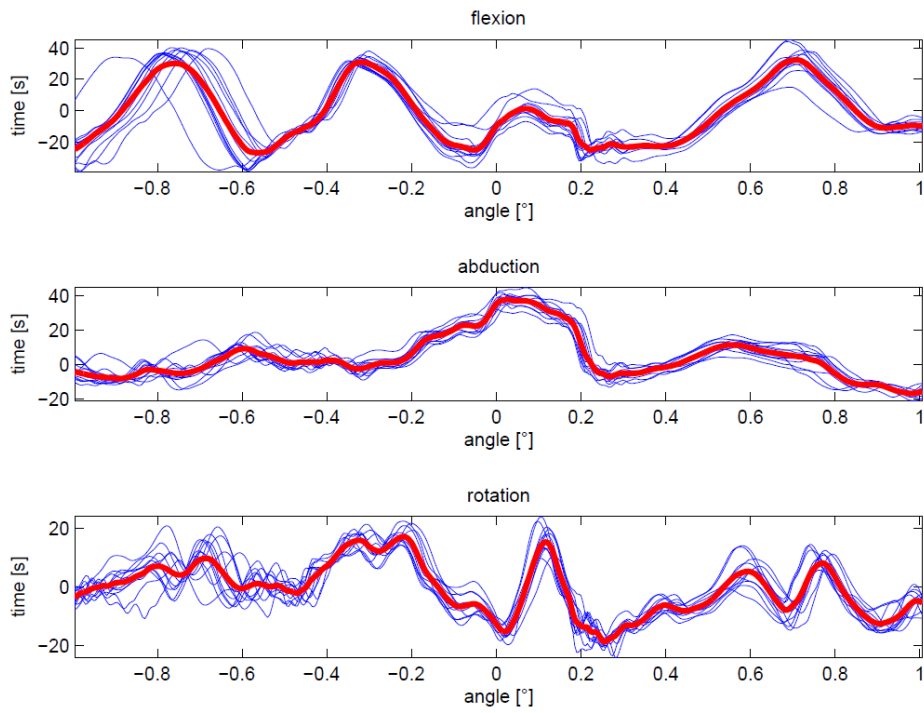
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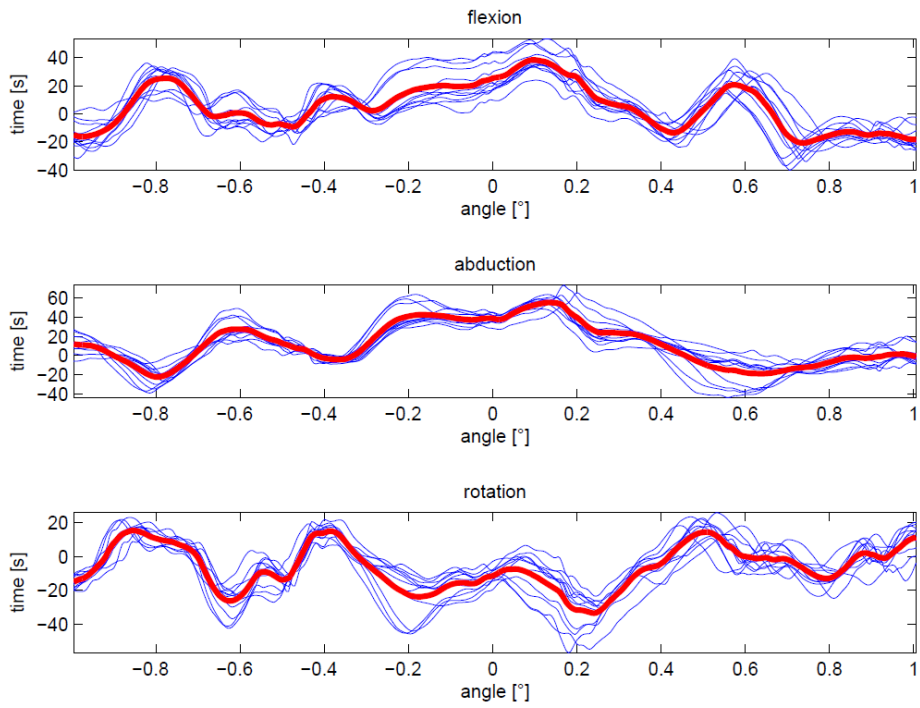
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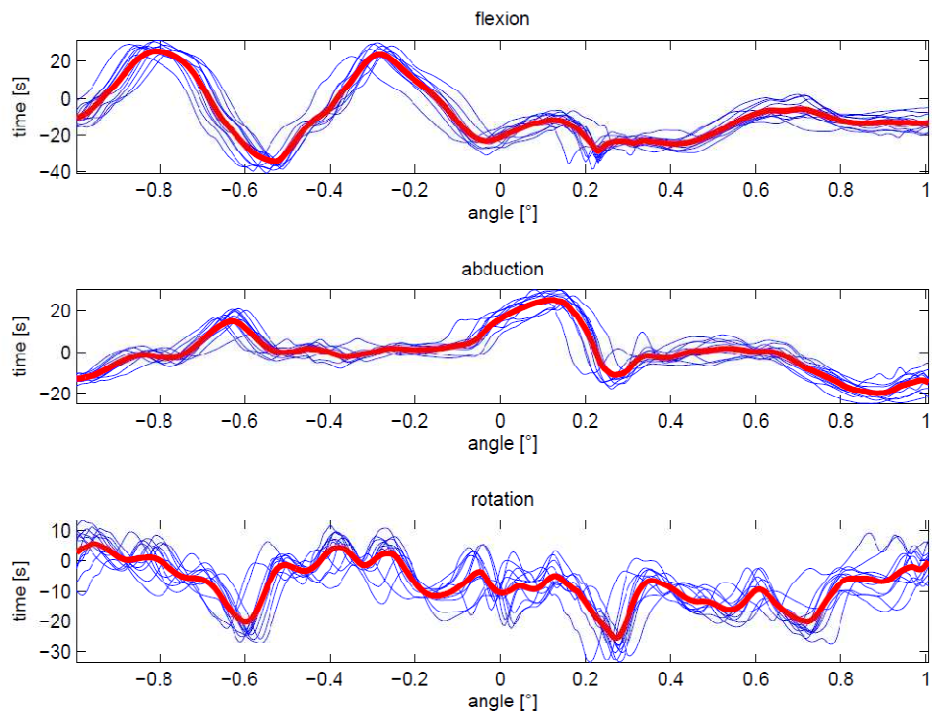
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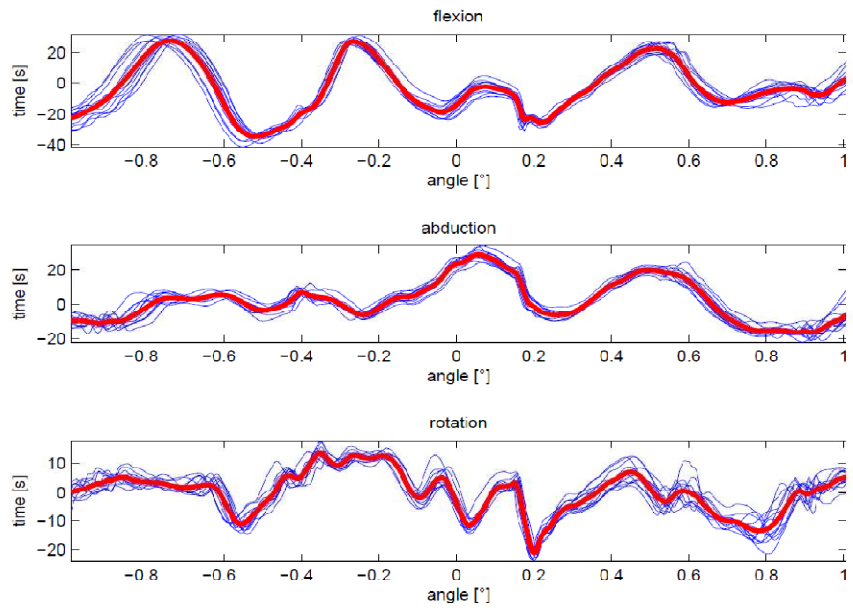
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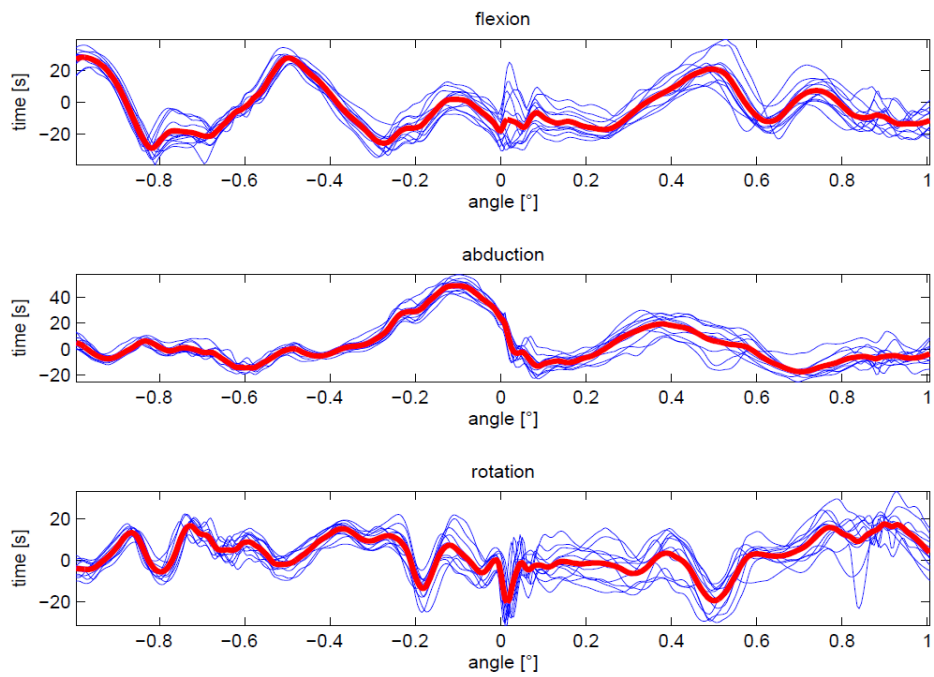
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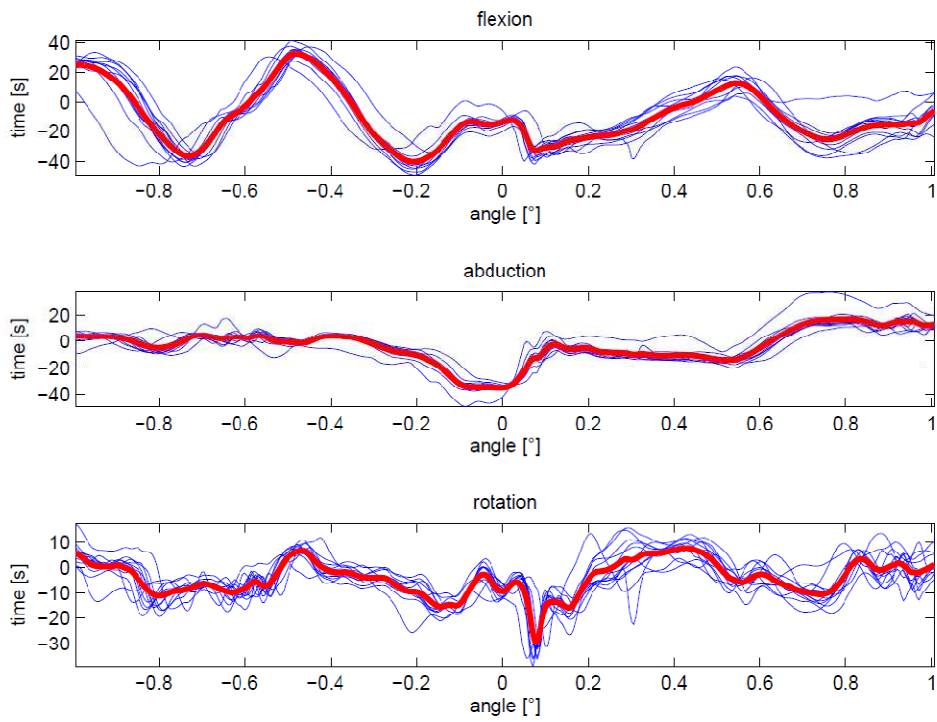
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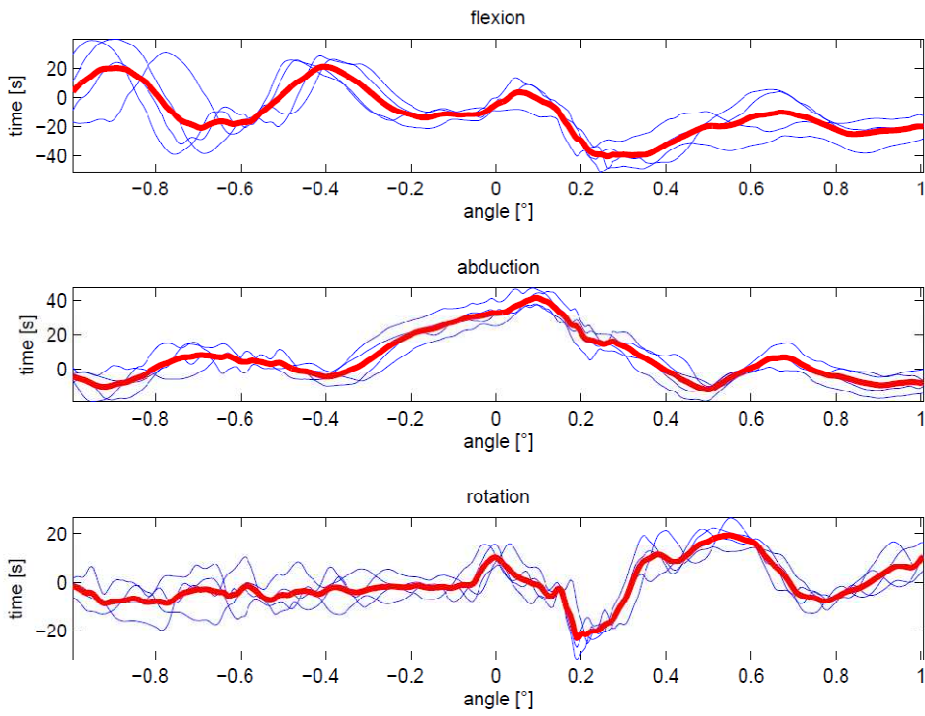
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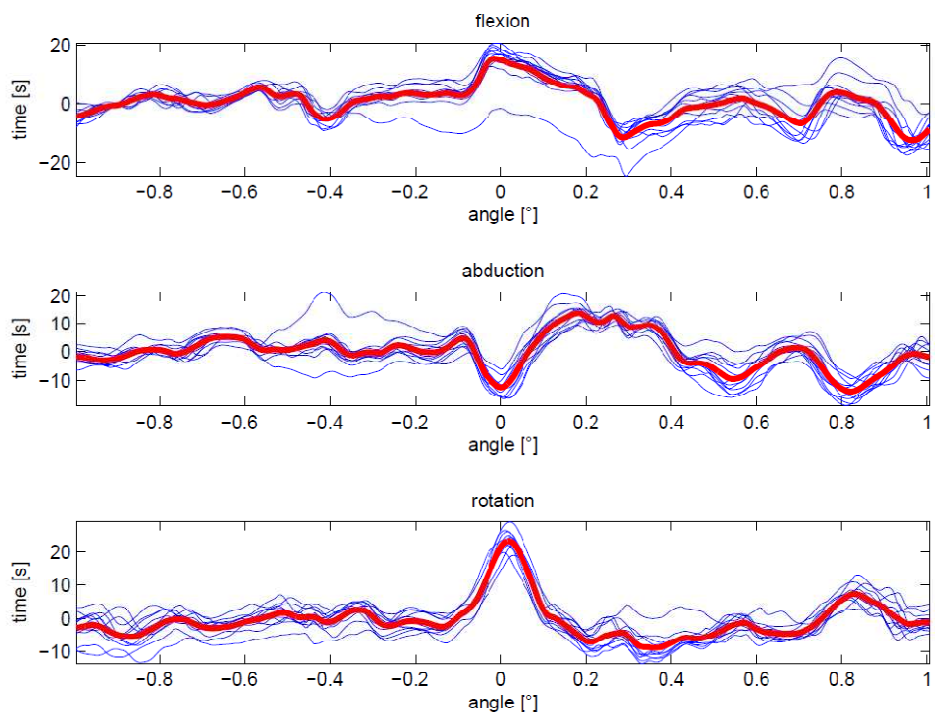
Bowler 12



Bowler 13



Bowler 14



Bowler 15

APPENDIX I

Welcome and thank you for participating in this study.

This is your personal information sheet. It outlines your day of testing. There are four areas in which the testing will be conducted. Please follow the assistant and make sure you locate each area:

- A) Questionnaire and consent area
- B) Bowling Preparation Station
- C) Warm up area
- D) Bowling laboratory

If at any stage you have any difficulties do not hesitate to ask the assistant who welcomed you today. We hope this will be an interesting experience for you.

Program for the day.

	Time	Procedure	Area
1	08h00	Consent	A
2	08h04	Questionnaire	A
3	08h20	Measurements	B
4	08h36	Warm-up and first over (See below)	C
5	08h48	Preparation for first bowling test	B
6	08h56	First and second bowling tests	D

Warm-up.

- Your warm up time allowed is 12 minutes in total
- Run around the field slowly for 2 minutes
- Do the stretching routine on the handout. It will take approximately 6 minutes
- Do shuttles runs.
- Do bowling as warm up from a short run-up for 1 minutes

Fielding drills.

- In between the un-filmed over and filmed overs, the following fielding drill will be done in the nets if you have to wait for the bowling trial:
- Stand and rest for 1 minute
- Run one shuttle between the stumps
- Throw one ball at the stumps
- Retrieve the ball
- Walk back to run up position
- Stand and rest for 1 minutes
- And repeat if necessary

APPENDIX J

OUTLINE OF DUTIES FOR RESEARCH ASSISTANT

The research assistant will be present at each of the testing opportunities at the clubs to assist the researcher with:

1. Preparation of the laboratory environment

- The laboratory will be set up on the field at the bowler's club.
- The 2D video camera will be mounted on top of the vehicle and the stencil will be used in order to create the crease and grid to define the area for the delivery stride.
- The plinth will be set up in close proximity to the vehicle as indicated by the researcher. This area will constitute the "Bowling Preparation Station" and the Anthropometric and ROM station. The photographic camera will also be set up for ROM measurements with the area of the tripod marked for both the measurements at the foot end for rotation and from laterally for the extension range. The station will include:
 - The Holtain caliper
 - Standard measuring tape
 - Data capture sheet (Appendix C)
 - Stationary
 - Gauze
 - Soap
 - Alcohol
 - The caliper scale
 - T-bar
- Page count of Questionnaire
- Stationary

2. The research assistant will be responsible for welcoming of the subject and explaining the logistics for the individual testing day. An information sheet with the information will be handed to the subject at this stage. (Appendix I)

- "Welcome to this study opportunity and thank you for participating in this study."
- "Your day will consist of nine parts as explained on your roster sheet."
- "Please read the letter of consent and sign it. Do not hesitate to ask any questions"

3. Administration of the Lumber Spine Questionnaire will be done by the research assistant.

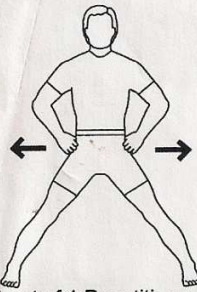
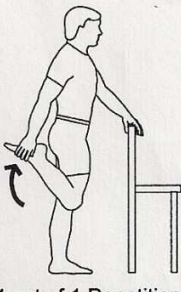
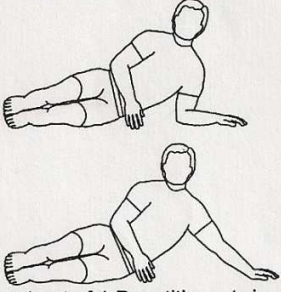
- Individual administration of the lumber spine questionnaire will be done
 - The questionnaire will be handed to the subject with the verbal instruction from the assistant: "Please fill out this questionnaire to the best of your ability as to insure that the information gathered during this research project reflects accurately on the reality of lower back problems in fast bowlers in cricket."
 - The assistant will encourage the subject to seek assistance in technicality of the filling out of the questionnaire: "If you have questions about the technical aspects of the questionnaire, please do not hesitate to seek my assistance."
 - The assistant is not required to interpret the questions for the subjects. A pilot study will aim to eliminate the difficulties in interpretation prior to trial capture and the assistant may cause an intra-rater reliability bias.
-
- "From here you will move on to the Bowling Preparation Station over there in order to have you hip movements measured and to undergo preparation of your skin for the application of the trackers. The process is painless and will be explained to you by Merike Hopkins the researcher."
 - "From there you will proceed to the nets on the side for warm up. You will follow the warm-up routine on your information sheet and then bowl one over in the nets."
 - "You will then be asked to bowl while measurements are taken via blue tooth with the trackers and with the overhead camera."
 - "You will bowl 18 balls in the nets and then return to bowl one more over to be measured"
-
- "Merike will give you instructions on what to do next"
 - "Please do not hesitate to come to me if you are unsure as to where you must be at any given time."
4. After subject completed the questionnaire the research assistant will assist the players in their logistics as needed.

APPENDIX K

Checklist:

Documentation:	Numbers for stations A-D	✓
	Numbers for bowlers 1-7	✓
	Questionnaires App C	✓
	Anthropometric data sheet App D	✓
	Individual information sheet App G	✓
	Consent forms App H	✓
	Exercise hand-outs App I	✓
	Time-sheet for XSENS data App K	✓
XSENS equipment:	3 MTx trackers.	✓
	X-Bus Master and belt	✓
	Cables	✓
	Laptop	✓
Preparation equipment:	EAB strapping	✓
	Scissors X2	✓
	Double-sided tape	✓
	Towel	✓
	Liquid sope	✓
2D Filming:	Video Camera	✓
	5 Tapes	✓
	Overhead frame	✓
ROM:	Markers	✓
	Plinth	✓
	Camera	✓
	Memory card	✓
	Scale	✓
Anthropometry:	Measuring tape	✓
	Holtain caliper	✓
	Anthropometric data sheet	✓
	T-bar	✓
Stationary	12 pens and pencils	✓
	3 Clip boards	✓
Cricket balls X2		✓
Furniture	2 Tables	✓
	2 Chairs	✓

APPENDIX L

<p>Stretch hip adductors stand</p>  <p>Perform 1 set of 1 Repetitions, twice a day.</p> <p>Hold exercise for 20 Seconds.</p>	<p>Stretch Quads standing</p>  <p>Perform 1 set of 1 Repetitions, twice a day.</p> <p>Hold exercise for 20 Seconds.</p>	<p>Stretch hamstring uni stand</p>  <p>Perform 1 set of 1 Repetitions, twice a day.</p> <p>Hold exercise for 20 Seconds.</p>
<p>Stretch trunk rotn supine</p>  <p>Perform 1 set of 1 Repetitions, twice a day.</p> <p>Hold exercise for 20 Seconds.</p>	<p>Stretch Quadratus lumborum</p>  <p>Perform 1 set of 1 Repetitions, twice a day.</p> <p>Hold exercise for 20 Seconds.</p>	<p>Stretch Rhomboids</p>  <p>Perform 1 set of 1 Repetitions, twice a day.</p> <p>Hold exercise for 20 Seconds.</p>
<p>Stretch shld capsule inferior</p>  <p>Perform 1 set of 1 Repetitions, twice a day.</p> <p>Hold exercise for 20 Seconds.</p>	<p>Stretch Trapezius upper</p>  <p>Perform 1 set of 1 Repetitions, twice a day.</p> <p>Hold exercise for 20 Seconds.</p>	

APPENDIX M

Table M1: Rainflow histograms for flexion/extension for bowlers with symptoms.

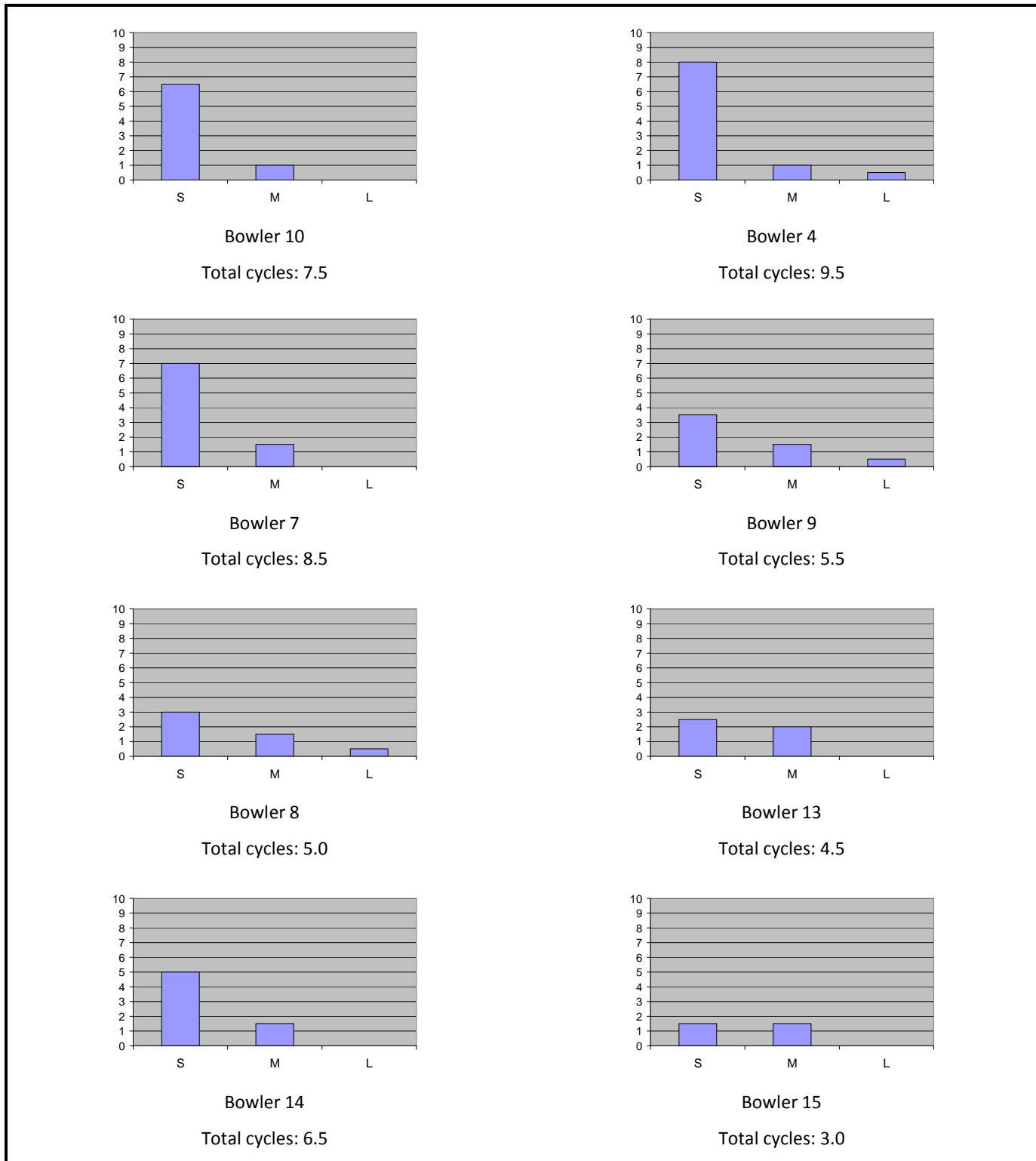
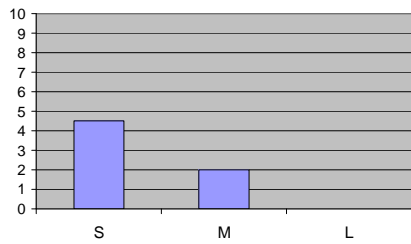
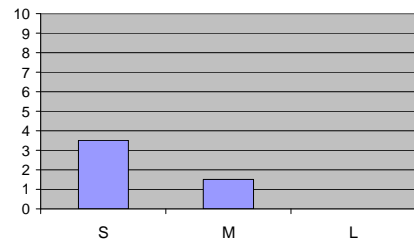


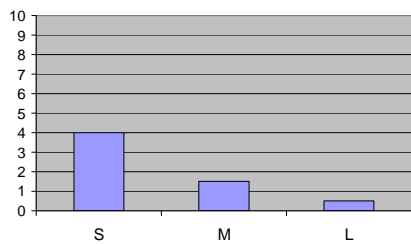
Table M2: Histograms for rainflow analysis for bowlers without symptoms flexion/extension.



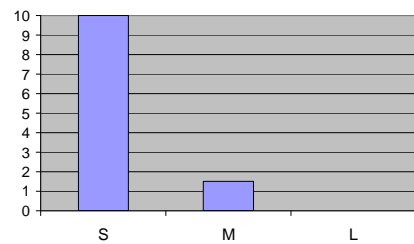
Bowler 1
Total cycles: 6.5



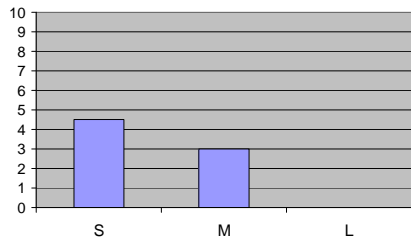
Bowler 3
Total cycles: 5.0



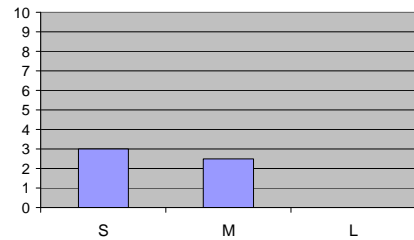
Bowler 5
Total cycles: 6.0



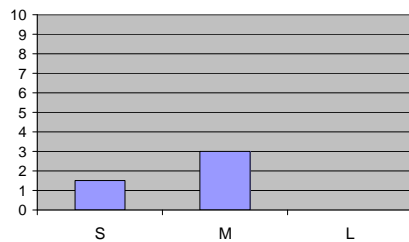
Bowler 6
Total cycles: 11.5



Bowler 12
Total cycles: 7.5



Bowler 11
Total cycles: 5.5



Bowler 2
Total cycles: 4.5

Figure M1: Amplitude count summary for F/E plane.

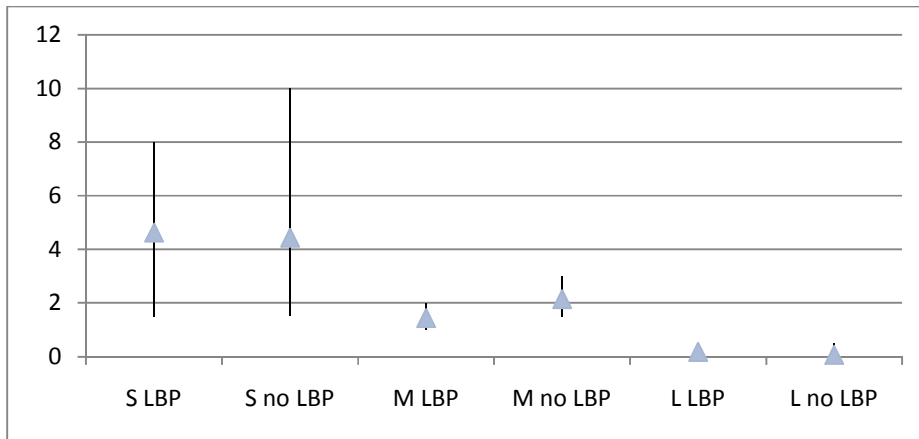


Table M3: Histograms for rainflow analysis for ab-/adduction for bowlers with pain.

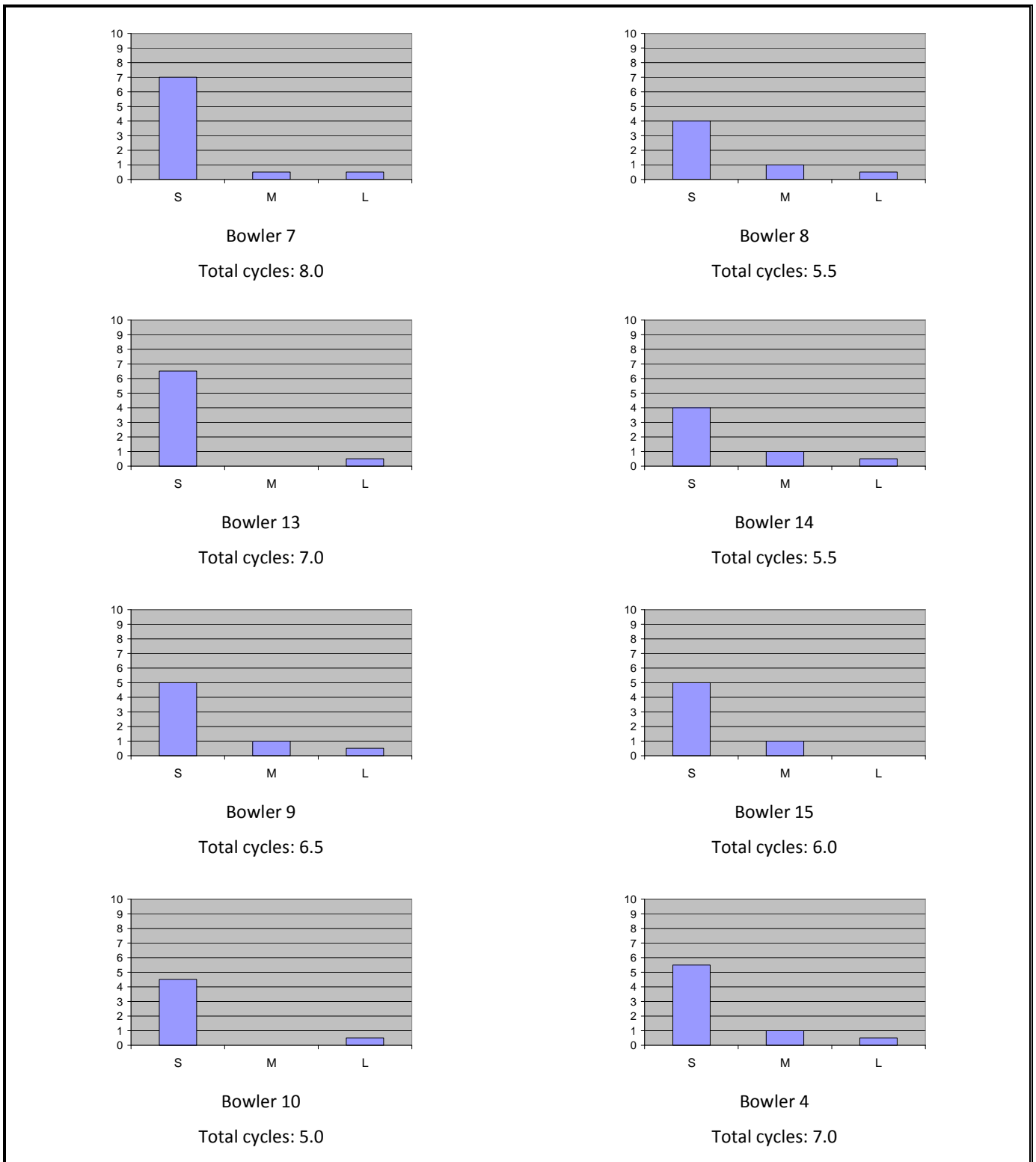
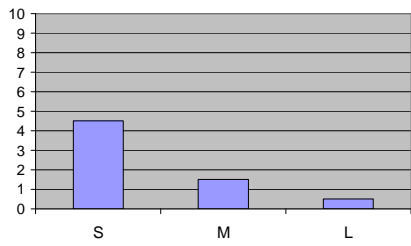
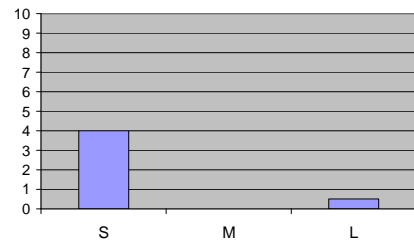


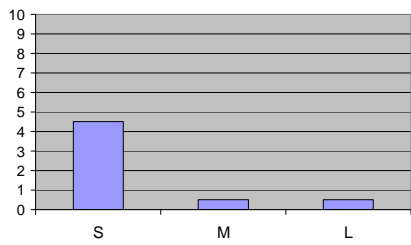
Table M4: Histograms for rainflow analysis for ab-/adduction for bowlers without symptoms.



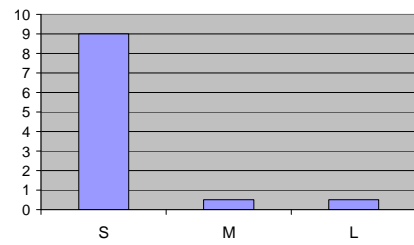
Bowler 1
Total cycles: 6.5



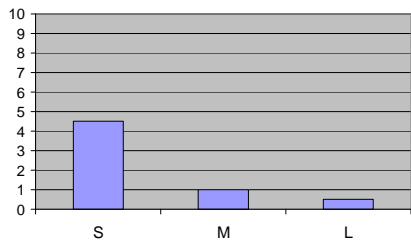
Bowler 3
Total cycles: 4.5



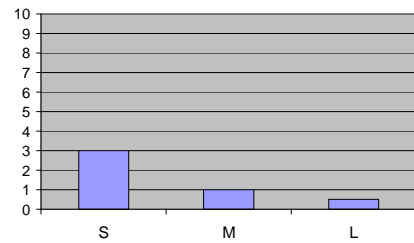
Bowler 5
Total cycles: 5.5



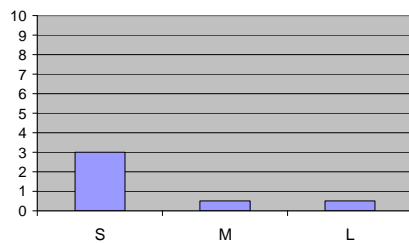
Bowler 6
Total cycles: 10.0



Bowler 12
Total cycles: 6.0



Bowler 11
Total cycles: 4.5



Bowler 2
Total cycles: 4.0

Figure M2: Amplitude count summary for Ab/Adduction plane.

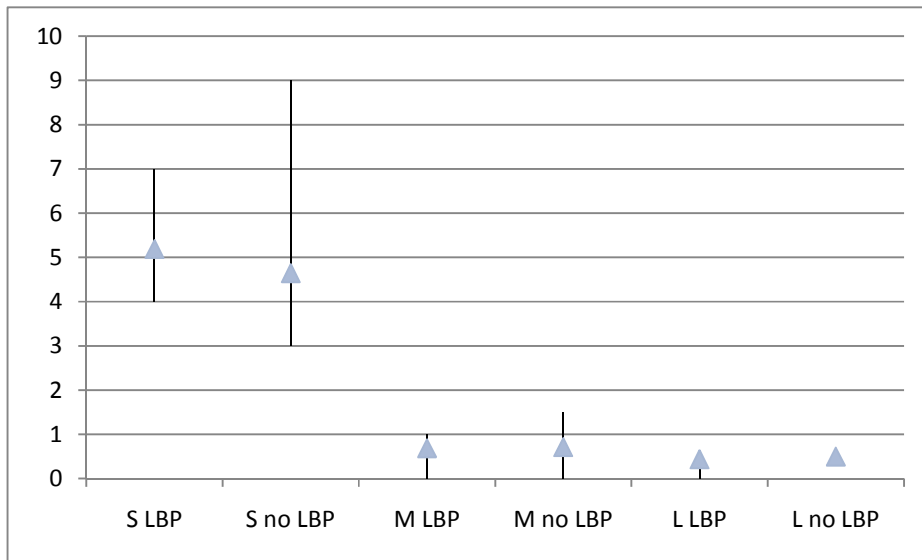


Table M5: Histograms for rainflow analysis for rotation for bowlers with pain.

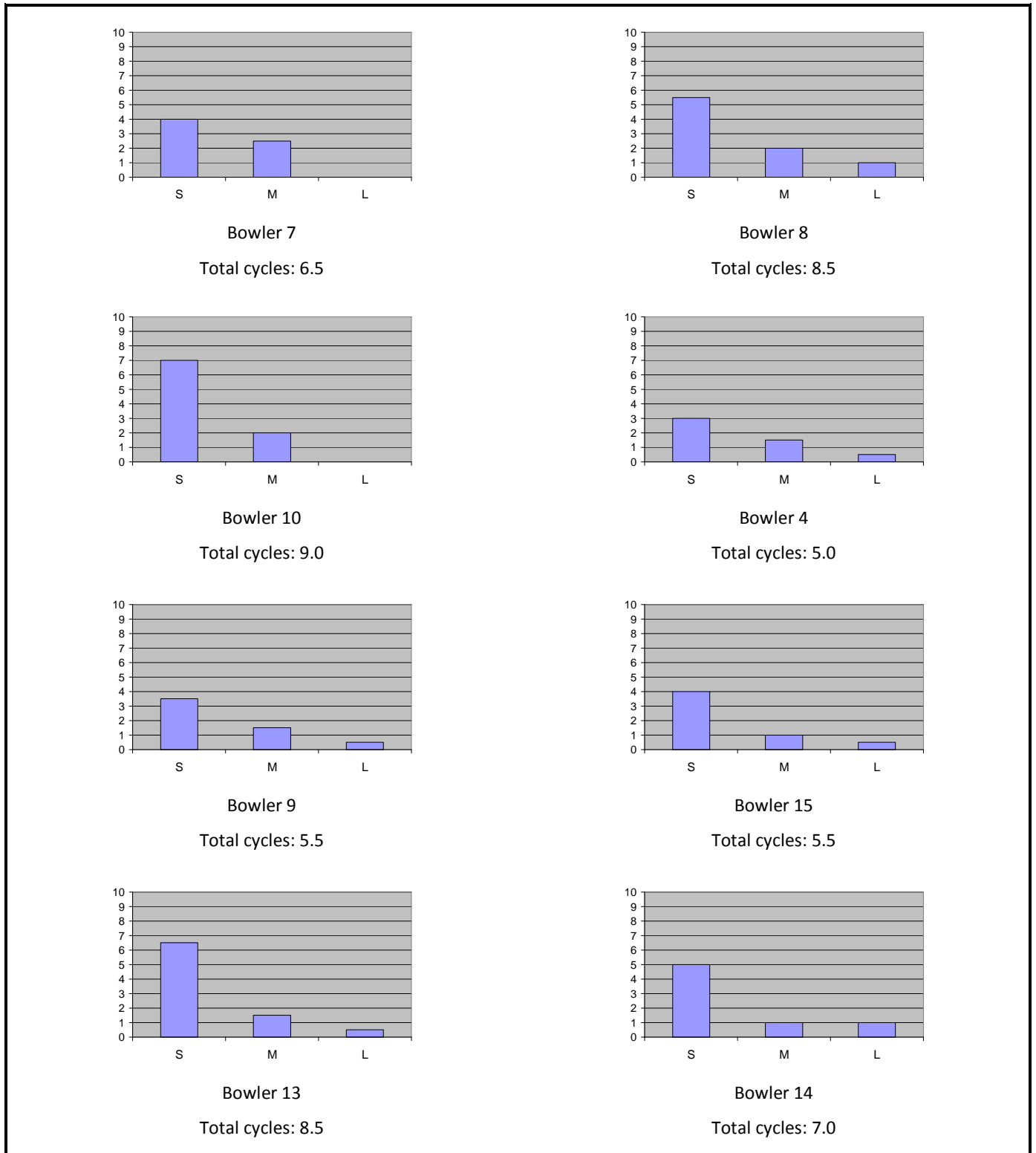
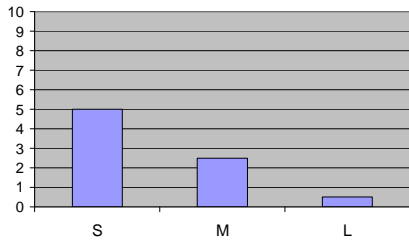
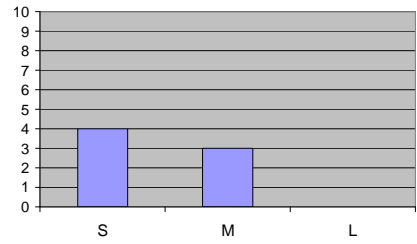


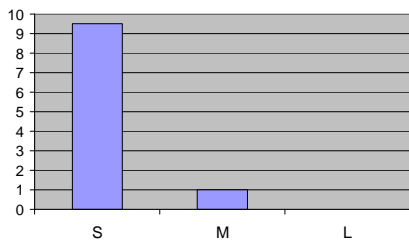
Table M6: Histograms for rainflow analysis for rotation for bowlers without symptoms.



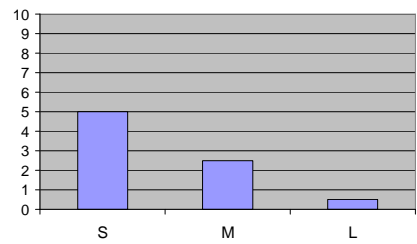
Bowler 1
Total cycles: 8.0



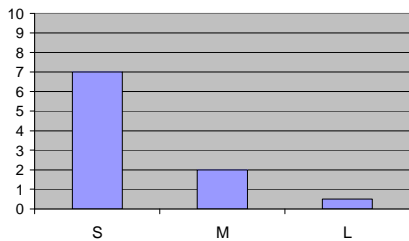
Bowler 3
Total cycles: 7.0



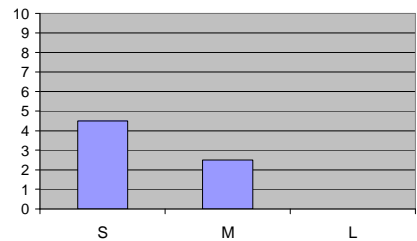
Bowler 5
Total cycles: 10.5



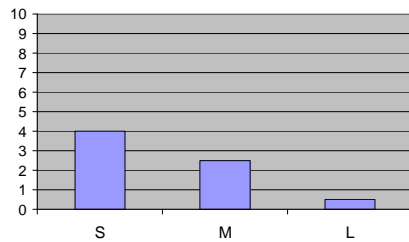
Bowler 6
Total cycles: 8.0



Bowler 12
Total cycles: 9.5



Bowler 11
Total cycles: 7.0



Bowler 2
Total cycles: 7.0

Figure M3: Amplitude count summary for rotation plane.

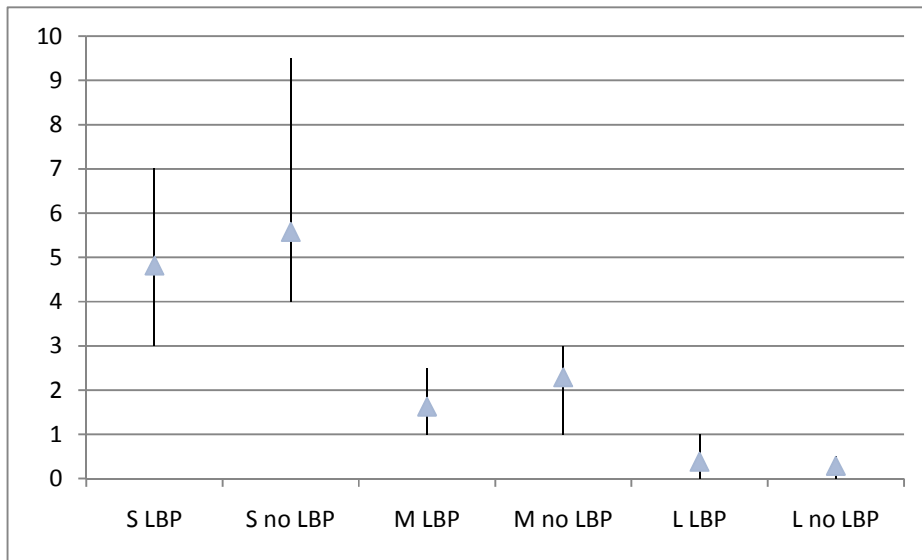
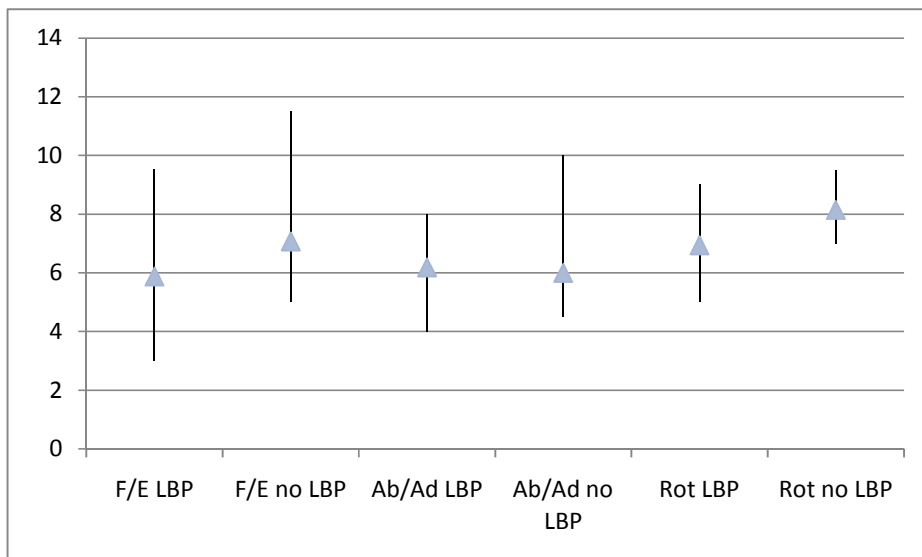


Figure M4: Amplitude count summary for total amplitudes.



APPENDIX N



UNIVERSITEIT • STELLENBOSCH • UNIVERSITY
jou kennisvennoot • your knowledge partner

24 April 2006

Ms M Hopkins
Discipline of Physiotherapy
Dept of Interdisciplinary Health Sciences

Dear Ms Hopkins

RESEARCH PROJECT: "A DESCRIPTION OF LOWER-BACK INJURY AND FRONT-FOOT HIP JOINT KINEMATICS DURING THE BOWLING ACTION OF CRICKET FAST BOWLERS"
PROJECT NUMBER : N06/02/043

At a meeting of the Committee for Human Research that was held on 8 March 2006 the above project was approved on condition that further information that was required, be submitted.

This information was supplied and the project was finally approved on 13 April 2006 **for a period of one year from this date**. This project is therefore now registered and you can proceed with the work. Please quote the above-mentioned project number in all further correspondence.

Please note that a progress report (obtainable on the website of our Division) should be submitted to the Committee before the year has expired. The Committee will then consider the continuation of the project for a further year (if necessary).

Patients participating in a research project in Tygerberg Hospital will not be treated free of charge as the Provincial Government of the Western Cape does not support research financially.

Due to heavy workload the nursing corps of the Tygerberg Hospital cannot offer comprehensive nursing care in research projects. It may therefore be expected of a research worker to arrange for private nursing care.

Yours faithfully

pp.

CJ VAN TONDER
RESEARCH DEVELOPMENT AND SUPPORT (TYGERBERG)
Tel: +27 21 938 9207 / E-mail: cjvt@sun.ac.za



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Privaatsak/Private Bag X1 • Matieland, 7602 • Suid-Afrika/South Africa, Faks/Fax: +27 (0) 21 808 3800

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