University of Alberta

Low Back Pain Risk Factors in Canadian Interuniversity Field Hockey

by

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ABSTRACT

Risk factors for low back pain (LBP) include type and repetition of movement, asymmetric loading, posture, and trunk strength and endurance. While these factors have been described extensively in the literature and while field hockey is characterized by many of these factors, the direct relationship to field hockey has not been quantified. The overall goal of this dissertation was to investigate and identify factors related to LBP in field hockey through three studies.

Study 1, "Repetitive Movements in Field Hockey and the Relation to Low Back Pain" sought to identify mechanical exposure factors that are related to injury. Frequent movements in and out of trunk flexion, rotation and side flexion characterize field hockey. Torsional stresses from these movements and total frequency of these movements are associated with high risk for LBP. The asymmetric nature of field hockey further increases the risk for LBP.

Study 2, "Pilot Study: Clinical Measures To Detect Mechanical Imbalance," sought to create a testing battery to investigate left-right mechanical imbalance in the low back and hip using methods that would allow practical application to clinical practice. Reliable and valid measures were developed. The majority of range of motion (ROM) and strength tests in the testing battery were found to have excellent intrarater reliability. The functional tests were not found to be as reliable, but the results may have been due to fatigue. With suggested modifications, these tests should produce valid and reliable results.

Study 3, "A Musculoskeletal Profile of Canadian Interuniversity Female Field Hockey Players," sought to investigate sport specific imbalances of the low back and hip

in female Canadian interuniversity field hockey players. Differences were investigated between healthy control, healthy field hockey, and field hockey back and thigh pain groups. Sport specific imbalances (related to sport performance but not causing injury) were found in sideways hop for distance, hip abduction ROM, hip internal rotation strength, hip adduction strength, and hip abduction strength. Injury related imbalances were found in 1-joint hip extension ROM, 1-joint hip flexion ROM, trunk rotation ROM, and hip extension strength.

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CHAPTER 1: LOW BACK PAIN RISK FACTORS IN CANADIAN INTERUNIVERSITY FIELD HOCKEY – INTRODUCTION

Despite well-designed training programs, many elite athletes suffer injury during their competitive careers. Given this perceived inevitability, and personal observations of the frustration that injuries cause athletes, it seems prudent to prevent injury. As a therapist, it has often been frustrating that therapeutic focus is on secondary prevention (i.e., preventing re-injury) rather than primary prevention (i.e., preventing injuries before they ever occur).[1] As a therapist with the National Women's, Ontario Women's, University of Toronto, and University of Alberta field hockey teams over 15 years, the frequent occurrence of many back injuries with the same patterns of pelvic asymmetry, muscle tightness and weakness have been noted anecdotally. It has been difficult, however, to determine whether these patterns caused the injury or were a result of the injury, and whether other factors were involved.

Anecdotal observation of high incidence of low back pain (LBP) in field hockey is supported in the literature. In a study by Lindgren and Twomey,[2] 78% of elite male and female Australian Institute of Sport field hockey participants had a history of at least one episode of hockey related low back pain, a frequency that is similar to that of the general population. Reilly and Seaton[3] found that 53% male field hockey respondents had, at some time, suffered from lower back pain. Murtaugh[4] found that back pain was reported by 59% of female high school, university and national team players, and 50% reported that back pain affected them during the field hockey season. This pain was serious enough to cause 12% of the athletes to miss a game or time at school or work. The lower back was the most common site of pain.[4] In a prospective cohort study on injuries that occurred during the Canadian women's national field hockey team's preparation for the 1999 Pan American Games, 20.2% of the total injuries occurred to the spine and most were chronic in nature.[5]

Injury prevention involves identifying areas of concern, identifying the extrinsic (outside the body) and intrinsic (inside the body) risk factors associated with the area of concern, introducing interventions to decrease the effect of these factors, and evaluating the intervention's ability to decrease injuries.[6,7] While the presence of chronic low back pain has been identified as a problem in field hockey, few investigations on the factors associated with this pain have been conducted.

PURPOSE

The overall goal of this dissertation was to investigate and identify factors that could be related to low back injury in field hockey. In order to accomplish this goal, three separate, yet linked, exploratory studies were conducted on elite female hockey players participating in Canadian Interuniversity field hockey. The purpose of the first study, a task description of field hockey, was to identify mechanical exposure factors that might be related to injury and to provide validation of the testing methods for the development of a musculoskeletal profile of female Canadian interuniversity field hockey players. The purpose of the second study, a pilot project, was to further establish validity and reliability of the testing methods chosen to develop the musculoskeletal profile. The purpose of the third study, the musculoskeletal profile, was to identify task appropriate and injury-related mechanical imbalances of the low back and hip region of female Canadian interuniversity field hockey players.

BENEFITS

This three-part dissertation identifies extrinsic and intrinsic risk factors associated with chronic low back pain in field hockey. This identification will provide researchers and therapists greater insight into the potential causes of LBP in field hockey. Armed with this knowledge, future epidemiological studies could be undertaken, prospectively tracking athletes to investigate the impact of these factors on injury occurrence. Using either the retrospective or prospective data, intervention programs that combat the causative factors could then be developed and investigated for effectiveness in reducing chronic LBP. Ultimately, the data collected from these three studies will continue a process that hopefully would lead to decreased LBP in field hockey.

A second benefit of this research is to provide coaches in the sport of field hockey with more knowledge to make educated decisions about training. Coaches strive to develop teams that are successful, and this success is measured by performance. An understanding of factors that enhance performance, yet do not increase the risk of injury, could allow coaches to develop safe specific training programs to enhance their athletes' performance.

A third benefit exists for therapists. Firstly, the studies of this dissertation employed assessment methods that could be easily used in a field or clinical setting. These methods provide a template that may be transferred to other activities. Secondly, therapists could use techniques of measuring mechanical imbalance described in these studies when evaluating and treating injured field hockey athletes. Thirdly, the musculoskeletal profile provides information regarding task appropriate and injury-related imbalances that could be used as a basis for the treatment of LBP in field hockey.

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CHAPTER 2: REPETITIVE MOVEMENT PATTERNS IN FIELD HOCKEY AND THE RELATION TO LOW BACK PAIN

Low back pain (LBP) is a common problem in many sports and field hockey is no exception. Frequencies of at least one episode of field hockey-related LBP have been reported between 53% and 78%.[1-3] For 12% of respondents, this pain was serious enough to cause missed games, school, or work.[2] In addition to loss of activity, LBP has also led to decreased performance of sport-related skills. The high incidence of these injuries presents an area of concern.

While chronic LBP has been identified as an area of concern in field hockey, few investigations have been conducted regarding the risk factors associated with LBP and their presence in field hockey. Commonly cited risk factors for any cumulative traumatic injury (chronic injury) in the low back include mechanical exposure factors – factors that are predominantly extrinsic or outside the body. Mechanical exposure factors include static muscle loading in prolonged positions (e.g. standing or sitting), type of movement, posture, repetitive bending, twisting or lifting, and asymmetric loading.[4-7] In order to discover the potential involvement of these risk factors in field hockey, some form of analysis of the activity or "task" of field hockey is required.

Purpose

The purpose of this study was to identify, quantify and compare potential mechanical exposure factors that might be related to low back injury in field hockey in women and men, for both game and practice conditions, using a task description of the sport.

Hypothesis

Movements that incorporated repetitive or prolonged forward flexion of the trunk, repetitive twisting of the trunk, and repetitive squatting or lunging would predominate in the sport of field hockey.

LITERATURE REVIEW

Cause of Injury

The following sections describe documented mechanical factors related to chronic LBP and their effects. Although they are discussed separately, these factors are interconnected and their effect on potential injury should be considered more globally.

Static Muscle Loading

Significant but often ignored factors in repetitive muscle strain are static and prolonged positions at the extremes of joint range of motion (ROM).[7] During dynamic activity, muscles contract and relax rhythmically and thus receive adequate blood supply.[8] Muscles forced into static holding positions do not contract and relax rhythmically, consequently missing the cycle of relaxation that brings a supply of fresh oxygenated blood to the tissues.[8] Two effects from static holding occur. Firstly, muscles subjected to repeated static muscle loading actually adapt by shortening themselves by increasing their fibrous tissue so that they do not have to contract to the same extent. As a result, the tendons are forced to stretch beyond their limits and tissue damage occurs.[8] Secondly, if particular tasks are carried out continuously, both the stabilizing muscles and the muscles performing the task tire.[7] As fatigue can be a precursor to strain, the effect of unchanging postures and static muscle work can be as damaging as highly repetitive movements.[7]

Type of Movement

Tissues tolerate some movements better than others. Pure lumbar flexion is tolerated well, but torsional stresses, by comparison, are poorly tolerated.[9] Combined movements of the lumbar spine, such as forward flexion and rotation, carry the highest potential for injury.[9]

Posture

Posture is one of the most important factors related to chronic injury[8] and is interrelated with static muscle loading, repetition and fatigue, and constrained working posture. Posture refers to the relative position and proper alignment of the body segments during rest or activity, and also to the repetitive pattern of certain frequently assumed positions.[10] A minimum amount of muscle work is required for the maintenance of good posture in any human static or dynamic situation.[10] Postures that are adopted for a given activity can lead to adaptive soft tissue lengthening and/or shortening, which may change the way the spine is loaded.[10] This change may lead to injury.

Constrained posture refers to extreme or awkward ranges of motion. When body parts are held in extreme or awkward positions, all structures of that body part (capsules, ligaments, tendons, and muscle) are stressed, especially if held for long periods or used repetitively.[7] The more movement or posture deviates from the position of function, the more extreme they are considered and the more likely they are to cause strain beyond the limits of the tissue.[7] For example, a number of sporting pursuits may either require, or involve through wrong technique, short- or long-term loading of the lumbar spine in extension (e.g. tennis, fast bowling in cricket, gymnastics and wind surfing).[11] In sports such as tennis or cricket, the movement into full extension is accompanied by explosive loading of the lumbar spine and followed by rapid active flexion. Sometimes this combination of movement and peak loading results in a stress fracture or spondylolysis of the pars interarticularis of a lower lumbar vertebra.[11]

Repetition and Fatigue

Muscle performance is considered in terms of a muscle's ability to generate a force immediately (muscular strength) and to sustain the required force during repeated activation (muscular endurance).[12] Decreased muscular endurance has been found to be one of the significant risk factors in the development and incidence of chronic LBP.[12-14]

Local muscle fatigue is believed to be one of the causes leading to trunk muscle dysfunction that predisposes an individual to injury.[5, 12, 15] However, the role of fatigue in LBP is still uncertain due to a lack of knowledge concerning the mechanism linking exposure to LBP disorders, difficulties in proper exposure assessment in epidemiological research, and an unclear relationship between exposure and effect.[4, 12] Consequently, there are no known quantitative relations because little is known about the tissues that are damaged.[4, 12]

Although the mechanisms associating muscle dysfunction to LBP are not clearly understood, it is commonly believed that the inability of trunk muscles to produce or maintain a force (muscle insufficiency) is an important component of LBP disorders.[12,15] Findings that subjects with prior bouts of LBP had less endurance capacity, but similar strength, in trunk extension as compared to LBP-free participants (where endurance referred to monitoring time to exhaustion during sustained isometric back extension) support this theory.[16,17] Persons with low isometric endurance had more serious attacks of LBP when strength was identical.[18] However, individuals with high muscular endurance in the back muscles and high general fitness had fewer incidences of back problems than deconditioned individuals.[16,17,19] Workload, the intensity of the work coupled with its duration and pace, is related to LBP disorders.[8] Because almost every task is time dependent, the endurance capacity of the musculature is a key component of the system.[12]

Static muscle loading in prolonged postures, heavy muscular effort and repeated movements all cause local and general fatigue.[7] When the trunk musculature loses its ability to generate tension due to fatigue, the muscular support to the spine is decreased and external loads are transmitted more readily to the passive structures of the spine, potentially leading to injury.[9,12]

Asymmetric Activity

Trunk position is defined by the combination of trunk angle and asymmetry.[20] Asymmetric lifting tasks are considered to be more dangerous than symmetric lifting tasks because of the combined effects of flexion and axial rotation on the lumbar spine.[21] Asymmetric activity is linked to changes in the kinetic chain and to posture. All of the risk factors (i.e. static muscle loading, type of movement, posture and repetition and fatigue) associated with LBP have an increased negative influence with asymmetrical loading. Many sporting, occupational, and daily situations involve asymmetric lifts with significant trunk motion.[20] Trunk muscles can play agonist and antagonist roles, depending on the plane in which they are working, and trunk muscle activation changes greatly as a function of posture.[22] Muscle reaction is dependent on a combination of moment magnitude, moment direction, and trunk flexion angles.[22] With asymmetrical loading, certain structures are stressed unevenly. This situation can overload tissue, cause injury, or develop a mechanical imbalance.

Asymmetric tasks can place passive and active structures of the lumbar spine joints near their end range. Muscles in an asymmetric position have a decreased force generating capacity.[22-24] These tasks decrease the load relieving properties supplied by intra-abdominal pressure (IAP).[20] Asymmetric tasks increase coactivation of antagonistic muscles, leading to an increased load on muscles that are smaller in cross-sectional area than the erector spinae (ES).[20,25] Increased coactivation also creates increased stability or stiffness of the trunk such that prime movers have to produce more force to overcome this resistance. This leads to increased compressive and shear loads on the passive structures of the spine.[21,24,25] All of these factors can increase the risk of injury to the spine during asymmetric tasks.

Field Hockey

A number of the factors associated with cumulative traumatic injury characterize field hockey. During games and practices, players spend a prolonged amount of time near the end range position of thoracolumbar flexion while dribbling, passing, receiving and contesting for the ball.[1, 3, 26] High demands are placed on the thoracic and lumbar paraspinal muscles for endurance, and eccentric and concentric strength.[27] From the position of thoracolumbar flexion, the player must twist forcefully from the hips and trunk to perform passing and shooting skills effectively. This combination of spinal flexion and rotation is known to increase the work of the back extensor muscles and the spinal compression loads.[27] Each player must be able to hit the ball with power and accuracy; dribbling, flicking, pushing, and trapping balls requires skill and considerable muscular strength and endurance.[1] Field hockey involves a repetitive cyclic movement into thoracolumbar flexion that is superimposed on skill performance. In games, which last 70 minutes, and practices, which at the Canadian intercollegiate level are often two hours in duration, this repetitive movement occurs many times.[1] Field hockey is a game with an inherent asymmetry (all field hockey is played right handed) in terms of individual and team play.[1, 28] These repetitive postural stresses, skill requirements, and asymmetries of movement are superimposed on the work rate demanded by the game and its pattern of play.[3] Consequently, there is the potential for adaptive tissue change, strain, and fatigue from the repetitive, forceful movement into the extreme position of thoracolumbar flexion which occurs during dribbling, passing, receiving and contesting the ball, and from work rate of the sport.

Activity Analysis

While the relation of mechanical exposure factors to low back injury has been described extensively in the literature, and while field hockey is described as being characterized by many of these mechanical factors, their direct relationship to field hockey has not been quantified. In order to discover their potential involvement in field hockey, some form of analysis of the activity or "task" of field hockey had to occur.

A task is a reference to human behavior, to the system goals for which people are employed, to how context constrains the attainment of these goals, or to some interaction of these factors.[29] A task analysis is an investigative tool or a method of modeling human behavior.[29] Models created by task analysis are used to understand, communicate, test and predict fundamental aspects of the human system being developed or evaluated.[30] However, there is a lack of agreement on the exact nature and purpose of task analysis.[29] Many researchers feel that a task analysis explores tasks through a hierarchy of goals that indicates what a person is expected to do and plans when subordinate goals should be carried out.[29-32] This definition implies that a task analysis describes both the physical characteristics of a task and the strategies the individual involved in the task can use to complete the task (i.e. a decision making process).[29] Other researchers define task analysis without this behavioural component.[33-35] The present study did not include an analysis of decision-making processes in field hockey and, consequently, was termed a "task description."

A number of different methods for the analysis of tasks have been described in the literature, including the MUSE method,[30] the Sub-Goal Template method, and the Hierarchical Task Analysis method.[29] Some form of physical description of the task is involved in the initial stages of every method. This physical description involves two steps -- a review of the literature related to established descriptions of the task and an investigation of the physical demands.[33-35]

Physical characterization involves investigating the commonly encountered components of an activity.[33-35] The most popular methods of data collection are interviews and walk-throughs.[32] Interviews with the major stakeholders currently involved with the activity allow these individuals to identify and rank components of the tasks.[32-35] These interviews can occur through informal discussions, formal discussions, or questionnaire.[32] They can occur either prior to or following the development of the basic set of task descriptions.[32] There is no evidence to suggest that one method is better; researchers can, therefore, choose the method of their preference.[32]

In walk-throughs, participants are observed in the environment of the activity and a detailed cataloguing of skills occurs.[33] One method of capturing the activity is to perform a time-motion study, in which an auditory or visual recording of the task is made and, through its analysis, the components of the activity are itemized and described in detail, including the time required to complete the tasks, various movements performed, repetition, distance moved, and any other influencing condition.[35-37] In sports, time-motion analysis is often concerned with work-rate and activity profile during competition and training.[36, 38] The present study, however, sought to quantify repetition of discrete movement patterns rather than establish the physiological energy systems involved with the activity.

The tools and techniques used to gather task-related information, and the level of detail with which a task should be described, depends on the purpose to which the description will be put.[29, 32] Task analysis may be seen as a specific and rigorous method or merely as a guiding framework.[29]

To develop a list of physically demanding activities captured by video recording, the analyst must look for similar components of the task (same goal or common elements, objects, or procedures).[30] The analyst searches for the broadest category of the component and then decomposes each component into sub-components.[29, 31] This process continues until the analyst feels that the decomposition has met its purpose.[31] The analyst makes this decision subjectively, based both on past experience and past data.[29, 31, 32] It should be recognized that task analysis, however undertaken, will always have this subjective element of past experience in the interpretation of movement.[39] Clear and concise criteria for decomposition will eliminate as many of the subjective elements as possible.[39]

METHODS

This task description employed both questionnaire and videotape analysis to identify potential mechanical exposure factors that might be related to low back injury in field hockey.

Participants

The task description was divided into two sections – game and practice. For the game section, participants were selected from a total of 138 female athletes and 115 male athletes participating in the Field Hockey Canada Senior National Tournament from July 3 to July 7, 2002 (London, Ontario). For the practice section, participants were selected from a total of 25 members of the Canadian national women's field hockey team participating in a pre-Commonwealth Games training camp from July 8 to July 17, 2002 (London, Ontario) and from a total 20 members of the University of Alberta Pandas field hockey team participating in Canadian Interuniversity Sport (CIS) competition from September 1 to November 3, 2002 (Edmonton, Alberta).

Inclusion/Exclusion Criteria

Any athlete, excluding goaltenders, attending the games or practices was eligible to participate in the study. However, for the videotape portion, the athlete had to physically be on the field of play at the beginning of video recording to be included in the study. Any athlete who was unable to enter the field of play either due to injury or coaching decision was excluded. Fitness to participate was determined by each team's coaching or medical staff. Athletes were videotaped only once to ensure a maximum number and variety of participants in the video portion of the study.

Ethical Approval

Ethical approval for this study was obtained through the Faculty of Physical Education and Recreation, Ethics Review Committee for Human Research. All participants completing questionnaires provided signed informed consent (refer to Appendix L for ethics documents).

Procedure

Games

The principal investigator randomly selected teams to be involved in the questionnaire portion of the study, with the goal of enrolling approximately half of the male and female athletes playing at the Senior National Tournament. Athletes on each selected team completed a questionnaire that asked what activities in field hockey the participants found particularly tiring (refer to Appendix A). The potential participant could decline to participate without consequence. The questionnaire took approximately 10 minutes to complete.

For the videotape portion, to allow for analysis of position-specific differences in movement patterns, the principal investigator pre-determined a representative number of forward, midfield, and defense positions to be selected based on the number of players on the field during a game (28% forwards, 27% midfielders, 36% defenders) based on a 3-3-3-1 system. In the 3-3-3-1 system, 3 forwards, 3 midfielders, 3 defenders, and 1 sweeper play on the field at any one time. Prior to the beginning of the tournament, one position per half game was randomly selected to be videotaped to assure the pre-determined representation was attained. The athlete who played this position was videotaped for the entire half. Adjustments were made to the position taped in a specific game only if it became apparent that the same athlete would be videotaped twice. This occurred once for both women's and men's games. Thirty-four women and 25 men were recorded.

Practice

One athlete from the respective team rosters (25 National Team athletes and 20 University of Alberta athletes) was randomly selected for each practice, to be videotaped for the entire practice. Twelve women (6 National Team and 6 University of Alberta) were recorded.

Position of the Camera

Players were filmed with a compact VHS digital zoom, auto-focus with full audio-recording capabilities (JVC, VHS GR-SXM245 Camescope, JVC Canada, Scarborough, Canada).

For both sections of the study, the camera was placed in the spectator stands opposite the centre line (50 m) with an unobstructed view and far from the participating athletes (approximately 20 rows from ground). As such, the camera did not interfere with the athletes during practice or game play.

Data Analysis

The principal investigator reviewed the completed questionnaires and compiled a list of fatiguing activities in field hockey (refer to Appendix B). Using this list, knowledge of body positions and actions cited in the literature as being associated with chronic injury, and the principle investigator's expertise in movement patterns of field hockey, a list of positions and movements that would be counted in the video analysis was created. The principle investigator then viewed 1.5 hours each of practice and game tape to ensure that all the recorded movements fit into the categories initially created. The final template for video analysis was then created (refer to Appendix C).

The principle investigator only coded each game and practice videotape segment. Viewing took place on a VCR with built in timer (RCA 4-head VHS VCR, Thomson, Cedex, France). The VCR timer was used to measure "total time recorded." Each player recorded was the only person in the view unless contesting ball, receiving the ball in a crowd, or jockeying for position with an opponent. If the principle investigator was unsure of any movement, the tape was rewound and observed as many times as necessary to obtain accurate data. Coded data were counted twice to ensure accuracy and entered into the Statistical Package for the Social Sciences (SPSS) for statistical analysis. Entered data was checked once to ensure completeness.

To establish intratester reliability, the same section of videotape was viewed 7 times separated by a minimum of 1 day. During this period, the criteria for coding was refined and practiced. The sixth and seventh trials demonstrated complete intratester agreement on distinct movements and no significant difference between timing of prolonged forward flexion and movement with the ball (Friedman test $p = .216$ and $.151$, respectively). At this point, the researcher felt that reliable coding had been demonstrated.

Coding Criteria

Area of the field and playing position was recorded as the position the athlete occupied at the beginning of the half. If the athlete changed position during the recording period and the change was distinct (e.g. the player left the game and returned in another position), the new position and/or area of the field was recorded. If there was no clear distinction, the playing position and/or area of the field was coded as "varied."

No movement coding took place if the ball, foot position, or movement could not be clearly seen (e.g. view of camera blocked by another athlete involved in the play). If the movement occurred at the exact time play was stopped, the movement was counted. If the movement occurred after a stoppage of play, it was not counted. Ball collection during or at the end of practice was not included in the analysis. Ball collection was not performed by athletes during the games. Warm-up and cool-down activities were not included in the analysis.

The following describes the discrete movements. Pictorial representations of these movements can be found in Appendix D.

Stationary ball propulsion involved the athlete and ball being at a standstill prior to the hit being taken (e.g. free hit, penalty corner shot). Running ball propulsion was classified as "feet forward" and "feet sideways" in order to differentiate between associated trunk movements. To be classified "feet forward," both feet and the front of the trunk had to be facing the same direction as the direction of ball movement. To be classified "feet sideways," the feet had to be positioned at an angle to the direction of ball movement, and the initial approach of the trunk and shoulders had to be perpendicular to the direction of ball movement.

Movement with the ball and prolonged forward flexion were timed from the videotape using a stopwatch (Ultrak 340 Sports Timer, CEI, Manhattan Beach, USA) and recorded to a 100^{th} of a second. The minimum time for movement with the ball and prolonged forward flexion was 2 seconds, based on the preview of the videotapes. This time period differentiated a continuous movement in and out of trunk forward flexion from distinct periods of time where a more static position of trunk forward flexion was maintained. For movement with the ball to be recorded, the ball had to be "under control." Under control during dribbling was considered to be within approximately 45 centimeters of the stick (estimated visually as a half stick's length). For example, if a ball was received and bounced off the stick, movement with the ball would not be timed until the player had gained control of the ball. For prolonged forward flexion to be recorded, the athlete had to bend forward 45° (estimated visually) or had to be in the defensive stance with the toe of the stick between the athlete's knees and the ground. Jockeying for position, bent over resting on stick while game time was still running, and channeling were included as prolonged forward flexion. Prolonged forward flexion did not include the slight forward bend of the trunk associated with upright running or bending to fix clothing or equipment. Timing of the movement started when the position was attained (not the initiation of the movement) and ended when upright standing (or the athlete's habitual upright posture) was attained. If an athlete moved directly from a position of forward flexion to a tackle, reception, bounce pass, or tip (i.e. the athlete did not stand up prior to the tackle) the timing of prolonged forward flexion ended when the ball contacted the stick. If distinct movements (e.g. lunge tackle, strong side push) occurred during periods of contesting the ball, the discreet movements were recorded rather than the prolonged forward flexion. If no distinct movements or no clear ball control occurred during contesting the ball, prolonged forward flexion was timed. In practices, prolonged forward flexion had to occur during the drill, not while waiting for instructions or for the drill to start.

A squat position was defined as both feet being in contact with the ground and parallel at the time of ball contact or attempt to tackle. The trunk had to be centered in between the feet, not toward one leg or the other. A lunge position was defined as either one foot being in contact with the ground at the time of ball contact or attempt to tackle, the feet being offset, or the feet being parallel but the trunk being centered over one leg.

The plant foot was defined as the foot in contact with the ground (one foot) or over which body weight was centered (two feet) at the most extreme position of the movement, at the point where the direction of movement of the stick changed (i.e. if tackle or reception was missed), or at ball contact with stick.

The tackle, reception, tip, bounce pass or penalty corner stop was counted regardless of the success of the skill or attempt. If the principle investigator was unsure whether movement was a tip/bounce or a reception, the movement was counted as a reception. Channeling with a poke tackle that did not contact the ball was not considered a tackle. In the reverse stick position the toe of the stick pointed down; in the strong side position the toe of stick pointed up.

Statistical Analysis

Statistical analysis was performed using the SPSS (SPSS edition 11.5, SPSS Inc., Chicago, USA). The Mann-Whitney test ($p < .05$) was performed to evaluate significant differences in frequencies of movements between women's and men's games and between women's games and practices. The sign, Wilcoxan ranked and paired t-tests ($p < .05$) were performed to evaluate significant differences in frequencies of movements in women's games, men's games, and women's practices between left/right lunge and strong side/reverse activities. The Kruskal-Wallis test and Mann-Whitney test post hoc ($p < .05$) were performed to evaluate significant differences in the frequencies of movements in women's games and men's games between area of the field, playing position and half. The varied category for area of the field and playing position was omitted from this analysis.

RESULTS

Questionnaire

The age range of potential participants was 17 to 35 years for women (game and practice) and 15 to 53 years for men. Sixty-eight questionnaires were distributed to the women and 67 were completed (return rate 98.5%); 50 questionnaires were distributed to the men and 23 were completed (return rate 46%). A complete list of fatiguing movements and muscle groups for women and men can be found in Appendix B.

For women during games, defensive skills (i.e. low position, marking, pressuring the ball, footwork, lunging, channeling) (36), running or sprinting with the ball (16) and dribbling under pressure (13) were most frequently cited as activities that led to muscle fatigue. For men during games, running or sprinting with the ball (6), defensive skills (i.e. marking, 1 versus 1 defence) (5), and sprinting back on defence (4) were most frequently cited as activities that led to muscle fatigue. For women during practices, running drills with stick work or dribbling (16), lunging drills without the ball (13), footwork/agility/speed drills (12), repetitive hitting (12), sprints (11), cone drills with the ball (10), and 1 versus 1 drills (10) were most frequently cited as activities that led to muscle fatigue. A common theme related to fatigue in all the answers was, "anything repetitive when you are bent over and no chance to stand up and stretch". For men during practices, dribbling/bounding/cone drills with the ball (5), sprints and long runs (5), and lateral movement/lunging/low position drills without the ball (4) were most frequently cited as activities that led to muscle fatigue.

The most frequently listed muscles that women found fatigued in games or practices included the quadriceps (38), hamstrings (37), low back (35), calves (24) and buttocks – gluteals and piriformis – (20). The most frequently listed muscles that men found fatigued in games or practices included the hamstrings (15), low back (10), quadriceps (8), and calves (6). Body positions identified as fatiguing in games or practices by women included dribbling (21), the defensive or ready stance (15), and penalty corner pull out (13). Body positions identified as fatiguing in games or practices by men included dribbling (8), the penalty corner pull out (4), the defensive or ready stance (2), and low running (2).

Videotape

Each participant was videotaped only once. For all game and practice segments, all participants played or practiced on artificial turf. The total time recorded was 41:23:08 (hour:minute:second): 14:29:45 for women's games, 11:14:43 for men's games, and 15:38:40 for women's practices. There were fewer men's teams than women's teams in the tournament and, consequently, fewer men's game segments available for recording. The practice segments were 1.5 hours long and, therefore, the total recorded time for women in game and practice conditions was similar. For the game segments, frequency distributions for field area, playing position, and half can be found in Tables 2.1 through 2.3. No significant differences between genders and distribution of field area (chi square $p = .913$), playing position (chi square $p = .876$), and half (chi square $p = .943$) existed.

Table 2.1. Area of Field Where Participant Playing at Time of Recording

Field Area	Gender Female Frequency (%)	Male Frequency (%)
Left	11 (32.3%)	7 (28.0%)
Center	8 (23.5%)	6 (24.0%)
Right	11 (32.3%)	10 (40.0%)
Varied*	4 (11.8%)	2 (8.0%)
Total	34 (100.0%)	25 (100.0%)

* no clear distinction of playing position

Table 2.2. Player Position at Time of Recording

Player Position	Gender Female Frequency (%)	Male Frequency (%)
Forward	10 (29.4%)	7 (28.0%)
Midfield	9 (26.5%)	9 (36.0%)
Defence	12 (35.3%)	7 (28.0%)
Varied*	3 (8.8%)	2 (8.0%)
Total	34 (100.0%)	25 (100.0%)

* no clear distinction of area of the field

Table 2.3. Number of Participants Recorded in First or Second Half of Game

Half	Gender Female Frequency (%)	Male Frequency (%)
First	16 (47.1%)	12 (48.0%)
Second	18 (52.9%)	13 (52.0%)
Total	34 (100.0%)	25 (100.0%)

The results of the video analysis can be found in Tables 2.4 through 2.7. Significant differences existed between the total time recorded per participant for women's games and practices (Mann-Whitney p = .000). Consequently, to provide meaningful interpretation, all of the results were calculated to reflect 35-minute periods (one half game). As discrete movements cannot occur in fractions, frequencies were rounded to whole numbers, except where doing so would create a frequency of 0. For frequencies that would have resulted in 0, the frequency was reported to two significant decimals to show that this movement did occur in the course of an entire game or practice. Times were rounded to the nearest 100th of a second.

Table 2.4. Average Frequencies of Discrete Movements in Games and Practices

Movement			Game – Women Mean(range)/35 min	Game –Men Mean(range)/35 min	Practice – Women Mean(range)/35 min
BALL PROPULSION					
Stationary					
Strong side					
	Push*	Off left	3 (0-9)	3 (0-21)	3 (0-7)
		Off right	0	0.04‡ (0-1)	0.28‡(0-3)
		Total	3	3	3
	Drive		2 (0-12)	1 (0-6)	5 (0-14)
	Sweep		0.03‡ (0-1)	0	0.30‡ (0-2)
	Flick		0.03‡ (0-1)	0	0.24‡ (0-2)
	High Flick		0.08‡ (0-1)	0.17‡ (0-2)	0.49‡ (0-6)
	Stroke		0	0	1 (0-10)
	Drag Flick		0	0.04‡ (0-1)	0
Reverse					
	Push	Off left	0.06‡ (0-1)	0.27‡ (0-1)	0
		Off right	0	0	0.03‡ (0-0.38)
		Total	0.06‡	0.27‡	0.03‡
Penalty Corner Pull out			1 (0-7)	0.29‡ (0-4)	1 (0-8)
Running					
Feet Forward†					
Strong side					
	Push	Off left	1 (0-4)	1 (0-6)	0.49‡ (0-2)
		Off right	0.50‡ (0-4)	1 (0-6)	1 (0-4)
		Total	2	2	1
	Drive		0	0	0.06‡ (0-1)
	Sweep		0	0	0.25‡ (0-2)
	Flick		0.07‡ (0-2)	0.09‡ (0-2)	0
Reverse					
	Push	Off right	0	0	0.04‡ (0-1)
Feet Sideways†					
Strong side					
	Push	Off left	3 (0-15)	4 (0-11)	4 (0-10)
		Off right	1 (0-6)	2 (0-7)	1 (0-3)
		Total	4	6	5
	Drive	Off left	1 (0-10)	1 (0-7)	9 (0-27)
		Off right	0.32‡ (0-2)	0.23‡ (0-2)	1 (0-4)
		Total	1	1	10
	Sweep	Off left	0.07‡ (0-1)	1 (0-6)	1 (0-3)
		Off right	0.03‡ (0-1)	0	0
		Total	0.10‡	1	1
	Flick	Off left	0	0.09‡ (0-1)	1 (0-6)
		Off right	0.06‡ (0-2)	0.04‡ (0-1)	0.15‡ (0-1)
		Total	0.06‡	0.13‡	1

...continued

Movement			Game – Women Mean(range)/35 min	Game –Men Mean(range)/35 min	Practice – Women Mean(range)/35 min
Feet Sideways†					
	Reverse				
	Push	Off left	0.27‡ (-0-3)	0.21‡ (0-1)	1(0-2)
		Off right	0.11‡ (0-2)	0.05‡ (0-1)	1(0-6)
		Total	0.38‡	0.26‡	2
	Drive	Off left	0.03‡ (0-1)	0.05‡ (0-1)	0.16‡ (0-1)
		Off right	0.08‡ (0-2)	0	0.33‡ (0-3)
		Total	0.11‡	0.05‡	0.49‡
	Sweep	Off right	0	0	0.03 (0-0.40)
	Flick	Off left	0	0.04‡ (0-1)	0.03‡ (0-0.38)
		Off right	0	0.12‡ (0-2)	0.22‡ (0-1)
		Total	0	0.16‡	0.25‡
SQUAT POSITIONS					
Tackle					
	Strong side		1 (0-5)	0.34‡ (0-2)	2 (0-14)
	Reverse		0.14‡ (0-4)	0.19‡ (0-2)	0.19‡ (0-1)
Reception					
	Strong side		2 (0-7)	3 (0-10)	5 (0-12)
	Reverse		0.34‡ (0-3)	1 (0-5)	0.20‡ (0-2)
Tip/Bounce Pass					
	Strong side		0.09‡ (0-2)	0.12‡ (0-2)	0.49‡ (0-2)
	Reverse		0	0.09‡ (0-2)	0.03‡ (0-0.38)
Penalty Corner Stop					
	Reverse		0	0.04‡ (0-1)	0
LUNGE POSITIONS					
Tackle					
	Strong side				
		Left	4 (0-8)	3 (0-9)	2 (0-9)
		Right	4 (0-11)	2 (0-9)	2 (0-7)
	Reverse				
		Left	1 (0-6)	1(0-5)	1 (0-3)
		Right	1 (0-6)	0.39‡ (0-2)	1 (0-5)
Reception					
	Strong side				
		Left	4 (0-10)	5 (0-11)	5 (2-16)
		Right	5 (0-13)	4 (0-8)	8 (3-30)
	Reverse				
		Left	2 (0-10)	2 (0-11)	2 (0-5)
		Right	1 (0-8)	1 (0-2)	1 (0-3)
Tip/Bounce Pass					
	Strong side				
		Left	1 (0-3)	0.24‡ (0-2)	1 (0-1)
		Right	0.41‡ (0-3)	0.04‡ (0-1)	1 (0-8)
	Reverse				
		Left	0.21‡ (0-3)	0.16‡ (0-2)	0.06‡ (0-1)
		Right	0.08‡ (0-2)	0.05‡ (0-1)	0
Penalty Corner Stop					
	Reverse				
		Right	0	0	1 (0-9)

* All movements are assumed to involve a left plant foot ("off left") unless otherwise noted; "off right" indicates a right plant foot

† Feet forwards = feet pointing in the same direction the ball was propelled; feet sideways = feet pointing at any angle that was not the same as the direction of ball movement with the initial approach of the trunk and shoulders being perpendicular to the direction of ball movement.

‡ Frequencies were rounded to the closest whole number. For frequencies that would have resulted in "0", the frequency was reported to 2 significant decimals to show that this movement did occur in the course of an entire game or practice.

Table 2.5. Frequency and Duration of Movement with the Ball

	Game – women Mean (range)/35 min	Game – men Mean (range)/35 min	Practice – Women Mean (range) /35 min
Number of carries	3 (0-12)	4 (0-10)	5 (0-11)
Total time of carries (sec)	10.29 (0-41.28)	11.91 (0-34.68)	19.86 (2.11-67.55)
Percentage of 35 minutes	0.49	0.57	0.94
Average time for individual carry(sec)	2.78 (0-10.19)	2.73 (0-6.60)	4.15 (2.03-33.56)

Table 2.6. Frequency and Duration of Prolonged Forward Flexed Positions

	Game – women Mean (range)/35 min	Game – men Mean (range)/35 min	Practice – Women Mean (range) /35 min
Number /35 minutes	24 (4-60)	13 (2-33)	16 (1-25)
Total time forward flexed (sec)	132.58 (11.23-378.22)	58.45 (4.59-142.33)	94.77 (19.18-212.56)
Percentage of 35 minutes	6.31	2.78	4.51
Average time for single forward flexed position (sec)	5.39 (3.15-9.33)	4.39 (2.10-9.81)	6.73 (2.62-19.66)

Table 2.7. Frequency of Movements From Upright Standing to Squat or Lunge Position

	Game – women Mean (range)/35 min	Game – men Mean (range)/35 min	Practice – Women Mean (range)/35 min
Total Number of Up and Down* movements †	68 (23-116)	56 (7-89)	82 (57-128)
Total lunges	37 (8-67)	34 (0-57)	52 (30-92)
Left lunges ‡	23 (8-49)	24 (0-43)	36 (13-61)
Right lunges §	13 (0-34)	10 (0-25)	17 (4-31)

*Up and Down: hip and back flexion with/without trunk rotation and side flexion
† Calculated as prolonged forward flexion positions + carries of the ball + all other movements
‡ Calculated as all ball propulsion off left + all left lunge positions
§ Calculated as all ball propulsion off right + right lunge positions

Significant differences were found between women's and men's games for the following: stationary strong side push off right and reverse push; running feet forward strong side push off right; running feet sideways strong side sweep; total time of prolonged forward flexion per player, frequency of prolonged forward flexed positions, and average time per prolonged forward flexion position; left lunge strong side tipping/bounce, and; right lunge strong side tackle and strong tipping/bounce. Exact p-values for all measurements can be found in Appendix E.

Significant differences were found between women's games and practices for the following: stationary strong side pushes off right, strong side sweep, and strokes; running feet forward strong side sweep; running feet sideways strong side drive, strong side sweep, strong side flick off right, reverse push off right, and reverse flick off right; total time of ball handling; squat reverse tackle, strong side reception, strong side tipping/bounce; left lunge strong side tackle; right lunge strong side tackle, and; total frequency of lunges and total frequency of left lunges.

Significant differences were found in women's games for the following: stationary strong side push and strong side push off right, stationary strong side drive and strong side drive off right; running feet sideways strong side push and strong side push off right; squat strong side tackle and reverse tackle, squat strong side reception and reverse reception; left lunge reverse reception and right lunge reverse reception, and; total frequency of left lunges and total frequency of right lunges. Exact p-values for all measurements can be found in Appendix F.

Significant differences were found in men's games for the following: stationary strong side push and strong side push off right, stationary strong side drive and strong side drive off right, stationary reverse push and stationary reverse push off right; running feet sideways strong side push and strong side push off right, running feet sideways strong side sweep and strong side sweep off right; squat strong side reception and reverse reception; left lunge reverse tackle and right lunge reverse tackle, and; total frequency of left lunges and total frequency of right lunges.

Significant differences were found in women's practices for the following: stationary strong side push and strong side push off right, stationary strong side drive and strong side drive off right; running feet sideways strong side push and strong side push off right, running feet sideways strong side drive and strong side drive off right, running feet sideways strong side sweep and strong side sweep off right; squat strong side reception and reverse reception, squat strong side tipping/bounce and reverse tipping/bounce, and; total frequency of left lunges and total frequency of right lunges.

For area of the field, no significant differences were found in women's games but in men's games squat strong side tackle occurred less frequently on the right than the centre or left ($p = .028$).

For playing position in the women's game, stationary strong side push ($p = .007$), stationary strong side drive ($p = .018$), running feet sideways strong side push ($p = .015$), total frequency of lunges ($p = .025$), and total frequency of left lunges ($p = .020$) all occurred more frequently in the midfield and defence than in the forwards. Left lunge strong side tipping/bounce occurred more frequently in defence than in forwards ($p = .038$)

For playing position in the men's game, running feet sideways strong side push ($p = .009$), total frequency of lunges ($p = .018$), and total frequency of left lunges ($p = .033$) all occurred more frequently in the midfield and defence than in the forwards. Running feet sideways strong side push off right ($p = .004$), left lunge reverse tackle ($p = .013$), right lunge strong side reception ($p = .049$), and total frequency of right lunges ($p = .027$) occurred more frequently in the midfield than in the defence or forwards.

Of interest, for playing position in both women's and men's games, the total frequency of up and down movements neared significance ($p = .062$) with higher frequency for midfield and defence than forwards.

For half in the women's game, squat reverse reception ($p = .046$) and left lunge reverse reception ($p = .011$) both occurred more frequently in the first half. For half in the men's game, left lunge reverse tackle ($p = .045$) and right lunge strong side reception ($p = .029$) both occurred more in the second half than the first.

DISCUSSION

Comparison to Other Time-Motion Analyses

Most time-motion analyses do not count distinct movements. Rather, they quantify the time athletes spend standing, walking, jogging, cruising, sprinting and performing sport-specific activity.[40, 41] Consequently, comparison of this task description to other studies is difficult. There were also no other time-motion analyses performed for men's field hockey or women's practices.

Lothian and Farally[38] performed a time-motion analysis of women's field hockey in England. They videotaped 12 National senior or under-21 athletes playing in first or second division National league matches and analyzed mean length of time for stand, walk, walk backward/sideways, jog, jog backward/sideways, cruise, cruise backward/sideways, sprint, and hockey related activities (combined from dribbling, passing, shooting, tackling). A cruise was a constant speed running movement faster than a jog and slower than a sprint. The maximum time any player was involved with the ball (field hockey related activities) on a single occasion was 10 sec (s). This is similar to the maximum time for a ball carry in the present study for women's games (10.19 s), greater than the maximum time for men's games (6.60 s), and much smaller than the maximum time for women's practices (33.56 s) (Table 2.5). Lothian and Farally[38] found that midfield players were involved in significantly more changes of activity than either defenders or forwards ($p < .05$). The present study found significant differences for running feet sideways strong side push off right, left lunge reverse tackle, right lunge strong side reception, and total frequency of right lunges between midfielders and defenders or forwards. It is likely that the greater change in activity in midfielders noted by Lothian and Farally is related to the differences in discrete movements seen in this study. However, there were a number of movements that were similar between defenders and midfielders, but different for forwards (stationary strong side push, stationary strong side drive, running feet sideways strong side push, total frequency of lunges and total frequency of left lunges). Consequently, the strength of the relationship between Lothian and Farally's findings and those of the present study is uncertain. A similar pattern to that observed in the women's games occurred in the men's games in the present study.

Robinson, Murphy, and O'Donoghue[42] performed a time-motion analysis to quantify the extent and type of movement activity displayed by elite female hockey players during competition. After analyzing 22 athletes over two mid-season matches on turf, they found that the total time spent executing movements with the ball constituted 3% of the duration of the match. The present study found a smaller percentage of movement with the ball (0.98 % of a match for women's games; 1.14 % for men's games) (Table 2.5). While the study by Robinson, Murphy, and O'Donoghue[42] timed all contact with the ball (receptions, tackles, propulsion, dribbling), the present study only timed dribbling which may account for the differences seen in the percentages between studies. The results of both studies imply that ball possession in a game is very brief. Similar to Lothian and Farally,[38] Robinson, Murphy, and O'Donoghue also found that midfielders spent a significantly greater percentage of total match time performing high intensity activities (jogging, running, sprinting, field hockey activity) than both forwards and defenders. Again, it is likely that the greater change in activity in midfielders is related to the differences seen in this study of discrete movements, but the exact nature of this relationship is unclear.

Kingman and Dyson[43] filmed 16 male roller hockey players (4 players per team over 2 English premier League Roller Hockey matches). In addition to the physiological analysis, they quantified the frequency of discrete movements. In roller hockey, they found the following frequencies for shooting: forehand flick 91; backhand flick 21; forehand slap 86; backhand slap 47. The Kingman and Dyson study showed a predominance of forehand puck propulsion movements. Similarly, the present study showed a predominance of forehand (i.e. strong side) ball propulsion (Table 2.4).

Cause of Injury

Significant differences were found for many movements between women's and men's games, women's games and practices, left versus right and strong side versus reverse, area of the field, playing position, and game half (i.e. 1st or 2nd). These findings are considered throughout the remaining discussion with respect to the activities or movements in field hockey that could be related to the possible mechanical causes of low back pain. For those differences not mentioned, the frequency of the movement was small enough (typically 0-1) that the finding was felt to have no clinical significance.

Static Muscle Loading

Static and prolonged positions near the end range of joint ROM are thought to be related to chronic injury by creating an environment where muscles do not receive adequate oxygenated blood.[7, 8] Prolonged forward flexion and ball handling are the two static activities in relation to low back position that occur in field hockey. This study showed that one bout of prolonged forward flexion is held on average 5.39, 4.39, and 6.73 s respectively for women's games, men's games, and women's practices, and that a single ball carry lasts on average 2.78, 2.73, and 4.15 s respectively for women's games, men's games and women's practices (Tables 2.6 and 2.5, respectively).

The average total time for prolonged forward flexion ranges from 1 minute (min) 57 s to 4 min 25 s of a men's and women's game and 3 min 9 s of a women's two hour practice (Table 2.6). The average total time for ball handling ranges from 20.58 to 23.82 s of a women's or men's game and 67.92 s of a women's two hour practice (Table 2.5).

In tests of low back muscular endurance where a horizontal position is held against gravity for as long as possible (Sorenson test), the average time for holding the static position for healthy individuals is 3 min.[44] Only total time for prolonged forward flexion in women's games and practices surpasses this test time. However, in games and practices, this total time is divided into 3 to 7 s segments. It is unlikely that, by themselves, the length of prolonged forward flexion and ball handling would be a major risk factor for low back pain in field hockey.

Type of Movement and Posture

Strong side activities were the most frequently occurring movements in the present study. Stationary, running feet forward, and running feet sideways strong side push, the stationary strong side drive, and squat and lunge strong side receptions and tackles occurred frequently for women's and men's games and women's practices. Running feet sideways strong side drive also occurred frequently in women's practices, and was significantly different from women's games. All of these movements involved a combination of knee, hip, and lumbar spine flexion combined with rotation and side flexion. Since movements with these torsional stresses are poorly tolerated in the lumbar spine and combined movements of lumbar spine flexion and rotation carry the highest injury potential,[9] the documented frequency of this movement pattern in the present study may be a contributing factor to the incidence of field hockey related LBP.

Constrained posture is defined as extreme or awkward ranges of motion. In field hockey, the most frequent movements of strong side push and strong side drive all involve rapidly and forcefully rotating the trunk from an extreme of right rotation to an extreme of left rotation with the lumbar spine flexed. In addition, men demonstrated a significantly higher frequency of running feet sideways strong side sweep than women in games. This technique involves forceful rotation with the entire stick flat on the ground – a more extreme position of forward flexion than the push or drive. Its increased frequency in the men's game may place men at greater risk of injury than women. Constrained postures are also found in lunge tackles and receptions. The force required to propel or contest the ball is intertwined with the postural stresses of the extreme position of forward flexion and left and right rotation. Again, performing these tasks can overload the muscles and joints and lead to injury[8] and, thus, may be linked to field hockey related LBP.

Repetition and Fatigue

Muscular endurance refers to how well a muscle can sustain the required force during repeated activation.[12] Decreased local muscular endurance has been found to be one of the significant risk factors in the development and incidence of chronic LBP.[12-15] For women and men during games, common activities most frequently cited as muscularly fatiguing included defensive skills (i.e. low position, marking, pressuring the ball, footwork, lunging, channeling, 1 versus 1 defense) and running or sprinting with the ball (Tables 1 and 2, Appendix B). For women and men during practices, common activities most frequently cited as muscularly fatiguing included running drills with stick work or dribbling/bounding/cone drills with the ball, lunging/lateral movement drills without the ball and sprints (Tables 3 and 4, Appendix B). Body positions identified as fatiguing in games or practices by women and men included dribbling, the defensive or ready stance, and the penalty corner pull out (Tables 7 and 8, Appendix B).

The frequency of low defensive skills and lunging/lateral movement drills without the ball was accounted for predominantly by prolonged forward flexion. Positions of prolonged forward flexion occur roughly twice per 3 min of a women's game, once per 3 min of a men's game, and once per 2.5 min in a women's practice. On average, prolonged forward flexion is only held roughly 5.5 s. As there was, on average, a *minimum* of 60 s rest between prolonged positions, the frequency alone does not pose a significant risk for injury. Even though the frequency of prolonged forward flexion, total time in prolonged forward flexion, and average time per prolonged forward flexion were all significantly higher in women's games than men's games, there was still adequate rest available to women such that they were not at increased risk of injury. Running or sprinting with the ball and dribbling/bounding/cone drills with the ball were captured in movement with the ball. Movement with the ball occurred infrequently with one 3.2 s (average) carry every 7 to 12 min of a game or practice. Again, this frequency alone did not pose a significant risk. The penalty corner pull out occurred very infrequently (0.29-1 time per 35 min of play or practice).

Repetition strains occur most frequently from cumulative loading of muscle, tendon, capsules, and ligaments due to repeated movement with an associated force.[7,8] Work tasks requiring over 400 repetitive trunk motions per week and those requiring bending, twisting, and lifting over 25 times per day (with a weight of 11.3 kg) were associated with a high risk for herniated disc and back injury.[5,45] Twisting while lifting 11.3 kg increased the risk of injury even if the lifting was done less frequently than 25 times.[45]

The frequency of movements reported in field hockey games from the current data set suggested that there was no one movement that would meet these criteria in a single game for either women or men. However, in the Senior National tournament filmed for the present study, there were 6 to 7 games played by each women's or men's team over the course of 6 days. While there was still no single movement, on average, that occurred with this frequency over the course of the tournament, when the ranges of frequencies were considered, there were individuals who met this criteria.

A different picture emerged with practices and when movements were combined. A typical women's practice lasted 2 hours. There were movements, such as running feet sideways strong side drive and right lunge strong side reception, that occurred more than 25 times per practice. Although no measurement was taken, it is possible that the musculature used to produce rapid movement of the ball produced a force nearing or greater than 11.3 kg. When movements were combined, a more significant picture emerged. Almost all of the movements in field hockey involve hip and back flexion with trunk rotation and side flexion. When one considers the total frequency of these up and down movements, both women and men on average will reach the 400-repetition threshold within the course of a tournament, and women on average will reach this threshold in 3 hours of practice. In rowing, a sport that, like field hockey, involves repetitive forward flexion and rotation, it has been found that a rower training for a single session of 90 min covers 20-25 km and performs approximately 1800 cycles of flexion.[46] This repetitive cyclic action of flexion and twisting in rowing was felt to predispose the rower to low back injury.[46] Similar to rowing, the repetitive nature of up and down movements in field hockey posed increased risk for LBP.

Running feet forward strong side drive, total lunges, total left lunges, and total time of ball handling occurred significantly more in women's practices than in games. Frequency, total time, and average time per prolonged forward flexion occurred significantly more in women's games than in men's. These findings indicate that certain players might reach this threshold more quickly than others and, consequently, would be at a higher risk for injury. The effect of these repetitions was increased with the added physiological fatigue of running during a 70-min game or 2-hour practice.

Asymmetric Activity

The combined effects of flexion and rotation on the lumbar spine make asymmetric tasks more dangerous than symmetric tasks.[21] The predominance of strong side activities that move through extremes of combined low back flexion, rotation and side flexion, fatiguing movements in forward flexed positions, and repetition of hip flexion and combined back forward flexion, rotation and side flexion more than 400 times per week all have a worsened effect in the presence of asymmetrical loading.

Field hockey is inherently asymmetric. The field hockey stick is flattened on one side and rounded on the other. The rules of field hockey allow the ball to contact only the flattened side of the stick. Consequently, all field hockey players hold the stick in a right-handed position (they "shoot right"). This right-sided stick position is called "strong side." The stick is flipped to keep the flat side in contact with the ball when it is taken to the left of the body and this position is called "reverse." The strong side and reverse labeling of skills implies a difference in the performance of the associated skills. For all games and practices, significant differences were found between plant foot (off left versus off right) for stationary pushes and drives and running feet sideways strong side pushes. In addition, women's practices showed a significant difference between plant foot in running feet sideways drives. In all of these movements, muscle force is generated to propel the ball through asymmetric movement. For all games and practices, significant differences were found between strong side and reverse squat receptions. All these movements were the most frequently occurring movements in their respective groupings (i.e. stationary, running feet sideways, and squat). Finally, a significant difference for all games and practices was found in the total number of left versus right lunges. In fact, there was only 1 participant of 71 who lunged more frequently on the right leg than the left. For women's and men's games, running feet forward strong side push, total lunges, and total left lunges occurred significantly more frequently in the midfield and defense positions than in the forward position. In women's games, stationary strong side pushes and drives also occurred significantly more frequently in the midfield and defense positions than in the forwards. In men's games, total right lunges also occurred significantly more frequently in the midfield than in the defense or forwards. These differences indicated the potential for increased injuries in positions in which asymmetric movements occurred more frequently.

Limitations

Any task description involves a subjective component. The methods used to collect information regarding the activity from major stakeholders currently involved with the activity depend on the researcher's preference.[32] The decomposition of the component activities is based upon past data and the researcher's past experience.[29,31,32] As such, two different researchers may develop two different task descriptions based solely on the operational definitions employed. Even with specific coding instructions, the results of any task description by a will not be completely reproducible.[47] The addition of an interrater reliability measure would enhance the reproducibility of the findings of the present study.

The questionnaire return rate was considerably lower for men than women. The reason for this difference is unclear, but sport culture differences between men and women may have been involved. The poor return rate for the men's questionnaires decreased the generalizability of these results and hindered the comparison to the female participants. There was some overlap between male game participants in this study and players involved in club and national team levels of Canadian field hockey. Consequently, while the results of the game portion of this study could be generalized to some extent to club and national team players, further investigation at the club and national level is recommended. There was a significant overlap in the female participants and players involved in university and national team levels. Consequently, the findings from the women's portion of this study can be generalized to these groups.

The coding definition for prolonged forward flexion led to an underestimation of some forward flexion motions. Specifically, oscillations less than 2 s into forward flexion where no distinct movement was performed, the forward flexion movement associated with a non-controlled ball carry, and positions of 10° to 30° of forward flexion that appeared to be the participant's habitual upright position were not recorded. Quality of practices (e.g. skill development, game play or set play) and games (more defensive or more offensive) were not considered for this study. Consequently, the impact of these factors was not considered in the analysis.

CONCLUSIONS

The purpose of this study was to identify potential mechanical exposure factors that might be related to low back injury in field hockey and to quantify and compare these factors for women and men in game and practice settings. Mechanical exposure factors included static muscle loading in prolonged positions, type of movement, posture, repetitive bending, twisting or lifting, and asymmetric loading.[4-7].

The hypothesis was that movements that incorporated repetitive or prolonged forward flexion of the trunk, repetitive twisting of the trunk, and repetitive squatting or lunging would predominate in the sport of field hockey. This hypothesis was supported based on the observed findings.

Field hockey is frequently characterized as a sport that requires sustained forward flexion of the spine[1,3,26,48] and this position is equated with an increased risk of injury. The results of this study show that the prolonged static positions of forward flexion and ball handling are brief (5.50 s and 3.22 s overall average, respectively) and by themselves are unlikely to produce significant injury. Field hockey would be better characterized as a sport with frequent movements in and out of lumbar spine forward flexion, rotation, and side flexion. When all the movements that combined lumbar spine forward flexion, rotation, and side flexion and hip flexion (up and down movements) were totaled, both women and men, on average, reached the 400-repetition threshold associated with high risk for back injury within the course of a tournament and women on average reached this threshold in 3 hours of practice.

The strong side movements that combine knee, hip, and lumbar spine flexion with spine rotation and side flexion are known to be poorly tolerated in the lumbar spine and carry the highest potential for injury.[9] The most frequently occurring ball propulsion movements (strong side push and strong side drive) all involved rapidly and forcefully rotating the trunk through the constrained posture of extreme right rotation to extreme left rotation with the lumbar spine flexed. Similar constrained postures were also found in lunge tackles and receptions.

In the most frequently occurring ball propulsion movements (stationary pushes and drives and running feet sideways strong side pushes), participants lunged to the left significantly more than to the right. The muscle force generated to propel the ball occurred through asymmetric movement. Overall, a significant difference for all games and practices was found in the total number of left versus right lunges. In addition to the repetition of asymmetric movement increasing the effect of the other risk factors, it is possible that over time, these asymmetric patterns might create a mechanical imbalance, an intrinsic risk factor associated with low back injury. Mechanical imbalance is defined as an alteration of structure and function which is reflected in combinations of muscle tightness and weakness, ligamentous laxity, and/or poor alignment of body segments.[49] Mechanical imbalances alter the kinetic chain and, either alone or combined with repetitive loading of the spine as seen in field hockey, may predispose a person to injury.[48,50,51]

This study found some significant differences in movements between midfielders and defenders and forwards similar to those found in physiological time-motion analyses. It is possible that the greater change in activity in midfielders noted in these physiological time-motion analyses was related to the differences seen in this study of discrete movements, but the exact nature of this relationship is unclear. It is possible that midfielders may be at greater risk for injury than other positions.

FUTURE DIRECTIONS

While it is possible, through the present study, to identify extrinsic risk factors that are likely to be related to LBP, future task descriptions combined with injury statistics would provide a clearer picture of the links between risk factors and LBP, and could help determine whether athletes performing more repetitions of movement are more predisposed to injury.

Given the repetitive and asymmetric nature of the sport, it is possible that intrinsic risk factors, such as mechanical imbalance, may be affected by the nature of the sport. Investigation of these intrinsic factors would provide more information on the cause of LBP in field hockey.

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CHAPTER 3: PILOT STUDY: CLINICAL MEASURES TO DETECT MECHANICAL IMBALANCE

Low back pain (LBP) is related to mechanical and individual exposure factors. Mechanical exposure factors are typically extrinsic to the body and include static muscle loading in prolonged postures (e.g. standing or sitting), the force used to perform the task, the type of movement, repetitive bending, twisting or lifting, fatigue, sudden forceful incidents, constrained working postures and asymmetric loading.[1-4] Individual exposure factors are typically intrinsic to the body and include posture, trunk extensor and flexor strength and muscular endurance.[1] The potential impact of the combined effects of many of these risk factors is the development of mechanical imbalance -- an alteration of structure and function which is reflected in combinations of muscle tightness and weakness, ligamentous laxity and/or poor alignment of body segments.[5] The measurement of such imbalances was of particular interest in the present study.

LBP is a common occurrence in sport and its presence in field hockey has been identified as an area of concern by many authors.[6-8] Field hockey is an inherently asymmetric sport where one might expect to find a sport induced mechanical imbalance. In order to detect mechanical imbalance in field hockey, there is a need to develop reliable and valid measures. By establishing and verifying convenient clinical and sport specific measures related to mechanical and individual exposure factors, the results of this study could serve as a precursor to future exploratory research on the presence of mechanical imbalance in field hockey.

Purpose

The purpose of this study was threefold: to create a testing battery to investigate left-right mechanical imbalance in the low back and hip in field hockey participants, based on clinical and activity sport specific measures; to develop tests that allow practical application to clinical practice, and; to establish the reliability and validity for this battery of tests.

Hypothesis

Reliable and valid clinical and sport specific measures, including range of motion, isometric strength, muscular endurance and power to detect left-right mechanical imbalance in field hockey can be developed.

LITERATURE REVIEW

Justification for Testing

Vincenzo and Vincenzo[5] define mechanical imbalance as an alteration of structure and function that is reflected in combinations of muscle tightness and weakness, ligamentous laxity and/or poor alignment of body segments. The works of Vladimir Janda, Shirley Sahrmann and Diane Lee have all contributed to the understanding of mechanical imbalance. Janda[9-16] related the patterns of tightness and weakness to patterns of hyper- and hypotonia common between cerebral lesions and postural syndromes. Sahrmann[17] related the patterns to use and positional length and strength changes in the muscle. Lee[18-20] identified muscular units that provide a stable base through the lower quadrant and described normal mechanics of low back and hip movement and altered mechanics that could occur with mechanical imbalance. While the cause of changes in muscle length and strength associated with muscle balance (e.g. reflex pain response, changes in activation, adaptive structural changes, peripheral paresis or spasticity, ischemia, synergist predominance) are a subject of debate, there is considerable agreement on the consequence of these changes. It should be noted, however, that the relationship of muscle imbalance to injury is theoretical.

Mechanical imbalance is believed to cause injury in the following fashion. Muscles held in either shortened or lengthened positions from the ideal posture will alter the efficiency of normal muscle contraction and thus cause the muscle to be used at a mechanical disadvantage.[21,22] When a muscle or group of muscles are placed at a mechanical disadvantage, subtle shifts in the pattern of motor activity occur. Synergistic muscles compensate for the prime mover muscular strength deficit and attempt to generate the necessary forces required for functional tasks.[21-23] With prolonged static holding or repetitive movement, prime movers can become so fatigued that they are unable to generate the force required to perform the desired activity correctly. Again, synergistic muscles will compensate for the prime movers. This muscle substitution of synergistic muscles both creates and perpetuates the problem of muscle imbalance[21,22] Without correction of the muscle imbalance, tight muscles become tighter, weak muscles become weaker and overused muscles continue to be overused.[21] The kinetic chain is altered and the breakdown in the effective function of the kinetic chain may predispose a person to injury.[24]

Mechanical imbalance develops in an environment of repetition and fatigue, forceful load and asymmetric activity. Repetition strains occur most frequently from cumulative loading of muscle, tendon, capsules and ligaments due to repeated movement with an associated force.[4,22] Work tasks requiring over 400 repetitive trunk motions a week were associated with a high risk for back injury.[2,25] In Chapter 2, the movement patterns of field hockey were described. Stationary and running strong side push, stationary strong side drive and squat and lunge strong side receptions and tackles occurred frequently (pictures of these movements can be found in Appendix D). All of these movements involve a combination of knee, hip and lumbar spine flexion combined with rotation and side flexion, and ball propulsion adds a rapid and forceful load. When one considers the total frequency of these forceful repetitive movements, the 400-repetition threshold was reached within the course of a 5-day tournament and within 3 hours of practice (Chapter 2).

The field hockey stick is flattened on one side and rounded on the other. The rules of field hockey allow the ball to contact only the flattened side of the stick. Consequently, all field hockey players hold the stick in a right-handed position (they "shoot right"). This right-sided stick position is called "strong side." The stick is flipped to keep the flat side in contact with the ball when it is taken to the left of the body and this position is called "reverse." The strong side and reverse stick positions make field hockey an inherently asymmetric sport. Strong side and reverse skills are performed differently. In Chapter 2, strong side activities were found to predominate and were the most frequently occurring movements in field hockey. For all games and practices, players planted on the left foot significantly more than on the right foot for stationary pushes and drives and running strong side pushes, consequently propelling the ball through asymmetric movement.

Finally, for all games and practices, players lunged significantly more to the left than to the right while performing field hockey skills (Chapter 2).

Repetition of movement has been documented in other studies. During games and practices, players spend a prolonged amount of time in the end range position of thoracolumbar flexion while dribbling, passing, receiving and contesting for the ball.[6, 7, 26] High demands were placed on the thoracic and lumbar paraspinal muscles for endurance, eccentric and concentric strength.[27] From the position of thoracolumbar flexion, the player must twist forcefully from the hips and trunk to perform passing and shooting skills effectively. Each player must be able to hit the ball with power and accuracy; the skills of dribbling, flicking, pushing and trapping of balls require skill and considerable muscular strength and endurance.[6, 28] Consequently there is the potential for adaptive tissue change, strain and fatigue from the repetitive and forceful movements in this extreme thoracolumbar flexion and from the work rate of the sport.[28]

Certain mechanical patterns have been noted previously in field hockey. Male and female players have similar postural characteristics.[6] "Hockey player's back" has been described as a long, flat curve in the thoracolumbar region with a noticeable absence of the normal smooth physiological curves in the sagittal plane, sometimes with some muscular asymmetry on the right side and a mild lateral curve to the right in the thoracolumbar region.[6, 27]

Given these findings, it is likely that field hockey is a sport in which mechanical imbalances could occur. Some studies have investigated mechanical imbalance in field hockey. Fenety and Kumar[27] investigated the clinical reports that female field hockey players with LBP had reduced lumbosacral sagittal isokinetic strength and range of motion. The researchers found that low back pain-free field hockey athletes were stronger in peak eccentric extension versus a LBP group, and that non-athletes had the highest peak eccentric extension. With respect to range of motion (ROM), Fenety and Kumar[27] found that LBP field hockey players had 12° to 18° less extension and 18° to 24° less total ROM than their pain-free counterparts. Lindgren and Twomey,[6] in a study on 32 Australian elite field hockey players (15 male and 17 female) between the ages of 17 and 26, measured flexion-extension and rotation lumbar spine mobility. They found that the total flexion-extension was similar for field hockey players and a non-field hockey control group but field hockey players showed greater total rotation than the control group.[6] Hoens, Telfer and Strauss[28] evaluated the isokinetic strength of trunk extensors and flexors of 11 elite female field hockey players utilizing a Kin Com II dynamometer at 30 and 60 degrees/second. They found that the trunk extensors possessed a greater average torque than trunk flexors. The greater trunk extensor torques were expected because of the sport specific requirements of maintaining long periods of trunk flexion and repeated extension in execution of game skills such as dribbling, tackling, flicking and scooping.[28] Unfortunately, except for Lindgren and Twomey's[6] investigation of trunk rotation, these studies do not specifically investigate differences between sides of the body. Considering that field hockey has been shown to be a left-right asymmetric sport, methods to evaluate left-right mechanical imbalances need to be developed.

Selection of Testing Methodology

The ability of individuals to perform tasks is influenced by the flexibility, strength and endurance of the trunk and hip muscles and the ability of these muscles to initiate and control movement of the trunk and extremities, provide stabilization of the lower spine segments and distribute forces within the abdominal and thoracic cavities.[1,29,30] Mechanical imbalance is reflected by alteration of muscle flexibility, strength and endurance.[5] Considering this overlap, any measurement of left-right mechanical imbalance should include the parameters of flexibility, muscular strength and muscular endurance. To evaluate left-right differences, all measures must include movements that can be differentiated into left and right. Consequently, the movements assessed in the present study included hip flexion, extension, adduction, abduction, internal and external rotation and lumbar spine rotation and side flexion.

Two approaches can be taken to assess flexibility, strength and endurance. The assessment of isolated muscle groups in order to discover the capabilities of these muscles and their effect on function of the whole body is considered an "inductive" approach.[29] The largest deficit, as identified by this testing, is considered the limiting factor for performance of a specific task.[29] Testing movement and strength about a specific joint would be considered inductive and could be performed by standard clinical measurements of ROM and isometric strength.

A "deductive" approach is an analysis of the whole body while a task is being performed.[29] With this approach, it is possible to determine the strength requirements for a function, but the weakest link in the system cannot be clearly identified. Both inductive and deductive approaches are needed to relate the requirements for optimal motor function with isolated anatomical, mechanical and physiological capabilities.[29]

The testing procedures of the present study were developed based upon standard clinical procedures, a time-motion analysis of the sport of field hockey with special interest in discrete movements, a literature review of field hockey related studies and adaptations of existing functional testing methods.

Range of Motion

Goniometry or inclinometry are generally used for testing ROM of peripheral joints. In the present study, ROM was tested by inclinometer based on standardized techniques developed by Kendall and McCreary[31] and Clarkson.[32] The inclinometer is an inexpensive, hand held, circular, fluid-filled disk with a weighted gravity pendulum indicator that remains oriented in a vertical direction.[33,34] It is available with a rotating concave base that permits two point contact with skin surface and allows the inclinometer to be "zeroed" in the erect position so that the end-range reading equals the full motion.[33,35] It measures 1° increments. As with goniometric testing, this testing has been shown to have excellent intrarater reliability (ICC = 0.98 to 0.99) but poorer interrater reliability (ICC = 0.86 to 0.90).[36-38] Much of the poor reliability between clinicians is related to the clinician's selection of bony landmarks.[34,37] Many researchers recommend standardization of patient position and land marking to minimize error.[36-38] The advantages and disadvantages of goniometry and inclinometry are the same, but because inclinometers can be attached directly to the limb, the examiner has more freedom to use his/her hands for limb placement. Consequently, inclinometry was chosen for hip joint ROM.

Lumbar spine twisting and bending is most often assessed by inclinometer, functional axial rotation or lumbar rotameter. Two inclinometers are used to measure lumbar ROM. One is placed on the upper edge of sacrum to evaluate hip motion and the other is placed on the lower edge of T_{12} to measure hip and lumbar range of motion.[34, 39] Lumbar ROM is estimated as the difference between the two readings.[34, 39] This double inclinometer method measures and differentiates movements of the hip from lumbar spine, provides results in degrees and can be learned quickly.[34, 39] It has high interrater reliability for total ($r = 0.94$) and flexion ($r = 0.88$) ROM measurements, but lower reliability for extension measurements ($r = 0.42$).[39]

The functional axial rotation (FAR) method measures a combination of neck and torso rotation relative to a fixed pelvis and is considered both a ROM and functional test.[40] The FAR technique is a deductive approach. A 1-meter diameter circular hoop is placed around a seated subject and a pointer affixed to a head-piece is positioned at the subject's forehead.[40] To measure thoracolumbar rotation, neck rotation is measured first followed by the total axial rotation.[41] Thoracolumbar range is determined by subtracting neck ROM from the total rotation ROM.[41] The advantages of FAR measures are that they are designed to determine how successful a person can be in twisting without consideration for the specific impairments that might limit performance.[40] It is inexpensive and portable and has a sensitivity of 5° for detecting changes. It has excellent test-retest reliability ($r = 0.90$ to 0.95) and interrater reliability ($r = 0.97$).[40]

The lumbar rotameter consists of a large protractor strapped at right angles to the subject's sacrum and a belt with a pointer strapped around L_1.[42] Test-retest and interrater reliability tests show a 5° sensitivity. Its disadvantages are that its readings may be influenced to a minor degree by lower rib cage movements and that the test can be cumbersome, taking 3 minutes for an experienced therapist to administer.[42]

While the advantages of all the methods are similar, the inclinometer was chosen for the present study to measure lumbar spine ROM because the two-inclinometer method is more sensitive, less cumbersome in the testing procedure and easier to perform.

Muscular Strength

Common clinical strength testing measures include manual muscle testing, hand-held dynamometry, strain gauge dynamometry (cable tensiometry), isokinetic dynamometry and functional tests.

Hand-held dynamometry has the advantage of being a portable, non-invasive and inexpensive testing method that correlates with manual muscle testing and has good criterion validity with isokinetic dynamometry.[43] It is easy to use, inexpensive for clinician and patient, and requires minimal time for a testing session.[44] Research varies on the degree of reliability of the hand-held dynamometer. Factors that decrease reliability include limited strength of the tester and poor stabilization of the test limb or of the dynamometer.[43-46] Test-retest reliability measures have varied between ICC's of 0.73 to 0.98.[43,44,46] Reliability of hand-held dynamometers increases when used in conjunction with specifically designed anchoring stations that hold the dynamometer in place.[47] For studies with strong standardization and anchoring systems, reliability has been found to be excellent (r = 0.93 to 0.98).[44,47,48]

Strain gauge dynamometry involves mounting a cable tensiometer in an anchoring apparatus. The cable is most often affixed to the subject via a harness.[29] Trunk flexors, extensors and lateral flexors can be tested isometrically with subjects in standing, prone or side lying depending on the apparatus used.[29] This technique maintains the advantages of portability, non-invasiveness and portability of the hand-held dynamometer while improving reliability through standardization and stability. Strain gauge dynamometry is easy to apply in the laboratory or field and has excellent test-retest reliability (r = 0.89-0.99 when joint tested in neutral).[1]

Manual muscle testing (MMT) is considered a traditional approach and involves inductive methods for individual muscles.[29] A 5-point scale is employed where 0 means no muscular action or activation occurs, 1 is a slight contraction, 2 is movement through full ROM in a gravity independent position, 3 is minimal movement in a gravity dependent position, 4 is a considerable contraction through a full gravity dependent ROM and 5 is a maximal contraction through the full gravity dependent ROM. While MMT is easily used and portable, the strength scales are based on the clinician's perception of force through the hands and consequently MMT is felt to be a subjective measure.[29]

Isokinetic dynamometry examines muscle performance throughout a range of movement, force produced at a constant lever arm velocity (isokinetic testing) and the velocity achieved when resistance to movement is held constant (isotonic testing).[49,50] It has excellent reliability at the knee at a variety of speeds,[49] although there is variable reproducibility in isokinetic tests at moderate to high velocities (test-retest r = 0.76-0.90).[1] Studies on the reliability of isokinetic dynamometry for joints other than the knee, however, are less conclusive.[43] Reliability coefficients for joints such as the knee are higher than those of the shoulder because the knee is an easier joint to stabilize and, consequently, less muscle substitution or force oscillation occurs.[49] The inability to completely stabilize the subject during isokinetic testing of joints other than the knee may lower the test-retest reliability.[49] Other disadvantages of isokinetic dynamometry also exist. The more central the area tested (e.g. lumbar spine versus knee), the more difficult it becomes to use isokinetic dynamometry, due to difficulties with proper stabilization and with the alignment of the axis of rotation of the machine to the axis of the joint. Alignment of the joint and lever arms axes is required for interpretation of forces applied to the lever arm.[49] When the axes are aligned, the limb and machine act upon the same moment arm.[49] A complex problem arises when attempts are made to align the axis of the dynamometer with multiaxial joints such as the shoulder, hip or lumbar spine.[49,50] These joints have instantaneous axes of rotation (constantly shifting axes as the joint moves through the its range); the isokinetic dynamometer is fixed and can at best only approximate the true anatomical axis, introducing measurement error.[51] Isokinetic dynamometers are time-consuming, expensive to use, have large space requirements[44,52] and are not portable.[43,53]

While isokinetic dynamometry has become the favored method to assess dynamic muscle performance,[29,54] it is not consistently available in the clinical setting, there are difficulties applying its use to the hip and lumbar spine, and it is not portable. It was hoped that the methodology developed in the present study would allow for portability and reliability. While the disadvantage of any isometric test is that it may not fully reflect the functional capacity of the muscles due to the differences in the motor recruitment pattern in isometric and dynamic muscle contractions,[1,29] a hand held strain gauge dynamometer mounted on a anchoring frame for measurement of isometric hip and trunk strength was chosen for the present study.

Muscular Endurance

Endurance is defined as the ability of a muscle to sustain a particular level of force output during an activity. It is measured statically or dynamically either by time until a target force output cannot be sustained or by number of repetitions to exhaustion.[1,29,55,56] Endurance testing has been completed predominantly through two methods – sustained tasks or repetitive tasks. There are no "gold-standard" tests to measure trunk endurance.[52,56]

When using sustained tests of the trunk, the subject is asked to maintain a position for as long as possible. There are a number of advantages to these tests. Sustained isometric trunk endurance tests can be easily performed without any expensive equipment.[53,57] They are often chosen because they mimic the function of the trunk muscles that are often exposed to static loads for long periods of time, because muscular endurance is believed to be an important prerequisite for long-term physical activity in work, rehabilitation, leisure and sport,[1] and because these tests provide roughly comparable loading for all individuals.[58] In addition, muscular endurance has been shown to have a high association with low back pain.[57]

One commonly used test is the "Sorenson test." In this test, the subject is asked to maintain a horizontal unsupported trunk extension position for as long as possible.[1,58] The advantages of this test include ease of use, the avoidance of pre-testing maximal effort to establish any percent of maximum voluntary contraction (a distinct advantage when testing in the presence of pain) and a high reliability (test-retest $r = 0.94$ to 0.97 in healthy subjects and 0.85 to 0.91 in persons with chronic low back pain).[52,59] The disadvantages of this method are related to poor comparability between individuals due to differences in body weight and muscle substitution of biceps femoris for the erector spinae.[1]

Repetitive fatigue tests include repetitive tasks where the subject is asked to complete as many movements, either with or without load, until unable to continue or until the movement pattern changes. Performance is measured often by time (time to complete a task, time maintaining a balanced position, number of repetitions in a specific time period).[60] Generally, functional tests are inexpensive, portable and practical.[40] The actual performance of a task, along with the balance and coordination for that task, is the most accurate and realistic way to evaluate a dynamic movement.[61] There are many functional tests that have excellent reliability and validity. The disadvantage with the use of repetitive tests to assess fatigue is that it may not be possible to isolate the structures that cause a limitation but, rather, only identify a limit in the task itself.[40, 56, 62]

Examples of repetitive tests are the lateral step up test[61] and lifting tests.[62] The lateral step test is an example of a closed kinetic chain test that has been utilized to assess lower extremity muscular performance.[61] This test can be evaluated in two ways: by counting the number of repetitions performed at a specific step height over a specified period of time or by assessing the time necessary to complete a specified number of repetitions at a specific step height.[61] This test has been shown to have a high interrater reliability (ICC = 0.99) and produces measurements that are significantly related to measurements on the Kin Com ($r = 0.74$, $p < .01$).[63] Lifting tests usually simulate work tasks (e.g. lifting a weight from the floor), and involve high stresses and demands on the musculoskeletal system.[62]

Tests to determine activity specific performance should be composed of items that are closely related to the type of effort and skills that players are required to produce during games and practices.[64] The results of Chapter 2 demonstrate that ball propulsion occurred frequently in practice and game play. The ballistic nature of repetitive ball propulsion and the summation of forces through the lower extremity kinetic chain to produce ball propulsion suggested the need for a functional power test of the lower extremity. Consequently, a single leg hop test was proposed. The most repetitive movements in field hockey practice and game play included trunk flexion, side flexion and rotation (Chapter 2). These findings and the work of others[6, 7, 26-28] suggest the need for an endurance measure of the low back. In addition, Chapter 2 also demonstrated that trunk flexion was not held statically. In order to attain measures that could differentiate between left and right, a dynamic sideways sit-up test was developed to assess trunk endurance. The most commonly cited fatiguing movements and the most frequently occurring movements all involved some form of lunging (Chapter 2). The lateral step up test was similar to the movements seen in field hockey but to make this endurance test more field hockey specific, it was modified to become a lateral lunge test.

Methodological Considerations

Standardization of Procedures

Standardization of testing procedures will improve reliability of testing methods.[50] As suggested by Jorgensen,[1] standardization was performed by ensuring consistent position of the test subject and area being tested, stabilization of the body part being tested, minimization of the contribution from secondary muscles and the control of gravitational forces during testing.

Test Position

Prone and supine positions are effective in stabilizing body parts against an immoveable surface. However, in these positions during strength testing the muscles must overcome the effect of gravity and the position may limit ROM.[29] Side lying negates the effect of gravity but it is harder to administer tests in this position.[29] Standing allows a full ROM and is functional but it becomes difficult to stabilize the pelvis and lower extremities and gravity will affect the movements.[29] Sitting provides good stabilization (especially for rotary and translatory movement) because external contact forces are applied through the pelvis and decreases the effect of gravity.[29] In order to eliminate the effect of gravity in strength testing, the standing and sitting positions were chosen.

Stabilization

Stabilization is felt to be very important to ensure reliability of testing procedures to negate or minimize the influence of other muscles, to record accurate position and motion and to ensure that the test subject exerts a maximal voluntary contraction.[29, 50] As the present study was hoped to be the precursor to a larger study on muscle imbalance in field hockey, the testing equipment had to be portable. Participants were stabilized via a fortified portable walker and a stool for strength testing and on a bed and stool for ROM testing.

Warm Up

It is assumed that warm-up will ensure the safety of the subject during testing.[50] However, optimum warm-up requirements to achieve this goal have not been identified. Researchers generally fail to provide justification for the selected warm-up procedures.[50] For the present study, the decision to use warm-up for ROM and strength testing was based on previous studies. No warm-up was given for ROM testing.[6, 36, 40, 41] A 5 minute warm-up period was given for strength and functional testing.[43, 44, 65]

Fatigue

The recovery interval between test repetitions may influence the measurements taken.[50] Recovery interval requirements may vary for individual subjects and the number of repetitions in a test will affect the results.[50] Recovery interval for the present study was based on strength and conditioning guidelines for strength, power and endurance activities and standards of practice in other studies. One-minute recovery was provided between strength tests, 2 minutes between power tests and 5 minutes between endurance tests was provided in this study.[43, 44, 58, 61, 62, 66]

Muscle Soreness

After the first or second session involving maximal or near maximal effort, most people develop delayed onset muscle soreness (DOMS).[29, 67] DOMS manifests 24-48 hrs post-activity and may persist for 1-5 days thereafter, usually peaking on second or third day after the activity.[29, 67] During DOMS, muscular performance is affected by a voluntary reduction in effort and inherent ability of muscles to contract vigorously.[29] Participants in the present study were asked not to exercise vigorously 2 days prior to testing. Any individual who reported soreness at the time of testing was rescheduled. Participants were advised of the potential for DOMS following the endurance tests and advised of methods, which anecdotally, are felt to decrease the potential soreness.

Participant Related Factors

Participant motivation in ROM, strength and endurance testing has been found to affect results.[33,44,50,56,66,68,69] Subjects with poor motivation will display apparent decreases in these testing areas. Feedback given to subjects during the test also affects the measurement.[50,66,68] At slow speed strength testing, positive feedback is likely to enhance force production.[50] Willingness to perform a fatiguing task has a large effect in endurance tests.[58] Motivating feedback can decrease the negative effect on endurance times of poor motivation.[56,66] The presence of subject pain or fear of pain can also detrimentally affect test results.[44,66] For consistency, in the present study, encouragement was provided for the endurance tests only.

Environmental Considerations

Measurements of lumbar ROM are influenced by circadian variation.[70,71] Disc height decreases by 83% in the first 3 hours 45 min after rising.[71] Consequently, for the present study, ROM was not tested in the morning.

METHODS

Participants

The participants included 7 female field hockey athletes and 5 healthy female volunteers.

Inclusion/Exclusion Criteria

Six former female national team athletes (all retired within 3 years prior to the study) resided in the Edmonton area. Their inclusion provided excellent "expert field hockey player" participants. To ensure consistency between former national team and University of Alberta (Edmonton, Alberta) interuniversity field hockey athletes, inclusion criteria for the University of Alberta field hockey athletes was any female athlete who graduated from the program within the last 3 years prior to the study. Inclusion criteria for the volunteer controls was any female student therapist from the University of Alberta and/or Northern Alberta Sport Therapy Service between the ages of 17 and 26 who was active at a recreational level in any symmetrical sport (e.g. running, weight lifting, swimming, cycling). For both groups, individuals with a history of low back pain that had resolved could participate.

The exclusion criteria for both groups included: any acute injury that led to pain and/or decreased ROM, strength or muscular endurance in the muscles and/or joints of the low back and hip regions; any acute exacerbation of a chronic injury that involved the muscles and/or joints of the low back and hip regions; any injury that affected the innervation and circulation to the muscles/joints being tested such that these regions had decreased ROM, strength and/or muscular endurance.

Ethical Approval

Ethical approval for this study was obtained through the University of Alberta Faculty of Physical Education and Recreation, Ethics Review Committee for Human Research. All participants provided signed informed consent (refer to Appendix M for ethics documents).

Procedure

A testing battery consisting of the following components was used in this study:

1. anthropometric data;
2. injury and sport participation history;
3. ROM measurements;
4. isometric strength measurements, and;
5. field hockey specific tests.

Female volunteers did not perform the lateral lunge endurance test, as this test required field hockey skills. Otherwise, all participants performed all tests. Based on the exclusion criteria, some participants were able to complete the ROM and isometric strength tests but not the field hockey specific tests (e.g., an acute injury to the ankle that did not affect the strength tests of the hip but precluded the athlete from completing the single hop for distance test).

In order to establish face validity, the Canadian Women's National Team head coach and 3 assistant coaches were asked to review the testing battery and comment on the relevance of the activity specific tests to field hockey. At their suggestion, a lateral movement for the single leg hop was substituted for the originally proposed forward single leg hop. During testing, former field hockey athletes were also given the opportunity at the end of the testing to comment on the relevance of the activity specific tests to field hockey. All participants were encouraged to comment on any potential problem areas in the testing procedures.

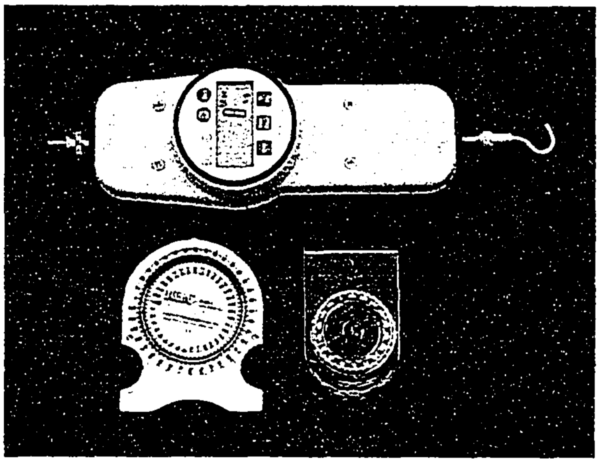
Descriptive Data

A questionnaire was designed to gather descriptive information for each participant (Appendix G). Each participant completed the first two questions regarding dominant hand and leg. The remaining parts of this questionnaire included years of participation in field hockey, primary and secondary position played including side of the field, highest level of participation achieved (university, provincial and/or national team member), other sports played, number of practices per week on average and number of hours per practice on average. Control participants did not complete these questions. Instead, the field hockey athletes only were asked to comment on any areas of the questionnaire that they felt was too time consuming, ambiguous or difficult to understand. Height, weight and age of the participant were noted on the sport participation questionnaire.

Injury History

Each participant completed an injury questionnaire (Appendix H) to gather information on previous injury, particularly low back and hip pain, which might have affected the results of the testing. Again, participants were asked to comment on any areas of the questionnaire that they felt were too time consuming, ambiguous or difficult to understand.

Figure 3.1. Testing Apparatus. Clockwise from top: push-pull dynamometer, compass, inclinometer.



ROM Tests

ROM was measured using inclinometers (Baseline bubble inclinometer, Chattanooga Group, Montreal, Canada) or compasses (Nexus Star 7DNL Compass, Sweden), based on standardized techniques developed by Kendall and McCreary[31] and Clarkson[32]. It was discovered prior to the start of the present study, that the blue liquid bubble in the inclinometer did not display a solid border in horizontal positions, making readings difficult to obtain. Consequently, a compass was substituted for the inclinometer for the measurement of trunk rotation and hip adduction and abduction. For measurements involving the leg, the inclinometer or compass was placed on the thigh via a Velcro strap at a point 10 centimetres (cm) above the medial joint line of the knee and/or on the lower leg at a point 10 cm below the medial joint line of the knee. For measurements of the lumbar spine, inclinometers were placed at the level of L_5/S_1 and T_{12}/L_1, respectively. Prior to each testing day, the inclinometers were calibrated against a level.

For measurements in supine lying, participants rested on a portable massage table. In order to provide a firm base of support, a 60 x 60 cm plywood board covered in a sheet was placed under the participant's pelvis with a small square of foam placed under the sacrum and posterior superior iliac spines for comfort.[36] The table was weighted at one end with a 25 kilogram (kg) sand bag so it would not tip when the participant was placed at the other end of the table. For measurements in sitting, participants sat on a height adjustable bath stool. Participants were strapped to the table or stool to ensure standardization of techniques and to eliminate extraneous movements of related body parts.

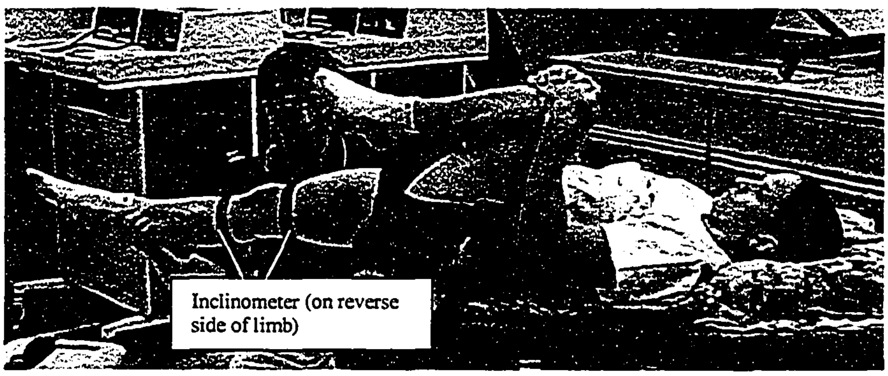
Each test included 5 consecutive trials of 15 seconds (s) with 15 s rest between trials.[34, 72] All tests were performed bilaterally and measurements were taken when the end position for each test was attained. Measurements were rounded to the nearest degree, as the inclinometer and compasses had 1° increments. There was no warm-up prior to measurement. One examiner took and recorded the measurements.

Test order was determined via stratified randomization. Tests were clustered based on the stabilization procedure used. One cluster included the table tests and had sub-clusters – 1. hip extension, 2. hip adduction/abduction/flexion. The second cluster included the stool tests and also had sub-clusters – 1. hip internal and external rotation and 2. trunk side flexion and rotation. Test order was randomized based first on the cluster (i.e. table versus stool), next on the sub-cluster (i.e. randomized order of 1 and 2 as listed above) and finally on the testing motions in multiple motion sub-clusters (e.g. randomized order of internal and external rotation or 1-joint and 2-joint hip extension).

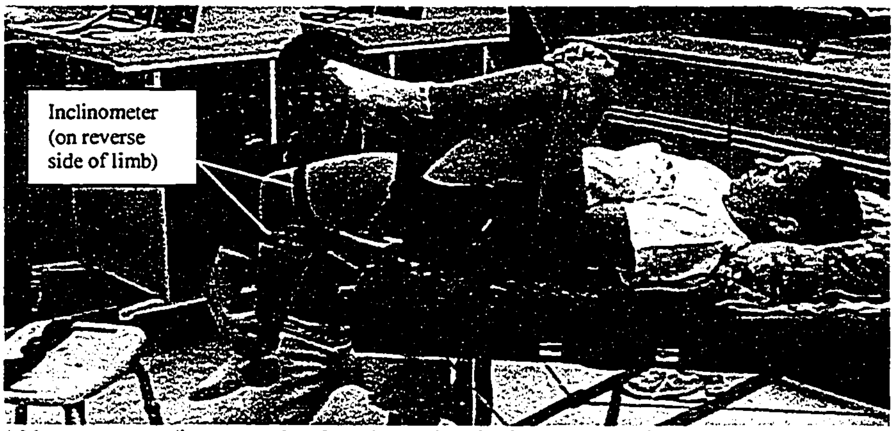
Hip Extension (Figure 3.2)

The participant was positioned in supine lying on the table with the foot of the test leg (TL) resting on a stool placed at the end of the table, such that the TL hip was at the end of the table and the TL thigh rested approximately horizontally (higher if necessary for the subject's comfort). The examiner placed one hand under the subject's low back and, holding the non-test leg (NTL) under the knee with the other hand, flexed the NTL hip until the examiner felt the low back flatten against the table. The participant then held the NTL in this position. The examiner then tightened a strap at the level of the participant's anterior superior iliac spines (ASIS) to maintain pelvic alignment. The examiner lifted the TL from the chair and brought it to 90° of hip flexion. To test 2-joint hip extension (knee flexed and hip extended), the TL was lowered until resistance was felt against the motion, maintaining the TL knee in 80° of flexion and without allowing the TL to adduct, abduct or rotate at the hip joint. To test 1-joint hip extension (knee and hip extended) the TL was lowered until resistance was felt against the motion, maintaining the TL knee in 0° of flexion (straight) and without allowing the TL to adduct, abduct or rotate at the hip joint.

Figure 3.2. Hip extension ROM.
A. One-joint hip extension*



B. Two-joint hip extension*

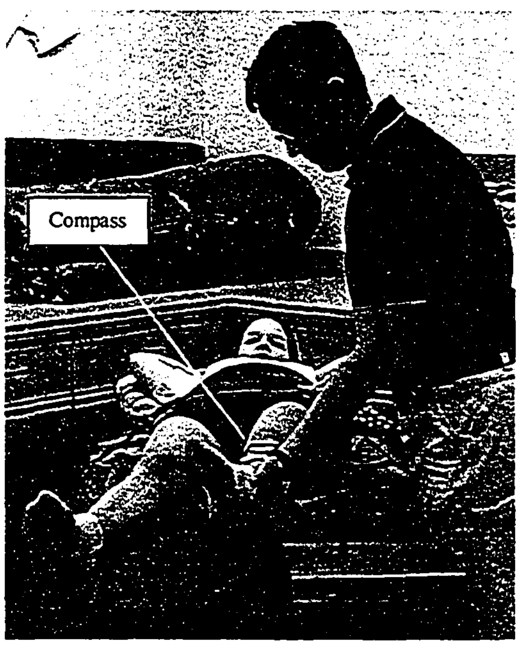


* Measurement readings were taken from the proximal inclinometer. The distal inclinometer was used to ensure knee position.

Hip Adduction (Figure 3.3)

The participant was positioned fully supported in supine lying on the table. A strap was tightened across the participant's ASISs. The examiner ensured that the TL was in the neutral position (0° of adduction/abduction) and placed the NTL in as much abduction as necessary to allow maximal adduction of the TL. The examiner placed one hand on the ipsilateral ASIS and the other hand under the TL calf. Without allowing the TL to rotate or flex at the hip joint, the examiner slowly adducted the TL until resistance was felt in the movement or until the ipsilateral ASIS moved inferiorly.

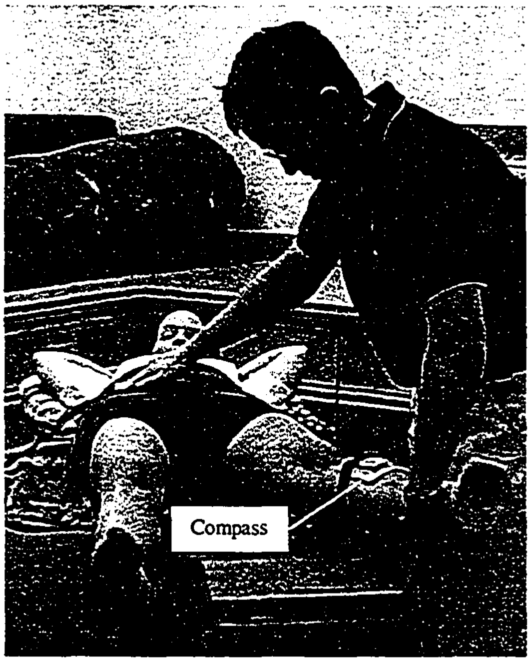
Figure 3.3. Hip adduction ROM.



Hip Abduction (Figure 3.4)

The participant was positioned fully supported in supine lying on the table. A strap was tightened across the participant's ASISs. The examiner ensured that the TL was in the neutral position (0° of adduction/abduction). The examiner placed one hand on the contralateral ASIS and the other hand under the TL calf. Without allowing the TL to rotate or flex at the hip joint, the examiner slowly abducted the TL until resistance was felt in the movement or until the contralateral ASIS moved inferiorly.

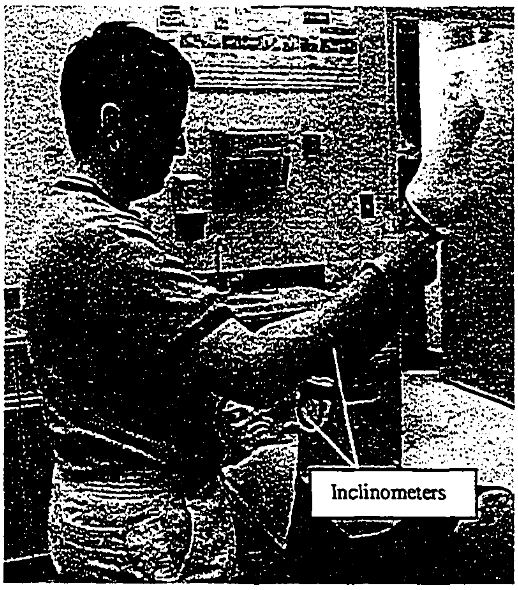
Figure 3.4. Hip abduction ROM.



Hip Flexion (Figure 3.5)

The participant was positioned fully supported in supine lying on the table. The examiner placed one hand under the participant's low back and, holding both legs under the knees with the other hand, flexed the hips until the examiner felt the low back flatten against the table. Maintaining this position of hip flexion with pillows under the NTL knee and a tightened strap, a second strap was secured at the level of the participant's ASISs to maintain pelvic alignment. The examiner placed one hand on the ipsilateral ASIS and the other hand under the TL mid-calf. Without allowing the TL to adduct, abduct or rotate at the hip joint, the examiner measured 2-joint hip flexion (hip flexed, knee straight) by slowly lifting the TL until resistance was felt or the ipsilateral ASIS moved superiorly. To measure 1-joint hip flexion (hip and knee flexed), the examiner bent the hip to 90° of flexion, and measured knee extension.

Figure 3.5. Hip flexion ROM.
A. One joint hip flexion*



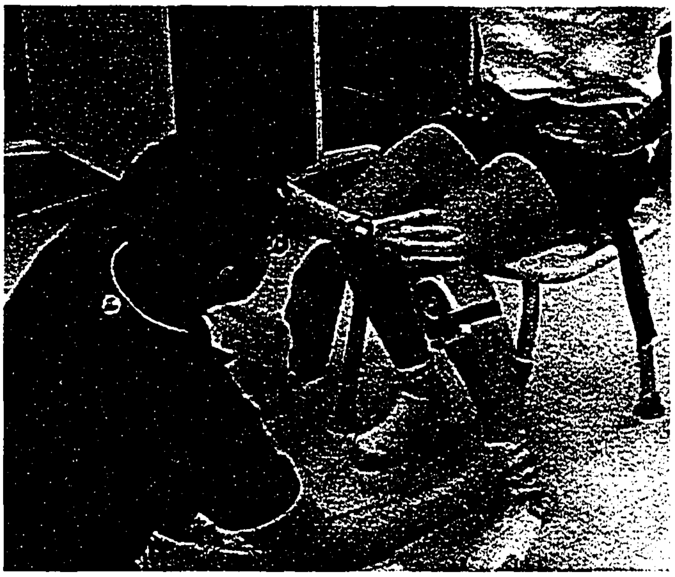
B. Two joint hip flexion*

* Measurement readings were taken from the proximal inclinometer. The distal inclinometer was used to ensure knee position.

Hip Internal Rotation (Figure 3.6)

The participant was positioned sitting on the bath stool with the TL and NTL knee and hip at 90° of flexion. A strap was fixed across the participant's ASIS's. Ensuring the TL was in the neutral position (0° of internal or external rotation, adduction or abduction), the examiner placed one hand on the TL knee and placed the other hand on the TL ankle. The examiner then slowly internally rotated the hip until resistance was felt.

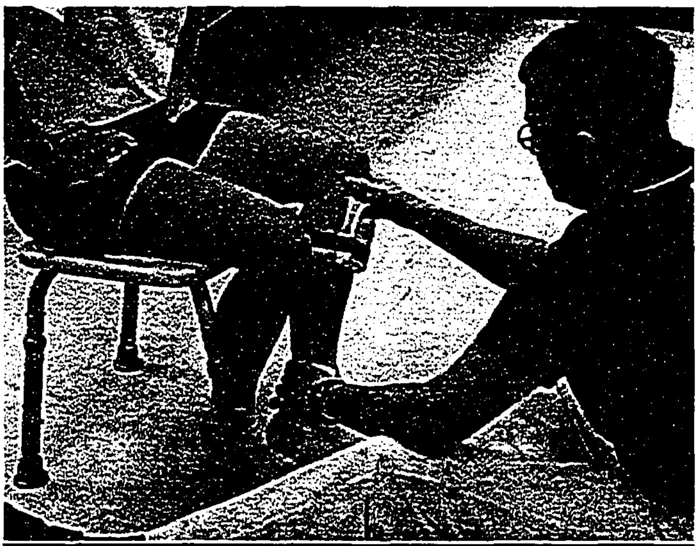
Figure 3.6. Hip internal rotation ROM.



Hip External Rotation (Figure 3.7)

The participant was positioned sitting on the bath stool with the TL knee and hip at 90° of flexion and the NTL foot tucked back under the stool. A strap was fixed across the participant's ASISs. Ensuring the TL was in the neutral position (0° of internal or external rotation, adduction or abduction), the examiner placed one hand on the TL knee and placed the other hand on the TL ankle. The examiner then slowly externally rotated the hip until resistance was felt.

Figure 3.7. Hip external rotation ROM.



Lumbar Side Flexion (Figure 8)

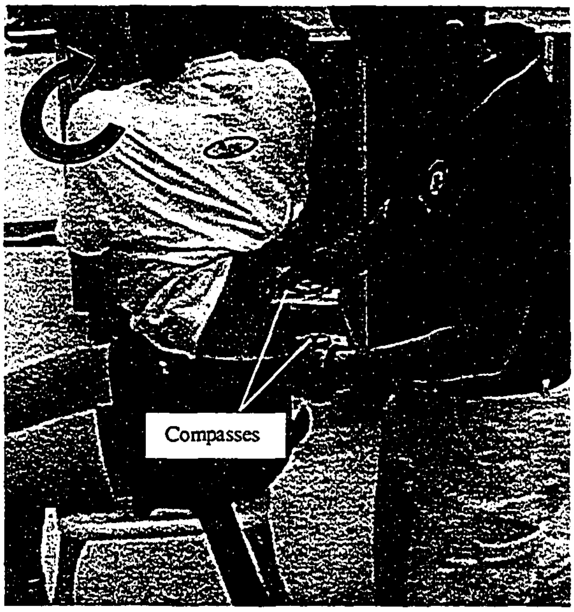
The participant was positioned on the bath stool with the feet flat on the floor, knees and hips bent to 90°. A strap was tightened across the participant's ASISs. The participant was asked to bend to one side as far as possible without allowing trunk flexion, extension or rotation. Side flexion was recorded by subtracting the T_{12}/L_1 reading from the L_5/S_1 reading.

Figure 3.8. Lumbar side flexion ROM.

Lumbar Rotation (Figure 3.9)

The participant was positioned on the bath stool with the feet flat on the floor, knees and hips bent to 90°. A strap was tightened across the participant's ASISs. The subject was asked to turn to one side as far as possible without allowing trunk flexion, extension or side flexion. Rotation was recorded by subtracting the T_{12}/L_1 reading from the L_5/S_1 reading.

Figure 3.9. Lumbar rotation ROM.



Isometric Strength Tests

Maximal isometric strength measurements were taken via a push-pull dynamometer (Baseline Hydraulic Push-Pull Dynamometer, Chattanooga Group, Montreal, Canada) in gravity independent positions modified from standardized manual muscle testing procedures.[31,32] Prior to each testing day, the strain gauge was calibrated with a known mass.

Tests of hip flexion, extension, adduction and abduction strength were performed with the participant standing in a specially fortified standard adjustable collapsible walker (Figure 3.10). Five-by-five cm oak strips were placed horizontally across both sides and front of the walker. The front of the walker was fitted with a 2 cm plywood board with a rectangular cut-out to allow the NTL and the pelvis to be stabilized via straps and the TL to be free. Padding was placed between the participant and the board to accommodate for individual anatomy that might cause the participant to be uncomfortable against the board or not flush with the board. The walker was set to the height of the participant's wrist creases with the arms resting at the side of the body. Tests of hip internal and external rotation and trunk strength were performed with the participant seated on a height adjustable bath stool (Figure 3.12). The height was adjusted so the participant would sit with hips and knees bent to 90°. Participants were strapped to the table or stool to ensure standardization of techniques and to eliminate extraneous movements of related body parts.

The push-pull dynamometer was mounted on the walker frame by a vertical cross bracing (Figure 3.11) and its height was set at the level of the strap or harness attachment on the participant. The dynamometer and strapping were joined via mountaineering carabineers (rated to 300 pounds) and aviation wire and turnbuckles (rated to 800 pounds). For tests of hip flexion, adduction, abduction and extension strength, the carabineer was positioned 10 cm above the medial joint line of the knee. For tests of hip rotation, the carabineer was positioned 5 cm above the medial malleolus. For tests of trunk rotation and side flexion, the carabineer was attached to a harness.

Figure 3.10. Strength apparatus in standing.

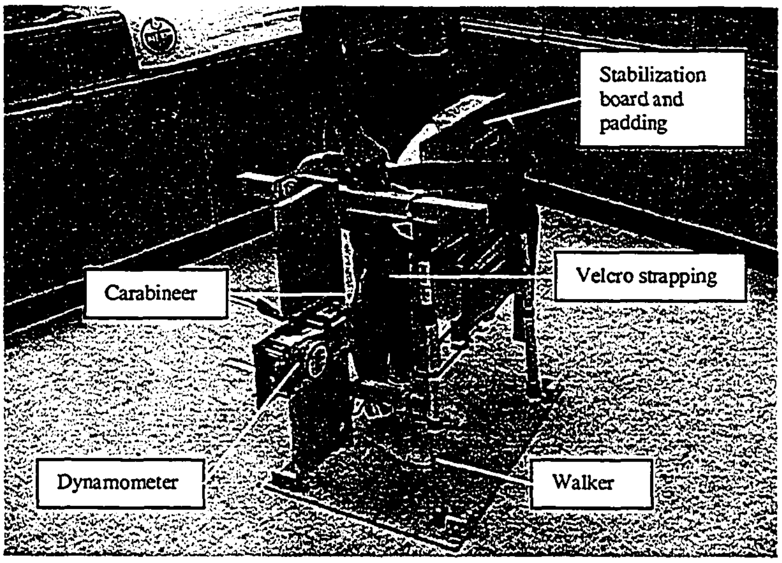


Figure 3.11. Fixation of dynamometer.

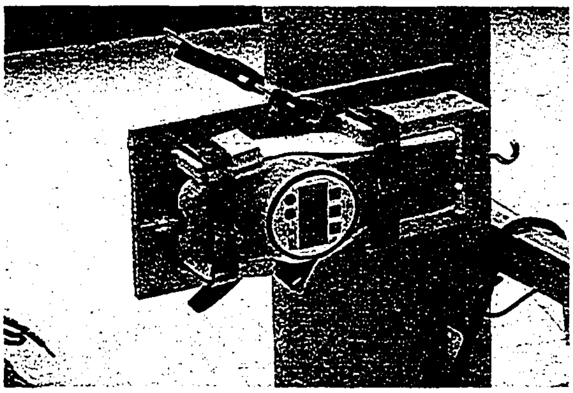
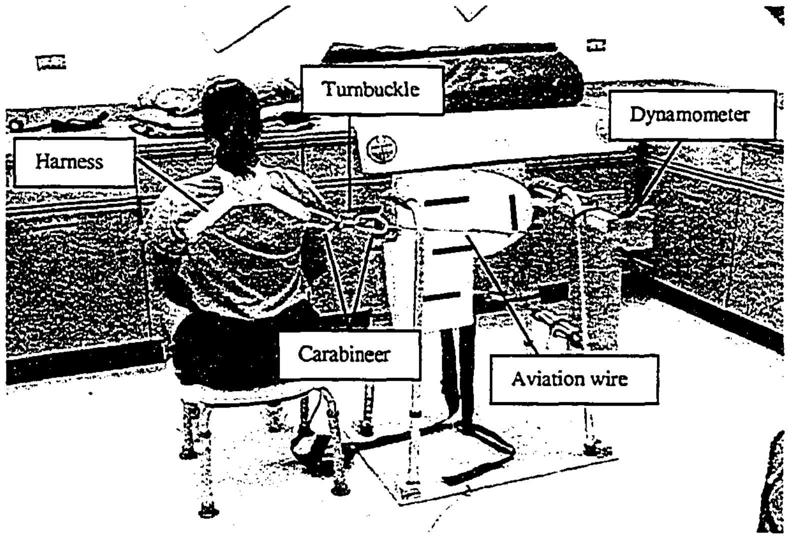


Figure 3.12. Strength apparatus in sitting.



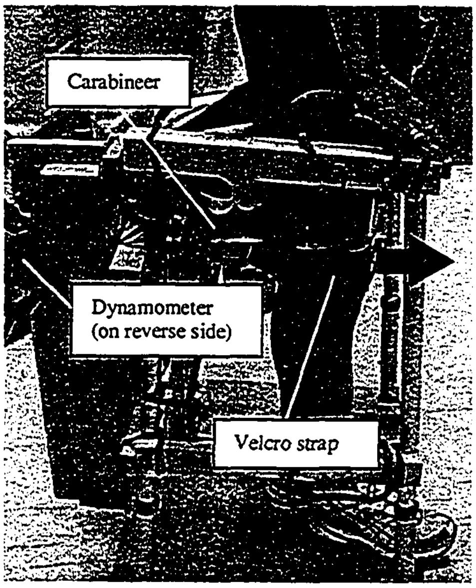
Isometric strength testing was preceded by a 5 minute (min) light cycling warm-up on a stationary bike. Each isometric contraction was held for 5 s.[62, 69, 73] The participant increased her effort gradually over the first 2 s to reach peak torque for the last 3 s.[69] Sixty seconds rest was given between each trial.[43, 61, 62, 66, 74] There were 5 trials per test per leg. All tests were performed bilaterally. The dynamometer readings were recorded in kilograms and were rounded to the nearest kilogram. One examiner took and recorded all measurements.

Test order was determined via stratified randomization. Tests were clustered based on the stabilization procedure used. The first cluster included the standing tests and had sub-clusters – 1. hip extension/adduction/abduction and 2. hip flexion. The second cluster included the chair tests and had sub-clusters – 1. hip internal/external rotation and 2. trunk side flexion/rotation. Test order was randomized based first on the cluster (i.e. table versus chair), next on the sub-cluster (i.e. randomized order of 1 and 2 of each cluster as listed above) and finally on the testing motions in multiple motion sub-clusters (e.g. randomized order of internal and external rotation).

Hip Flexion (Figure 3.13)

The participant was positioned facing backwards (back against the board) in the walker facing away from the strain gauge dynamometer. Straps were tightened around the board and participant at the level of the ASISs and across the thigh of the NTL. The strain gauge was positioned at the front of the walker and separated from the participant such that there was no slack in the cable attaching the participant and dynamometer. The participant was asked to un-weight the TL and keeping the foot off the floor perform a maximal contraction of hip flexion against the strain gauge dynamometer.

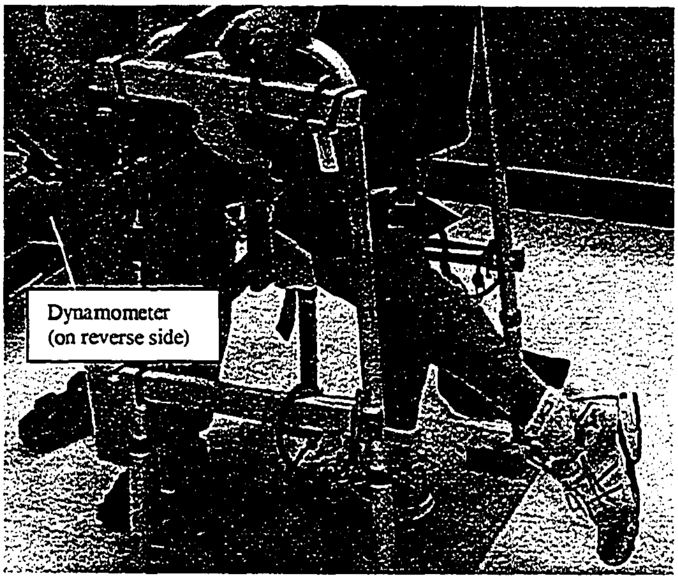
Figure 3.13. Hip flexion strength.



Hip Extension (Figure 3.14)

The participant was positioned facing forwards (front against the board) in the walker. Straps were tightened around the board and participant at the level of the ASISs and across the thigh of the NTL. The strain gauge was positioned at the front of the walker and separated from the participant such that there was no slack in the cable attaching the participant and dynamometer. The participant was asked to un-weight the TL, keeping the knee slightly bent and the foot off the floor, perform a maximal contraction of hip extension against the strain gauge dynamometer.

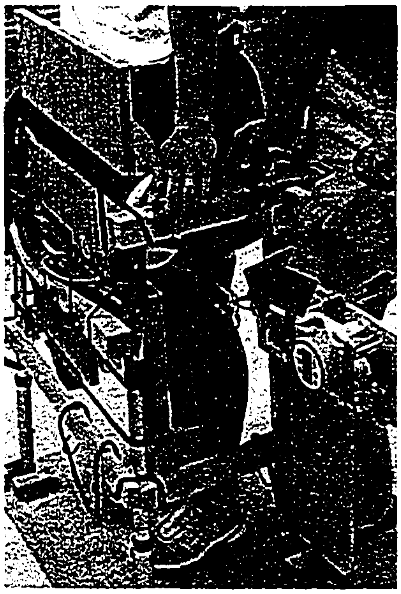
Figure 3.14. Hip extension strength.



Hip Adduction (Figure 3.15)

The participant was positioned facing forwards in the walker. Straps were tightened around the board and participant at the level of the ASISs and across the thigh of the NTL. The strain gauge was positioned beside the participant on the same side as the TL and separated from the participant such that there was no slack in the cable attaching the participant and dynamometer. The participant was asked to un-weight the TL and keeping the foot off the floor perform a maximal contraction of hip adduction against the strain gauge dynamometer.

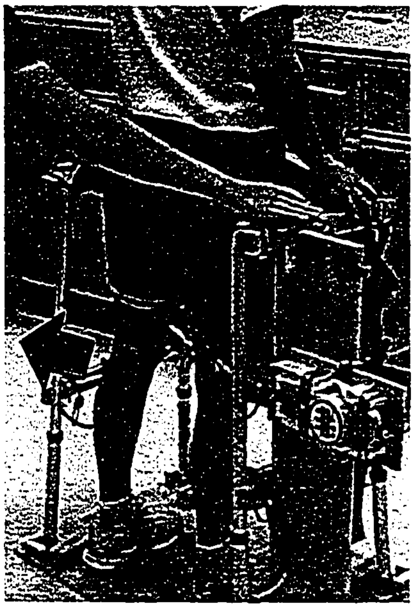
Figure 3.15. Hip adduction strength.



Hip Abduction (Figure 3.16)

The participant was positioned facing forwards in the walker. Straps were tightened around the board and participant at the level of the ASISs and across the thigh of the NTL. The strain gauge was positioned beside the participant on the opposite side to the TL and separated from the participant such that there was no slack in the cable attaching the participant and dynamometer and with the cable running behind the NTL. The participant was asked to un-weight the TL and keeping the foot off the floor perform a maximal contraction of hip abduction against the strain gauge dynamometer.

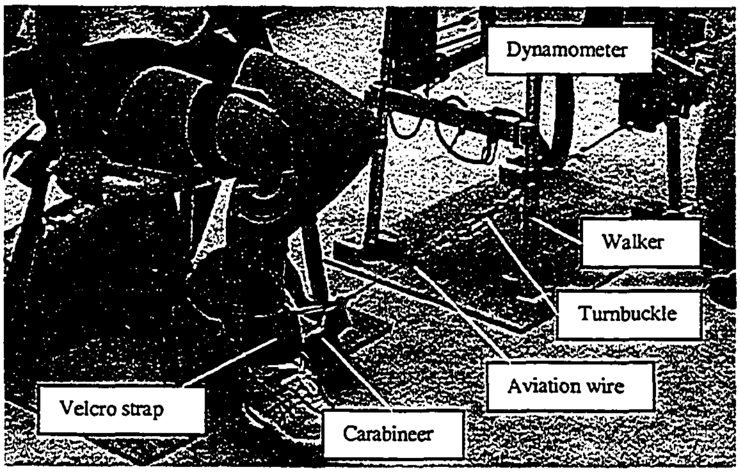
Figure 3.16. Hip abduction strength.



Hip Internal Rotation (Figure 3.17)

The participant was positioned on the bath stool facing the same direction as the front of the walker. The strain gauge was affixed to the walker on the opposite side of the participant. The NTL was moved backward slightly to allow the strain gauge dynamometer cable to clear the NTL. The strain gauge dynamometer and participant were separated such that there was no slack in the cable attaching the participant and dynamometer. The participant was asked to un-weight the foot and perform a maximal contraction of hip internal rotation against the strain gauge dynamometer. The participant was turned to face the opposite direction to test the opposite side.

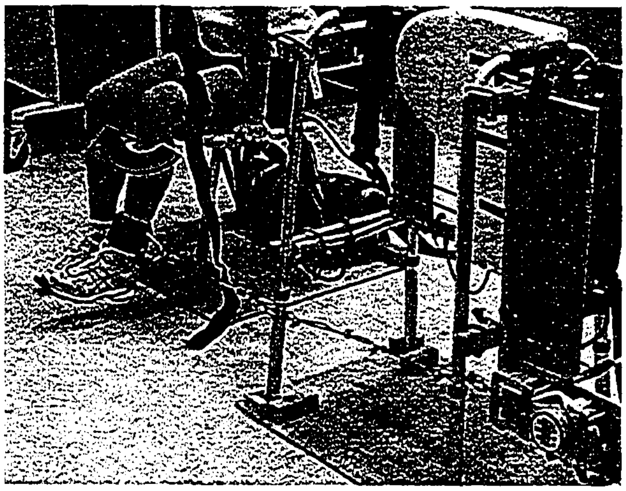
Figure 3.17. Hip internal rotation strength.



Hip External Rotation (Figure 3.18)

The participant was positioned on the bath stool facing the same direction as the front of the walker. The strain gauge was affixed to the walker on the opposite side of the participant. The strain gauge dynamometer and participant were separated such that there was no slack in the cable attaching the participant and dynamometer. The participant was asked to un-weight the foot and perform a maximal contraction of hip external rotation against the strain gauge dynamometer. The participant was turned to face the opposite direction to test the opposite side.

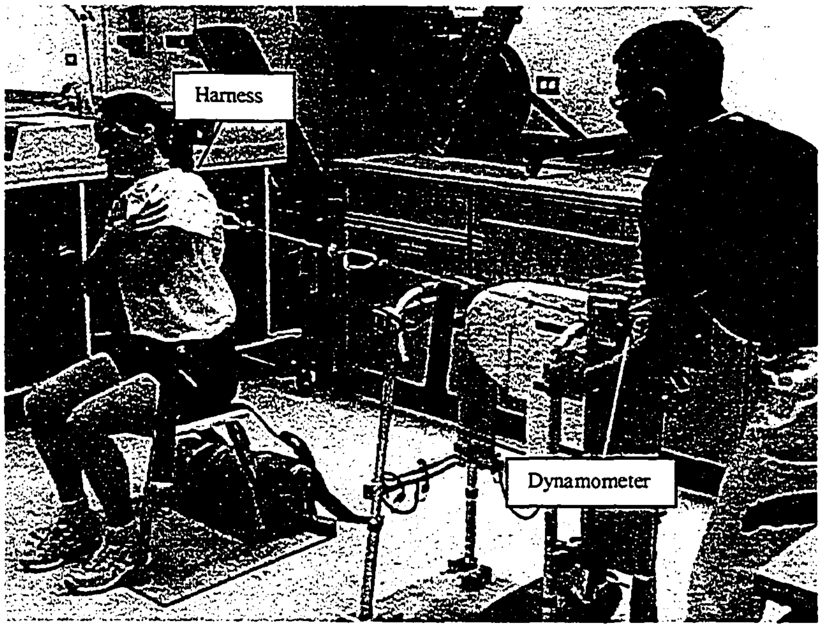
Figure 3.18. Hip external rotation strength.



Trunk Side Flexion (Figure 3.19)

The participant was positioned on the bath stool facing the same direction as the front of the walker. The strain gauge dynamometer was positioned beside the participant opposite the direction to which the participant would bend. The strain gauge dynamometer and participant were separated such that there was no slack in the cable attaching the participant and dynamometer. The participant crossed her arms in front of her trunk and performed a maximal contraction of trunk side flexion against the strain gauge dynamometer. The participant was turned to face the opposite direction to test the opposite side.

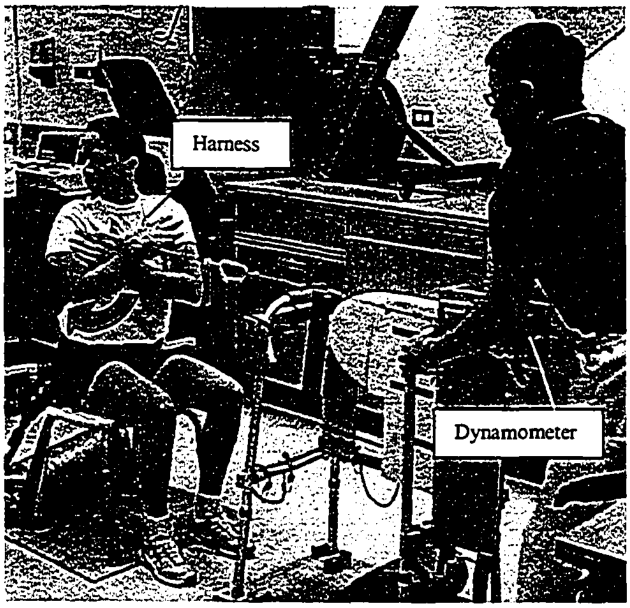
Figure 3.19. Trunk side flexion strength.



Trunk Rotation (Figure 3.20)

The participant was positioned on the bath stool facing toward the walker. The strain gauge dynamometer was positioned ahead of the participant opposite the shoulder to which the participant would turn. The strain gauge dynamometer and participant were separated such that there was no slack in the cable attaching the participant and dynamometer. The participant crossed her arms in front of her trunk and performed a maximal contraction of trunk rotation against the strain gauge dynamometer.

Figure 3.20. Trunk rotation strength.



Field Hockey Specific Tests

All functional tests were preceded by a 5 min light cycle on a stationary bike.

Single-Leg Hop for Distance (Figure 3.21)

This test procedure has been described by Worrell, Borchert, Erner, Fritz and Leevar[75] and the direction only was modified to become a lateral hop. The participant was positioned standing with the instep of the foot of the TL lined up with a starting line facing sideways. From this line, a tape measure stretched out beside the participant. Standing on the TL with the NTL touching for balance only, the participant hopped sideways as far as possible to land on the TL (e.g. if the TL was the right leg, the participant would hop to the left). There were 5 consecutive trials per leg with 2 min rest between trials.

Figure 3.21. Single leg hop for distance.

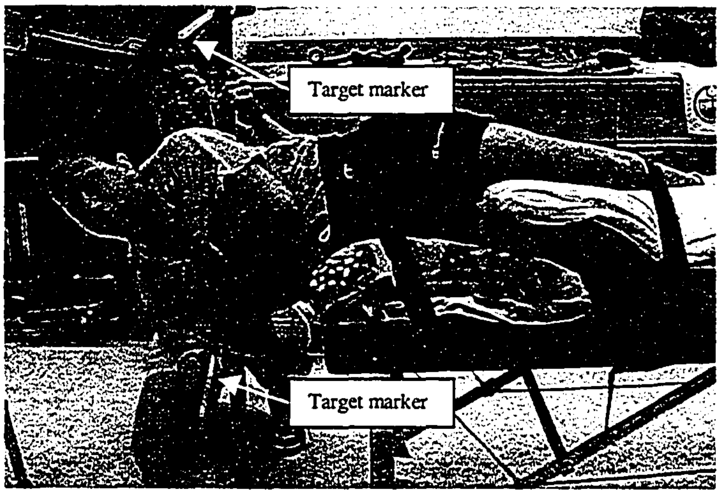
A. Starting position.

B. Finish position.

Trunk Side Flexion Endurance (Figure 3.22)

The participant was positioned in side lying on a portable massage table with the iliac crests level with the end of the table. A chair of equal height to the table was placed at the end of the table so that the participant could rest on the chair until the test began. The bath stool was placed in front of the chair for the participant to support her body weight when the chair was removed prior to the start of the test. Padding was placed under the participant's hips, between the participant's knees and under the strapping. Straps were placed at the level of the participant's iliac crests and mid-calf to anchor the pelvis and lower leg to the table. A 25 kg sand bag was placed at the end of the table to prevent it from tipping. The participant was asked to move through her full range of side flexion with her hands crossed in front of her trunk until exhaustion paced by a calibrated metronome counting at 60 beats per minute (bpm).[52, 63] The ROM was marked and defined the test range. The test ended if the participant stopped, was unable to move through the entire ROM, could not keep pace with the metronome, or twisted the trunk. Participants were warned of any technique problem and given one repetition (up and down) to correct. If they did not correct the technique, the test was stopped. Each side was tested 3 times, alternating between sides (i.e. left and then right), with 5 min rest between trials.[76-78]

Figure 3.22. Trunk side flexion.

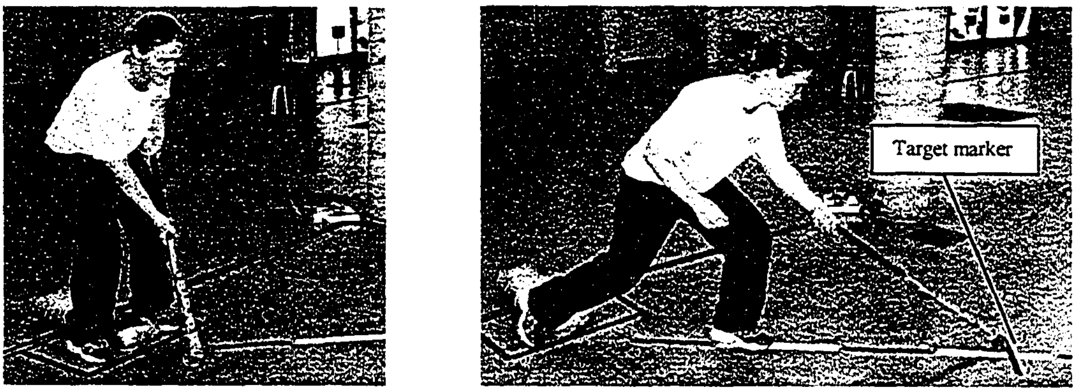


Lateral Lunge Endurance (Figure 3.23)

Rosenthal, Baer, Griffith, Schmitz, Quillen, and Finstuen[63] described the lateral step up test as a measure of leg muscle endurance in the sport setting. The protocol of this test was adapted to the lunge movement. The participant was asked to assume a familiar field hockey "ready" stance (i.e. the position the participant would assume if waiting to defend against an opponent) with the feet parallel. The participant had to hold a field hockey stick (the same stick was used for each participant). The participant was asked to lunge diagonally forward on a 45° angle to a position that the participant would consider a reaching poke tackle. The distance the stick traveled was marked and defined the test range.

The participant then resumed the ready stance with both hands on the stick. A step diagonally forward, reaching to touch the target with the tip of the stick and return to the starting position with the toe of the TL foot touching the ground behind the starting line was one repetition. The stick was held in the same hand as the TL and was dragged across the ground. The participant moved through the test range paced by a metronome counting at 72 bpm. The goal of the test speed was to induce fatigue relatively quickly (within 3 to 4 min) and was developed through principal instructor trials prior to the study. The test ended if the participant stopped, was unable to reach the target, did not bring the foot back to the starting position or could not keep pace with the metronome. Participants were warned of any technique problem and given one repetition to correct. If they did not correct the technique, the test was stopped. Each leg was tested 3 times, alternating between sides (i.e. left and then right), with 5 min rest between trials.[76-78]

Figure 4.7. Lateral lunge endurance.
A. Start and end position B. Lunge position



Time Commitment

The time commitment for this study was as follows:

- Sport Participation Questionnaire: 5 to 10 min
- Injury History Questionnaire: 5 to 20 min (depending on injury history)
- Height and Weight: 5 min
- ROM Testing: 65 min
- Isometric Strength Testing: 3 hours
- Activity Specific Testing: 2 hours (female volunteers) to 2.5 hours (field hockey athletes)

Total Time Commitment: 7 to 8 hours

Testing Location

All the tests were performed in the University of Alberta, Faculty of Physical Education and Recreation Sport Performance Lab and Van Vliet Pavilion Concourse.

Data Analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS edition 11.5, SPSS Inc., Chicago, USA). Intrarater reliability was evaluated by a repeated measures analysis of variance (ANOVA) and interclass correlation (ICC). Prior to the application of these tests, the data were explored for normality using the Shapiro-Wilk test and Q-Q plots. The assumption of sphericity was determined using Mauchly's test of sphericity. If the assumption of sphericity was violated, the Greenhouse-Geisser epsilon was used, as this adjustment value is conservative for small sample sizes (SPSS). The Bonferroni post-hoc test was used to ascertain significant differences between trials. If only 1 of the 5 trials for any particular activity was non-normal, the repeated measures ANOVA was still used. According to Norusis,[79] this violation of normality would not significantly affect the results. If the non-normal distribution was due to an extreme outlier, the outlier was removed and the parametric tests described previously were used. If the cause of non-normality was due to bimodal distribution, the data was transformed using Log10 and the parametric tests were used. If removal of the outlier and Log10 transformation did not result in a normal distribution, the non-parametric Kendall's W test and Wilcoxan ranked test for pairwise analysis were used. All tests were performed at $p < .05$, except the Wilcoxan ranked test ($p < .01$).

RESULTS

Twelve participants were tested (7 field hockey players and 5 student therapists). Six participants did not complete the full testing battery. One did not complete the lateral lunge due to a knee injury; 2 did not complete the lateral hop due to knee and ankle injuries; 1 did not complete the seated strength tests due to an acute low back injury, and; 2 did not complete the full battery of strength testing due to scheduling conflicts. Participants had an average age of 26.1 years, an average height of 162.5 cm, and an average weight of 60.2 kg.

Validity was established through expert group feedback from national coaching staff, field hockey athletes and student therapists. All participants felt that the testing was appropriate for the purpose. Apart from a few spelling errors, the questionnaires were felt to be encompassing of sport participation and injury history.

Forty-two variables were tested. Repeated measures ANOVA and ICC were used with 33 of these variables and the results are listed in Tables 3.1 and 3.2. ICC values ranged from 0.03 to 0.99. The Bonferroni post-hoc test was used to ascertain significant differences between trials for significant findings in the repeated measures ANOVA (Table 3.5).

Table 3.1. Repeated Measures ANOVA and ICC Results for Normally Distributed Data (sphericity assumed)

Variable	Standard Error of the Mean*	Repeated measures ANOVA p-value	ICC	(95% CI)
Range of Motion				
Right 1 joint hip extension	2.2-2.4	.314	0.99	(0.97-0.995)
Left 1 joint hip flexion	3.0-3.4	.018†	0.97	(0.93-0.99)
Right 1 joint hip flexion	2.7-3.2	.000†	0.97	(0.94-0.99)
Right hip internal rotation	1.2-2.0	.235	0.98	(0.95-0.99)
Left hip external rotation	2.1-2.5	.345	0.97	(0.93-0.99)
Left trunk side flexion	1.4-1.6	.048†	0.68	(0.45-0.87)
Right trunk side flexion	1.4-1.8	.080	0.70	(0.47-0.88)
Right trunk rotation	0.9-1.6	.158	0.29	(0.04-0.69)
Strength				
Left hip flexion	3.1-3.7	.476	0.96	(0.91-0.99)
Right hip flexion	2.9-3.3	.391	0.92	(0.83-0.97)
Left hip extension	2.6-3.0	.559	0.91	(0.81-0.97)
Right hip extension	2.6-3.3	.052	0.89	(0.76-0.97)
Left hip adduction	2.1-2.9	.146	0.92	(0.83-0.98)
Right hip adduction	2.0-2.4	.000†	0.92	(0.83-0.98)
Left hip abduction	2.1-2.6	.872	0.94	(0.87-0.98)
Left hip internal rotation	0.9-1.1	.684	0.91	(0.81-0.97)
Right hip internal rotation	1.0-1.2	.504	0.89	(0.75-0.97)
Left hip external rotation	0.8-1.0	.983	0.91	(0.79-0.98)
Right hip external rotation	0.6-0.8	.250	0.90	(0.78-0.97)
Left trunk rotation	2.1-2.6	.043†	0.91	(0.81-0.97)
Functional				
Left lateral hop	1.9-2.3	.000†	0.83	(0.65-0.95)
Left side flexion endurance	1.1-1.9	.162	0.68	(0.34-0.87)
Right side flexion endurance	1.0-1.4	.945	0.60	(0.28-0.85)
Right diagonal lateral lunge	5.4-15.4	.210	0.03	(-0.32-0.67)

*Expressed as range of standard errors of mean across each trial for each variable
† Significant at $p < .05$

Table 3.2. Repeated Measures ANOVA and ICC Results for Normally Distributed Data (sphericity not assumed)

Variable	Standard Error of the Mean*	Greenhouse-Geisser epsilon p-value	ICC	(95% CI)
Range of Motion				
Right 2 joint hip extension	2.0-2.2	.131	0.98	(0.96-0.99)
Left 1 joint hip extension	1.7-2.1	.172	0.96	(0.92-0.99)
Left hip internal rotation	1.4-1.6	.185	0.94	(0.87-0.98)
Right hip external rotation	1.7-2.1	.068	0.95	(0.90-0.98)
Left trunk rotation	0.8-1.3	.388	0.63	(0.35-0.88)
Strength				
Right hip adduction	2.0-2.4	.121	0.90	(0.78-0.97)
Left trunk side flexion	1.9-2.5	.126	0.96	(0.90-0.99)
Right trunk side flexion	1.6-2.3	.208	0.97	(0.93-0.99)
Right trunk rotation	2.1-2.6	.072	0.80	(0.60-0.94)

* Expressed as range of standard errors of mean across each trial for each variable

Six variables had a non-normal distribution in one trial due to an extreme outlier. In these cases, the outlier was removed and parametric tests were used (Tables 3.3 and 3.4). ICC values ranged from 0.84 to 0.98.

Table 3.3. Repeated Measures ANOVA and ICC Results for Outlier Removed (sphericity assumed)

Variable	Standard Error of the Mean*	Repeated Measures ANOVA p-value	ICC	(95% CI)
Range of Motion				
Left 2 joint hip extension	2.0-2.2	.905	0.97	(0.94-0.99)
Right hip adduction	1.9-3.0	.677	0.90	(0.78-0.97)
Left 2 joint hip flexion	4.5-4.9	.662	0.98	(0.95-0.99)

* Expressed as range of standard errors of mean across each trial for each variable with the outlier included

Table 3.4. Repeated Measures ANOVA and ICC Results for Outlier Removed (sphericity not assumed)

Variable	Standard Error of the Mean*	Greenhouse-Geisser epsilon p-value	ICC	(95% CI)
Range of Motion				
Left hip adduction	1.2-2.0	0.203	0.84	(0.67-0.95)
Left hip abduction	3.4-4.3	0.049†	0.87	(0.73-0.96)
Right hip abduction	3.2-4.0	0.135	0.98	(0.95-0.99)

* Expressed as range of standard errors of mean across each trial for each variable with the outlier included
†Significant at $p < .05$

The Bonferroni post-hoc test was used to ascertain significant differences between trials for significant findings in the repeated measures ANOVA (results listed in Table 3.5). To ensure that the removal of the outlier did not affect the results, non-parametric tests of Kendall's W was substituted for the repeated measures ANOVA and significant differences were investigated by post-hoc Wilcoxan ranked test with the alpha level adjusted to $p < .01$ to accommodate repeated testing. Results are found in Table 3.6.

Table 3.5. Bonferroni Post-hoc Test for significant Findings in the Repeated Measures ANOVA

Variable	Trials with largest differences (p-value)
Range of Motion	
Left hip abduction	1-5 (.358), 2-5 (.204)
Left 1 joint hip flexion	1-5 (.314), 3-5 (.271)
Right 1 joint hip flexion	1-5 (.026), 2-5 (.044)
Left trunk side flexion	1-3 (.455)
Strength	
Right hip adduction	1-5 (.016), 1-4 (.064), 1-3 (.078)
Left trunk rotation	1-5 (.070)
Functional	
Left lateral hop	1-3 (.052), 1-5 (.078)

Table 3.6. Kendall's W and Wilcoxan Ranked Tests for Non-normal Data

Variable	Kendall's W p-value	Wilcoxan ranked test for pairwise differences Trial (p-value)
Range of Motion		
Left 2 joint hip extension	.770	
Left hip adduction	.127	
Right hip adduction	.730	
Left hip abduction	.025*	1-5 (.014)†, 2-5 (.014)†
Right hip abduction	.005*	1-5 (.019)†
Left 2 joint hip flexion	.728	

* Significant at $p < .05$
† Not Significant at $p < .01$, but largest noted difference

Right 2 joint hip flexion ROM had a bimodal distribution and was transformed using the SPSS Log10 function. With this transformation, the Greenhouse-Geisser F-value was 1.32 (p = .287) and an ICC of 0.99 (0.97 to 0.996 95% CI). The Kendall's W for this variable was p = .213. The standard error of the mean across the 5 trials for this variable prior to transformation was 4.4 to 5.0.

Right lateral hop had a bimodal distribution, which did not correct with the Log10 transformation. The Kendall's W was not significant (p = .152). The left diagonal lateral lunge had 1 skewed trial, which did not correct with the Log10 transformation. The Kendall's W was not significant (p = .607). To obtain an indication of reliability, the outlier was left in and parametric tests were performed. The repeated measures ANOVA F-value was 0.92 (p = .431) and the ICC was 0.004 (-0.33 to 0.65 95% CI). The standard error of the mean across the 3 trials for this variable prior to transformation was 1.7 to 2.1.

Part-way through data collection, ICC calculation was performed on all data (assuming normality) to gain an indication of the reliability of the testing methods. Trunk rotation ROM was found to have very poor reliability. When the participants were grouped into field hockey and control subjects, the ICCs were lower for the field hockey group for both left and right rotation (left rotation ICC 0.45 field hockey versus 0.66 control; right rotation ICC 0.02 field hockey versus 0.66 control). The principal investigator noted anecdotally that field hockey subjects appeared to fatigue over the 5 trials of active trunk rotation ROM. The testing protocol was changed, two new trials were performed and results were tested via the paired t-test (p < .05) and the ICC. Subjects were asked to perform two practice trials in the direction of choice, followed by two measurement trials. All participants were re-tested with this new protocol. The new protocol resulted in non-significant paired t-tests (left trunk rotation p = .465; right trunk rotation p = .756) and the ICCs improved dramatically (left rotation 0.92; right rotation 0.96).

DISCUSSION

Validity refers to the ability of a measuring tool to reflect what it is designed to measure[80] and face validity refers to whether the measuring tools are related to the activity they are supposed to measure.[81] Face validity is established by deciding whether the tests measure the factors involved in the activity.[81] Face validity was established in this study by asking national field hockey team coaches, former field hockey athletes and student therapists to comment on the relation of the questionnaires and the functional tests to activities in field hockey. All participants in this process felt that the tests were measuring factors related to physical aspects of field hockey.

With the exception of left trunk side flexion and rotation, all ROM measurements were found to have excellent intratester reliability.[82] This excellent reliability is similar to many other goniometrical and inclinometry studies.[34,36-39] With the exception of left hip abduction, left and right 1 joint hip flexion and left trunk side flexion, no significant differences were found between trials, indicating that ROM testing could occur without warm-up and that 15 sec between trials was sufficient. However, anecdotally, the researcher noticed that hip flexion increased 2-5° after the first trial that seemed in part related to participant anxiety (i.e. many felt their hamstrings were going to be very tight). While this perceived increase was not statistically significant, 1 warm-up trial for hamstring flexibility is recommended for future studies prior to measuring the hip flexion ROM. For the significant repeated measures ANOVA findings, typically the 1st and 5th trials were the most different. Differences between trials for right hip abduction were found to be non-significant with parametric testing with the outlier removed, but had significant differences with the Kendall's W. Again, the 1st and 5th trials were significantly different. Consequently, two consecutive trials (e.g. trials 1 and 2, 2 and 3, 3and 4, or 4 and 5 but not 1 and 5) should be used when testing ROM.

Trunk rotation ROM had very poor reliability during the first part of testing 5 trials. In particular, right rotation in field hockey players was poor. While the introduction of the new protocol improved the ICC for trunk rotation dramatically, the very poor initial reliability raised the question of whether right rotation is problematic in field hockey players. This area requires further investigation.

Left trunk side flexion ROM had moderate reliability, but was not discovered partway through the testing as was trunk rotation. It was felt that changes to the protocol to make this test similar to the trunk rotation ROM tests would increase the reliability for future studies.

The principal investigator observed visually during testing that many of the field hockey participants had decreased rotation and side flexion from L_1 to L_5 with increased movement at T_{12}. It was felt that measuring rotation and side flexion at the T_{12} level might be misleading in the actual amount of rotation occurring in the rest of the lumbar spine (i.e. T_{12}/L_1 hypermobility masking L_1 to L_5 hypomobility). Consequently, it was recommended that in future investigations of mechanical imbalance in field hockey including lumbar spine rotation and side flexion, measurements should be taken at the L_1/L_2 and L_5/S_1 interspinous spaces.

All isometric strength measurements were found to have excellent intratester reliability.[82] This reliability has been demonstrated in other studies that employ anchored hand-held dynamometers.[44,47,48] Significant differences between trials were found for right hip adductor and left trunk rotation strength and were greatest, again, between the 1st and 5th trials. Familiarity with these movements is necessary to produce consistent measurements. The lack of significant differences between trials for the majority of strength measurements indicated that warm-up trials were not necessary and that 1 min rest between trials was sufficient. However, due to the significant differences for adduction and trunk rotation and to decrease measurement error, it was recommended that participants be given up to a maximum of 5 trials to obtain measurements within 1 kg of each other. Although not statistically significant, it was noted anecdotally that there was a decrease in strength measurement between 4th and 5th trials for many movements. It was recommended that whenever possible the 5th trial be avoided as the drop may indicate onset of accumulative fatigue.

The lateral hop was modified from Worrell's[75] single leg hop for distance. Worrell's test involved 2 warm-up hops, followed by 1 min rest, followed by 2 hops (averaged for data analysis). An ICC of 0.99 was reported, with the average distance being most reliable for test-retest procedures that occur several days apart.[75] Ross[61] also reported ICC's ranging between 0.90 and 0.96 for the hop. This study reported an ICC of 0.828 for the left lateral hop. An ICC for right lateral hop was not obtained due to the bimodal distribution of this variable, but Kendall's W was not significant. This result is not quite as strong as Worrell's findings and may be due to this study's measurements not being averaged at the time of analysis. The left lateral hop had differences between the 1st and 3rd and 1st and 5th trials. While the ICC was excellent, it was recommended that warm-up trials to develop consistent jumping distance and technique be given with 2 min rest before the actual testing trials.

The sideways sit-up had moderate intratester reliability. Unfortunately, there are no other dynamic studies to which to compare this result. Tests of the Sorensen test (static endurance) have reported high reliability (test-retest $r = 0.94$ to 0.97 in healthy subjects and 0.85 to 0.91 in persons with chronic low back pain).[52] It is likely that the lower reliability between trials is a function of fatigue, as this was a test to exhaustion. It was recommended that future participants be given one warm-up trial and one test trial separated by 5 min rest.

The diagonal lateral lunge test was modified from the lateral step test.[61] The lateral step test has been shown to have a high interrater reliability (ICC=0.99).[63] Both left and right diagonal lateral lunges had poor interrater reliability. Neither, however, showed significant differences between trials on the repeated measures ANOVA. It was felt that the non-significant ANOVA finding was related to the small sample size in the pilot study ($n = 6$ field hockey players). The poor reliability relates to fatigue in this test to exhaustion. Half the participants suffered between 1/3 and 1/5 drop off in number of lunges between the 1st and 2nd trials. Consequently, it was recommended that this test be performed with one trial to exhaustion preceded by a brief practice trial and 5 min rest.

CONCLUSIONS

The purpose of this study was threefold: to create a testing battery to investigate left-right mechanical imbalance in the low back and hip in field hockey; to develop tests that allow practical application to clinical practice, and; to establish the reliability and validity for this battery. The hypothesis was that reliable and valid clinical and sport specific measures, including range of motion, isometric strength, muscular endurance and power to detect left-right mechanical imbalance in field hockey could be developed. While reliable and valid measures have been developed, based on statistical analysis and expert group feedback, their usefulness to detect left-right imbalance will require further study.

The majority of ROM and strength tests in the battery were found to have excellent intrarater reliability. The functional tests were not found to be as reliable, but these findings were most likely due to fatigue. With suggested modifications, these tests should produce valid and reliable results. As ROM and isometric strength tests are already standard procedures in clinical practice, they have obvious clinical application. The functional tests were modified to fit field hockey and are easy to perform in the clinical setting. The procedure to develop these kinds of tests can be done clinically, but until some norms for different populations are established, an immediate applicability of results is not possible.

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CHAPTER 4: A MUSCULOSKELETAL PROFILE OF CANADIAN INTERUNIVERSITY FEMALE FIELD HOCKEY PLAYERS

Low back pain (LBP) is a common problem in field hockey. Frequencies for at least one episode of field hockey related LBP in male and female athletes have been reported between 53% and 78%.[1-3] Chronic low-grade back pain can cause an athlete to miss a practice or game and can lead to decreased successful performance of sport related skills. While the presence of chronic low back pain has been identified in field hockey, few investigations have been conducted on the risk factors associated with this pain.

Risk factors for any cumulative traumatic injury (chronic injury) in the low back include mechanical exposure factors (predominantly extrinsic or outside the body) and individual factors (predominantly intrinsic or inside the body), all of which interrelate with each other. Mechanical exposure factors include static muscle loading in prolonged positions (e.g. forward flexion while ball handling), the force used to perform the task, the type of movement, repetitive bending, twisting or lifting, sudden forceful incidents, constrained working postures and asymmetric loading.[4-7] Individual factors include posture, trunk extensor and flexor strength and trunk extensor and flexor endurance.[4]

Mechanical imbalance can be defined as an alteration of structure and function which is reflected in combinations of muscle tightness and weakness, ligamentous laxity and/or poor alignment of body segments.[8] It is related to mechanical risk factors as an outcome that may lead to chronic injury and is characterized by asymmetries in individual risk factors. The investigation of individual risk factors that may characterize a mechanical imbalance is hampered by the possibility of a pre-existing sport specific pattern of flexibility, strength and muscular endurance that develops as a result of intense training in the sport but that is not necessarily associated with injury. Silver, de la Garza and Rang[9] called this sport specific pattern a "task appropriate" mechanical imbalance. Injury related patterns of flexibility, strength and muscular endurance must be differentiated from task appropriate mechanical imbalances in order to introduce effective injury reducing interventions.[10] Currently, very little information exists on the potential presence of a task appropriate imbalance in field hockey.

Some work has been done in field hockey to begin developing norms by investigating strength and range of motion (ROM) parameters of players with and without LBP in relation to normals.[1,11,12] However, these studies do not specifically investigate differences between left and right sides of the body. In this asymmetric sport, there is potential for the presence of a specific task appropriate imbalance, which may or may not be related to injury.

Purpose

The purpose of the present study was to investigate the potential presence of a left/right task appropriate imbalance of the trunk and hip region in Canadian female interuniversity field hockey players, employing measures that could be easily used in a field or clinical setting, and to differentiate between these and injury-related mechanical imbalances.

Hypothesis

It was hypothesized that the asymmetric demands of field hockey would produce left/right task appropriate muscle imbalances that would be different from a healthy control group and from right/left imbalances seen in players with a history of low back or thigh pain.

LITERATURE REVIEW

The Kinetic Chain and Muscle Imbalance

There are many factors that are related to LBP. Mechanical imbalance, the focus of the present paper, is theorized to cause injury by affecting the kinetic chain. The kinetic chain is the sequencing of unique movements from proximal to distal where a proximal base of support or stability is required for successive activation of each kinetic chain segment.[13] The net result is a summation of the developed force and energy through the segments and efficient transfer of the energy to the terminal segment. The sequencing is accomplished by specific motor control patterns that allow segment stabilization, force generation, joint positioning and segment motion. These patterns depend on feedback from joint and limb position and motion, and are intimately linked with the kinetic chain, so that changes in either physiology or biomechanics will affect each other.[13] The ability of one body part to move is enhanced by full mobility of the kinetic chain.[7] When one segment does not have optimum movement, all areas of the kinetic chain suffer strain.[7] Segments of the kinetic chain that do not perform optimally due to fatigue or decreased coordination can cause problems both locally and distally, as other segments have to compensate for the lack of force or energy delivered through the more proximal segments.[13] Inefficient transfer of energy in the kinetic chain is dangerous to the distal segment because it may create more load or stress than the segment can safely handle. Small alterations in specific segments have been demonstrated to have major effects on the kinetic chain and on the performance that is based on these chains. Ultimately, increased risk of injury may result.[13]

A mechanical imbalance is an alteration of structure and function, which is reflected in combinations of muscle tightness and weakness, ligamentous laxity and/or poor alignment of body segments.[8] Vladimir Janda, Shirley Sahrmann and Diane Lee have all contributed to the understanding of mechanical imbalance. Janda relates the patterns of tightness and weakness to patterns of hyper- and hypotonia common between cerebral lesions and postural syndromes.[14-21] Sahrmann relates the patterns to use and positional length and strength changes in the muscle.[22] Lee relates consequences of muscle imbalance to the muscular units that provide a stable base through the lower quadrant.[23-25]

While the cause of changes in muscle length and strength associated with muscle balance (e.g. reflex pain response, changes in activation, adaptive structural changes, peripheral paresis or spasticity, ischemia, synergist predominance) are a subject of debate, there is considerable agreement on the consequence of these changes. It should be noted, however, that the relationship of muscle imbalance to injury is theoretical.

Muscles positioned in either shortened or lengthened positions from the ideal posture will alter the efficiency of normal muscle contraction and cause the muscle to be used at a mechanical disadvantage.[26,27] At normal resting length, a maximal number of actin and myosin filament cross-bridges exist and a muscle can generate its greatest force.[28] In either a shortened or lengthened position, the number of actin-myosin cross-bridges are decreased because, respectively, the actin filaments overlap or a smaller number of actin and myosin filaments lie next to each other. In either the shortened or lengthened position, force generation is decreased (i.e. mechanical disadvantage). When a muscle or group of muscles are placed at a mechanical disadvantage, subtle shifts in the pattern of motor activity occur, causing synergistic muscles to generate the necessary forces required for functional tasks as a compensation for the prime mover muscular strength deficit.[26,27,29] With prolonged static holding or repetitive movement, prime movers can become so fatigued that they are unable to generate the force required. Again, synergistic muscles will compensate for the prime movers. This muscle substitution of synergistic muscles both creates and perpetuates the problem of muscle imbalance.[26,27] Without correction of the muscle imbalance, tighter muscles become tighter, weaker muscles become weaker and overused muscles continue to be overused.[26] The kinetic chain is altered. Any breakdown in the effective function of the kinetic chain may predispose a person to injury.[30] The weakened muscles and synergistic muscles not designed to be prime movers continue to be stressed and repetitive injury occurs.[26,30] Joint function may be altered through mechanical and neurological avenues.[8] If tight muscles pass over nerve tissue, they may secondarily put pressure on the nerve.[26] Diminished load bearing capacities of the skeletal structures occurs with postural changes; altered posture changes shock absorption abilities of tissues; and, early fatigue associated with muscle weakness leads to poor coordination of movement.[30] Performance of a task requiring strength, power, endurance, coordination or skill is impaired if the muscles required for that task are functionally impaired by being weak, inhibited, shortened, stretched, excessively developed or have poor neuromuscular coordination.[30]

Muscle tightness can change both habitual resting posture and total range of dynamic postures available to the segment of the kinetic chain crossed by the tight muscle.[31] A reduction in the range of lumbar spine movement reduces the potential of the spine to respond to sudden demands of loading and movement and, consequently, increases its vulnerability to injury.[32] In a person with normal range of motion, loading of the spine in a position well within the normal range can be easily tolerated. However, the same load applied to an individual with reduced range will be poorly tolerated as it puts shortened soft tissues under stress. Weakened antagonistic muscles often accompany tightened muscles about a joint. With this weakening, a joint whose ROM is already decreased by tightness may also be forced beyond the end range leading to subsequent injury because the weak muscles are not strong enough to control the load.[32] Weak, unstable or strained positions affect the kinetic chain, and the changes that accompany these positions may result in anatomical or biomechanical situations that increase injury risk, perpetuate injury patterns or decrease performance.[13]

Task Appropriate Imbalance

It is widely accepted that injury in sport is related to the factors that cause cumulative traumatic disorders and imbalances in the kinetic chain. However, there is a difference between imbalances that cause injury and those that enhance performance. Silver, de la Garza, and Rang[9] coined the phrase "task appropriate" imbalance. Each muscle in the body must fulfill certain tasks that require a particular strength, endurance, flexibility and coordination with other portions of the kinetic chain.[9] Every sport has specific movement patterns that will commonly result in a task appropriate imbalance that enhances performance, but that may also lead to injury.[33, 34] What becomes difficult is deciding where the boundary between the two lies.[9]

One way of investigating this boundary is to develop a musculoskeletal profile. Agre and Baxter[35] investigated symmetry in ROM and strength in the legs of soccer players and determined the average difference between the dominant and non-dominant leg. The authors noted that although most soccer players have a definite foot preference for kicking the ball, it was uncertain whether or not this preference resulted in asymmetry in the flexibility and strength of the lower extremities. A health questionnaire focusing on musculoskeletal injury and years played organized soccer was administered. Anthropometric measurements of height, weight and leg lengths were taken. Goniometric measurement of flexibility was performed for left and right hip abduction, hip flexion, hip extension and ankle dorsiflexion. Isokinetic dynamometer measurement of strength was performed for knee extension, knee flexion, hip flexion and ankle plantar flexion. They found preference in kicking foot did not affect lower extremity flexibility or strength and that players who sustained non-traumatic local back strain injuries had significant differences in hamstring flexibility between legs (greater than 2 standard deviations side to side difference versus the group mean side to side difference).[35]

Hamilton, Hamilton, Marshall, and Molnar[36] created a musculoskeletal profile of 28 principle dancers and soloists (14 men and 22 women) with the American Ballet Theatre and the New York City Ballet. A questionnaire was administered to ascertain age, education, dance training, dominant hand, turning preference, years of professional dance and history of injuries. Anthropometric measurements included age, height, weight, arm length, and leg length. Goniometric measurement of ROM included hip external and internal rotation, hip abduction and adduction, knee flexion, extension and hyperextension, tibial torsion, tibial external and internal rotation, ankle plantar and dorsiflexion. Isokinetic dynamometer strength measurements were taken for left and right hip abduction and adduction, knee flexion and extension, and ankle plantar and dorsiflexion. The results indicated that men and women had increased hip external rotation ROM (+30% for both) and increased ankle plantar flexion ROM (+123% and +135%, respectively) compared to general population norms. Men and women had significant imbalance between hip abduction when compared to general population norms. Men had +18% stronger abductors and -25% weaker adductors; women had +21% stronger abductors and -24% weaker adductors.[36]

Howell[37] created a musculoskeletal profile of 17 lightweight female rowers. A questionnaire established number of years rowed, the presence of chronic low backache or discomfort and other musculoskeletal symptoms, and the extent of regular flexibility exercises. Strength was measured via an abdominal curl, lowering legs from 90°, and back extension and flexibility was measured via the sit and reach test, straight leg raise, knee to chest, Thomas test, prone extension and arms straight over head. The results showed that 94% of participants were hyperflexible on a sit and reach test, that excessive lumbar flexion was highly correlated with the incidence of low back pain or discomfort and the existence of an asymmetry in the latissimus dorsi.[37]

Field Hockey

Field hockey involves a repetitive cyclic movement into thoracolumbar flexion that is superimposed on skill performance and is a game with an intrinsic asymmetry (all field hockey is played right handed) in terms of individual and team play.[1, 38] These repetitive postural stresses, skill requirements and asymmetry of movement of the sport are superimposed on the work rate demanded by the game and its pattern of play.[3] Consequently there is the potential for adaptive tissue change, strain and fatigue from the repetitive movement into thoracolumbar flexion, from the repetitive forceful movements in thoracolumbar flexion to dribble, pass, receive and contest the ball, and from the work rate of the sport.

A task description of elite women's and men's field hockey (Chapter 2) found that in the most frequently occurring ball propulsion movements (stationary pushes and drives and running feet sideways strong side pushes), the participants lunged to the left significantly more than to the right. The muscle force generated to propel the ball occurred through asymmetric movement. Overall, a significant difference for all games and practices was found in the total number of left versus right lunges. It is possible that, over time, these asymmetric patterns might create a mechanical imbalance. The development of a musculoskeletal profile of field hockey players may provide a clearer delineation between injury related mechanical imbalance and task appropriate imbalance.

METHODS

Participants

Participants included two groups: (1) 61 Canadian female interuniversity field hockey players, and (2) a control group of 31 age range matched sedentary to recreationally active female university students.

Inclusion/Exclusion Criteria

Inclusion criteria for field hockey athletes included any athlete who had completed a minimum of one outdoor season of interuniversity field hockey for a Canadian Interuniversity Sport (CIS) member team and who participated in 80% of the university's outdoor field hockey practices. Most university teams practice 4 to 5 times per week. It was felt that 80% participation in these practices would provide a sufficient training effect to produce a task appropriate imbalance.

Inclusion criteria for the control group was any sedentary to recreationally active female who fell into the same age range as the field hockey group. These participants were recruited from the general University of Alberta student population.

The exclusion criteria for both groups included: any acute injury that led to pain and/or decreased ROM, strength or muscular endurance in the muscles and/or joints of the low back and hip regions; any acute exacerbation of a chronic injury that involved the muscles and/or joints of the low back and hip regions; any injury that affected the innervation and circulation to the muscles/joints being tested such that these regions had decreased ROM, strength and/or muscular endurance; not participating regularly (less than 80%) in field hockey training and competitions of the respective team. Individuals in the control group could not be involved in any asymmetrical activity (i.e. an activity that used predominantly one leg or hand) that had regular practices, competitions and/or physiological training sessions for 2 or more times per week, as training in a specific activity could create a task appropriate mechanical imbalance that could affect the results.

Ethical Approval

Ethical approval for this study was obtained through the University of Alberta Faculty of Physical Education and Recreation, Ethics Review Committee for Human Research and through the University of Toronto Health Sciences I Research Ethics Board. All participants provided signed informed consent (refer to Appendix N for ethics documents).

Procedure

The head coaches of 8 CIS field hockey teams were contacted to ascertain interest in their team's participation in the present study (Queen's University, University of Alberta, University of British Columbia, University of Calgary, University of Toronto, University of Victoria, University of Waterloo, and York University). These teams were selected based on (1) a top ten ranking in the 2003 CIS season, because the principal investigator felt that a top ten ranking would guarantee that the teams would have well-established and rigorous training and competitive programs that would most likely create a task appropriate imbalance, and (2) their geographical location and proximity to each other, due to funding limitations. The initial contact included a summary of the purpose of the study and the testing procedures, an explanation of the risks, benefits and time requirements and asked the coach to arrange mutually agreeable days and times when the testing could occur. Six of these teams agreed to participate; Queen's University and University of Waterloo declined.

Once the coach had agreed to the university team participating, individual athletes were recruited in advance of the testing dates. Participation was voluntary. In order to obtain the best participation rate, data collection occurred between November and April, during the off-season and indoor field hockey season. All athletes from one team were tested during the same week.

Control subjects were recruited through posters and public addresses in classes in the Faculty of Physical Education and Recreation, University of Alberta.

The testing battery consisted of the following components:

1. anthropometric data;
2. injury and sport participation history;
3. ROM measurements;
4. isometric strength measurements, and;
5. field hockey specific tests.

Both experimental groups performed all tests with the exception of the control group, which did not perform the lateral lunge endurance test, as this test was directly related to a field hockey skill. Based on the exclusion criteria, some participants were not able to complete all aspects of the testing. (e.g. an acute injury to the ankle that did not affect the strength tests of the hip but precluded the athlete from completing the single hop for distance test). All participants were asked not to participate in vigorous exercise 2 days prior to the first testing session.

Field hockey participants attended 3 testing sessions over 5 to 6 days (depending on the number of participants). Questionnaires were distributed prior to testing and participants were asked to bring completed questionnaires and consent forms to the first testing session. For a maximum of 16 participants per university team and a 6-day testing period, ROM testing, height and weight measurements and review of completed questionnaires occurred in 1-hour blocks over the first 2 days. Strength testing occurred in 2-hour blocks over days 2 to 5. Sport specific testing occurred in 1.5-hour blocks over days 5 and 6 (2 participants per testing time). The order of testing over the days (ROM followed by strength followed by field hockey specific) was chosen to ensure that subsequent testing would not be affected by delayed onset muscle soreness produced by previous testing. Participants could not test two different aspects (e.g. strength and field hockey specific) on the same day.

Control participants attended either 2 testing sessions of 1.5-hour duration each or 3 testing sessions of 1-hour, 1.5-hour and 1-hour duration. For 2 testing sessions, strength was tested in the first session, and ROM and field hockey specific tests (in that order) in the second session. For 3 testing sessions, ROM was tested in the first session, strength in the second and field hockey specific skills in the third. At least one day separated each testing session. Consent forms (Appendix N) were completed on the first day of testing. Questionnaires (Appendices G and H) were distributed at the first testing session and returned and checked for completeness at the second session.

Pilot testing of the entire testing battery established face validity and reliability for the testing procedures in the present study (Chapter 3). The following provides a brief description of the testing methods. A more detailed account of procedures, including justification and figures, can be found in the pilot study (Chapter 3).

Descriptive Data

A sport participation questionnaire (Appendix G) was designed to gather descriptive information for each participant. This questionnaire included questions about dominant hand and leg, years of participation in field hockey, primary and secondary position played including side of the field, highest level of participation achieved (university, provincial and/or national team member), other sports played, number of practices per week on average and number of hours per practice on average. Field hockey athletes completed the entire questionnaire while control participants completed only questions on dominant hand and foot and other sports played. Height, weight and age of the participant were noted on the sport participation questionnaire.

Injury History

All participants completed an injury questionnaire (Appendix H) to gather information on previous injury, particularly low back and hip pain, which might have affected the results of the testing.

Range of Motion Tests

Measurements were taken for hip extension, flexion, adduction, abduction, internal, and external rotation, and trunk side flexion and rotation. To control for circadian variation, all ROM testing took place after 12:00 PM and was scheduled to ensure that at least 4 hours had passed since rising.[39,40] ROM was measured using inclinometers (Baseline bubble inclinometer, Chattanooga Group, Montreal, Canada) or compasses (Nexus Star 7DNL Compass, Sweden), based on standardized techniques developed by Kendall and McCreary[41] and Clarkson.[42] For measurements involving the leg, the inclinometer or compass was placed on the thigh via a Velcro strap at a point 10 centimetres (cm) above the medial joint line of the knee and/or on the lower leg at a point 10 cm below the medial joint line of the knee. For measurements of the lumbar spine, inclinometers were placed at the level of L_5/S_1 and T_{12}/L_1, respectively. Prior to each testing day, the inclinometers were calibrated against a level.

For measurements in supine position, participants rested on a portable massage table (Figure 4.1). To provide a firm base of support, a 60 x 60 cm plywood board covered in a sheet was placed under the participant's pelvis with a small square of foam placed under the sacrum and posterior superior iliac spines for comfort.[43] The table was weighted at one end with a 25 kilogram (kg) sand bag so it would not tip when the participant was placed at the other end of the table. For measurements in the sitting position, participants sat on a bath stool (Figure 4.2). Participants were strapped to the table or stool to ensure standardization of techniques and to eliminate extraneous movements of related body parts.

Figure 4.1. Range of motion testing in lying.

Figure 4.2. Range of motion testing in sitting.

Each test included 2 trials of 15 seconds (s) with 15 s rest between trials. Both trials were recorded and averaged at the time of data analysis. All tests were performed bilaterally and measurements were rounded to the nearest degree. There was no warm-up prior to measurement. One examiner took and recorded the measurements.

Test order was determined via stratified randomization. Tests were clustered based on the stabilization procedure used. One cluster included the table tests and had sub-clusters – 1. hip extension, 2. hip adduction/abduction/flexion. The second cluster included the chair tests and also had sub-clusters – 1. hip internal and external rotation and 2. trunk side flexion and rotation. Test order was randomized based first on the cluster (i.e. table versus chair), next on the sub-cluster (i.e. randomized order of 1 and 2 as listed above) and finally on the testing motions in multiple motion sub-clusters (e.g. randomized order of internal and external rotation). The movements tested included hip extension (one and two joint), hip adduction, hip abduction, hip flexion (one and two joint), hip internal rotation, hip external rotation, lumbar side flexion, and lumbar rotation.

Isometric Strength Tests

Maximal isometric strength measurements were taken for hip extension, flexion, adduction, abduction, internal, and external rotation, and trunk side flexion and rotation. These measurements were taken using a push-pull strain-gauge dynamometer (Baseline Hydraulic Push-Pull Dynamometer, Chattanooga Group, Montreal, Canada) in positions independent of gravity modified from standardized manual muscle testing procedures.[41, 42] Prior to each testing day, the strain gauge was calibrated with a known mass.

Tests of hip flexion, extension, adduction and abduction strength were performed with the participant standing in a specially fortified, standard, adjustable, collapsible walker (Figure 4.3). Five-by-five cm oak strips were placed horizontally across both sides and front of the walker. The front of the walker was fitted with a 2 cm plywood board with a rectangular cut-out to allow the non-test leg and the pelvis to be stabilized via straps and the test leg to be free. Padding was placed between the participant and the board to accommodate for individual anatomy that might cause the participant to be uncomfortable against the board or not flush with the board. The walker was set to the height of the participant's wrist creases with the arms resting at the side of the body.

Tests of hip internal and external rotation and trunk side flexion and rotation strength were performed with the participant seated on a height adjustable bath stool(Figure 4.4). The height was adjusted so the participant would sit with hips and knees bent to 90°. Participants were strapped to the table or stool to ensure standardization of techniques and to eliminate extraneous movements of related body parts.

The push-pull dynamometer was mounted on the walker frame by a vertical cross bracing and its height was set at the level of the strap or harness attachment on the participant. The dynamometer and strapping were joined via mountaineering carabineers (rated to 300 pounds) and aviation wire (rated to 800 pounds). For tests of hip flexion, adduction, abduction and extension strength, the carabineer was positioned 10 cm above the medial joint line of the knee. For tests of hip rotation, the carabineer was positioned 5 cm above the medial malleolus. For tests of trunk rotation and side flexion, the carabineer was attached to a harness.

Figure 4.3. Strength apparatus in standing.

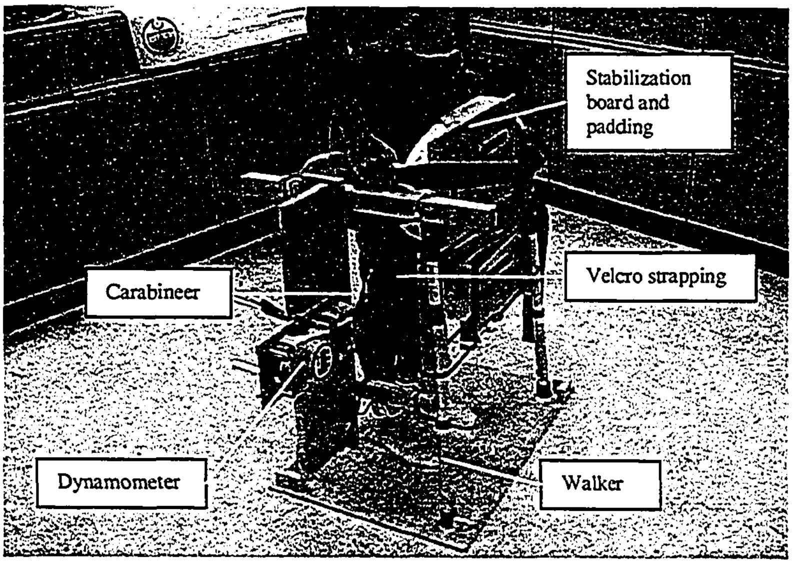
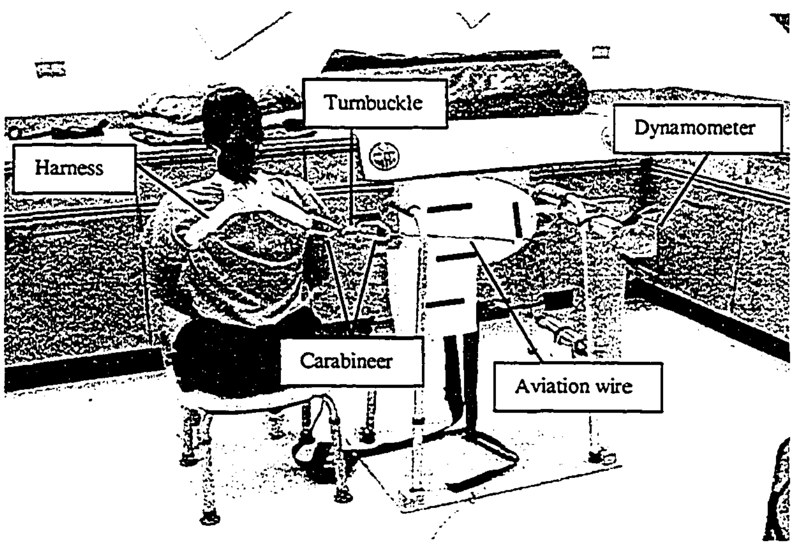


Figure 4.4. Strength apparatus in sitting.



Testing was preceded by a 5-minute light cycling warm-up on a stationary bike. Each isometric contraction was held for 5 s.[44-46] The participant increased her effort gradually over the first 2 s to reach maximal contraction for the last 3 s.[44] Sixty seconds of rest was given between each trial.[45, 47-50] There were a maximum of 5 trials per test per leg. For each test to be complete, two measurements within 2 pounds (lb) had to be collected. If at the end of 5 trials, no measurements were within 2 lb, the 2 closest measurements were recorded, based on the trend observed (e.g. if the 5 measurements gradually increased by 3 lb each, the last 2 measurements were recorded). Wang[51] employed a similar method, where at least 3 maximal contractions that did not differ by more than 10% were collected for isokinetic strength measurements of the shoulder. The two trials were recorded and averaged at the time of data analysis. All tests were performed bilaterally. The dynamometer readings were measured in pounds and were rounded to the nearest pound. In the pilot study (Chapter 3), measurements were taken in kilograms. However, as the dynamometer only records in whole pounds or kilograms, pounds were chosen to improve sensitivity. All results were converted to kilograms (1 kg = 2.2 lb). One examiner took and recorded all measurements.

Test order was determined via stratified randomization. Tests were clustered based on the stabilization procedure used. The first cluster included the standing tests and had sub-clusters – 1. hip extension/adduction/abduction and 2. hip flexion. The second cluster included the chair tests and had sub-clusters – 1. hip internal/external rotation and 2. trunk side flexion/rotation. Test order was randomized based first on the cluster (i.e. table versus chair), next on the sub-cluster (i.e. randomized order of 1 and 2 of each cluster as listed above) and finally on the testing motions in multiple motion sub-clusters (e.g. randomized order of internal and external rotation).

Field Hockey Specific Tests

All functional tests were preceded by a 5-minute light cycle on a stationary bike.

Single-Leg Hop for Distance

The participant was positioned standing with the instep of the foot of the test leg (TL) lined up with a starting line facing sideways. From this line, a tape measure stretched out beside the participant. Standing on the TL with the non-test leg (NTL) touching for balance only, the participant hopped sideways as far as possible to land on the TL (e.g. if the TL was the right leg, the participant would hop to the left). There were 2 trials per leg with 2 minutes rest between trials. The two trials were recorded and averaged at the time of data analysis. All tests were performed bilaterally.

Figure 4.5. Single leg hop for distance.
A. Starting position. B. Finish position.

Trunk Side Flexion Endurance

The participant was positioned in side lying on a portable massage table with the iliac crests level with the end of the table. A chair of equal height to the table was placed at the end of the table so that the participant could rest on the chair until the test began. The bath stool was placed in front of the chair for the participant to support her body weight when the chair was removed prior to the start of the test. Padding was placed under the participant's hips, between the participant's knees and under the strapping. Straps were placed at the level of the participant's iliac crests and mid-calf to anchor the pelvis and lower leg to the table. A 25 kg sand bag was placed at the end of the table to prevent it from tipping. The participant was asked to move through her full range of side flexion with her hands crossed in front of her trunk until exhaustion paced by a calibrated metronome counting at 60 beats per minute (bpm).[52, 53] The ROM was marked and defined the test range. The test ended if the participant stopped, was unable to move through the entire ROM, could not keep pace with the metronome, or twisted the trunk. Participants were warned of any technique problem and given one repetition (up and down) to correct. If they did not correct the technique, the test was stopped. Each side was tested 1 time with 5 minutes rest before testing the opposite side.

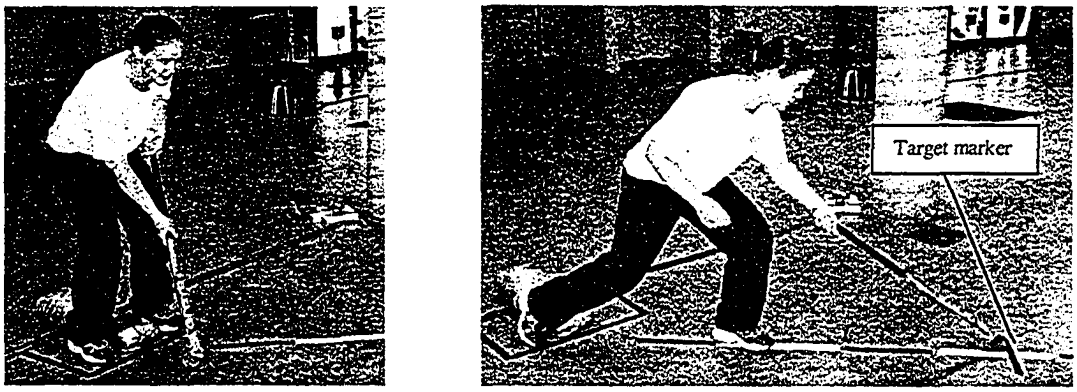
Figure 4.6. Trunk side flexion.

Lateral Lunge Endurance

A 60 cm box, separated in half by a 25 kg sand bag was marked off with tape. The participant was asked to assume a familiar field hockey "ready" stance (i.e. the position the participant would assume if waiting to defend against an opponent) with the feet parallel and with each foot in the box and on either side of the sand bag. The participant held a field hockey stick (the same stick was used for each participant). The participant was asked to lunge diagonally forward on a 45° angle to a position that the participant would consider a reaching poke tackle. The distance the stick traveled was marked and defined the test range.

The participant then resumed the ready stance with both hands on the stick. A step diagonally forward, reaching to touch the target with the tip of the stick and return to the starting position with the toe of the TL foot touching the ground behind the starting line and within the box was one repetition. The stick was held in the same hand as the test leg and was dragged across the ground. The participant moved through the test range paced by a metronome counting at 72 bpm. The test ended if the participant stopped, was unable to reach the target, did not bring the foot back to the starting position or could not keep pace with the metronome. Participants were warned of any technique problem and given one repetition to correct. If they did not correct the technique, the test was stopped. Each leg was tested 1 time with 5 minutes rest before testing the opposite side.

Figure 4.7. Lateral lunge endurance.
A. Start and end position B. Lunge position



Time Commitment

The time commitment for the present study was as follows:

- Sport Participation Questionnaire: 5 min (control group) to 15 min (field hockey athletes)
- Injury History Questionnaire: 5 to 20 min (depending on injury history)
- Height and Weight: 5 min
- ROM Testing: 40 min
- Isometric Strength Testing: 1.5 hrs
- Activity Specific Testing: 45 min (control group) to 1.25 hours (field hockey athletes)

Total Time Commitment: 3.5 to 4.25 hours

Testing Location

Field hockey participant testing was held at each participating university in a space allocated by that institution. All testing areas had similar floor surfaces for the lateral hop and lateral lunge endurance tests. All testing equipment was transported to each institution.

All control and University of Alberta field hockey testing was performed in the University of Alberta, Faculty of Physical Education and Recreation Sport Performance Lab and Van Vliet Pavilion Concourse.

Data Analysis

Statistical analysis was performed using the Statistical Package for the Social Sciences (SPSS edition 11.5, SPSS Inc., Chicago, USA). Dependent variables (DV) included all ROM, strength and sport specific measurements (21 in total). For measurements of ROM and strength, the average of the two recorded measurements for each movement was used for statistical analysis. Independent variables (IV) for all participants included hand and foot dominance, history of back and thigh injury, and participation in activities other than field hockey. Additional IVs for field hockey participants only included years of field hockey played, highest level of field hockey played, number of levels of field hockey played, university team, primary position played, and primary area of the field where position played. Interactions amongst DVs were not investigated, as this type of analysis becomes uninterpretable with greater than 4 to 5 variables.[54] Mann-Whitney tests ($p<0.05$) were used to test differences between control and field hockey groups for age, height, and weight.

Normality was tested for each DV and IV using the Shapiro-Wilk test for the control group ($n < 50$) and the Kolmogorov-Smirnov test for the field hockey group ($n > 50$) ($p < .05$) (SPSS). Lists of non-normal variables can be found in Appendix I. Parametric statistical tests were used for variables that had normal distributions and equal variances and numbers; the non-parametric corollary statistical tests were used for variables that had a non-normal distribution, or had unequal variances or numbers.[54, 55]

Both back and thigh pain were categorized based on the following definitions. Categories 3 and 4 represented chronic injury.

1. Healthy: No history of low back or thigh pain that had limited function, or for which the individual had sought medical attention; low back discomfort associated only with menstruation, or due to delayed onset muscle soreness or post-exercise soreness[11, 46, 56-58]
2. Acute episode: One-time only bout of low back or thigh pain that had resolved, with or without medical intervention[59]
3. Non-significant limiting: greater than 3 months of low back or thigh pain that had not interfered with activities of daily living, training, practicing or playing[11, 29, 46, 49, 52, 57, 60-63]
4. Significant Limiting: greater than 3 months of low back or thigh pain or 3 episodes of the similar pain in the last year for which the individual had sought medical attention and which interfered with activities of daily living, training, practicing or playing.[11, 29, 46, 49, 52, 57, 60-63]

Differences between groups for history of low back and thigh pain were evaluated via the Chi Square test ($p < .05$).[54, 64]

Difference scores were calculated as left minus right for each DV. A positive mean difference score indicated that the left side was larger than the right. Paired-t and Wilcoxan Ranks tests were used to evaluate significant differences between left and right scores for each DV, depending on whether the variable was normally or non-normally distributed.[35, 36, 43, 54] Differences between groups (based on control and field hockey back and thigh pain categories) were evaluated via the Kruskal Wallis test with post-hoc evaluation via the Mann-Whitney test.

Significance was grouped according to a combination of effect size (ES), type I error (i.e., alpha or p value) and power. No other investigation of left/right differences had been performed in field hockey and very little knowledge existed on what size of muscle imbalance causes injury. Calculated ES for retired field hockey players, based on the results of the pilot study (Chapter 3), were small.[65] Given these results, a sample size of 400 was estimated as necessary to ensure power of .80. An approximate total of only 250 women played field hockey at the intercollegiate level in Canada at the time of the present study. Consequently, the principal investigator was aware of the limitation of sample size prior to beginning the present study. Effect size represents the degree of departure of the observed phenomenon from the null hypothesis (i.e. ES = 0).[65] Effect size is a function of means and standard deviations, but not sample size. Consequently, ES is an important measure of significance that can be used when sample size is known to be problematic in conventional assignment of alpha levels and power.[65]

Type I error is the risk of mistakenly rejecting a true null hypothesis; type II error is the risk of failing to reject a false null hypothesis.[65] In simpler terms, Type I error is the risk of saying there is a difference when there is no difference and Type II error is the risk of saying there is no difference when there is. Statistical inference is based on a relative weighing of these two errors.[65] The ratio of Type I to Type II error weighs which of the two errors is worse – saying there is a difference when really there is not, or saying there is no difference but really there is.[65] Due to the exploratory nature of this study, the principal investigator felt that it was worse to say there was no difference between variables when there really was (Type II error), than to say there was a difference between variables when there really was not (Type I error). Consequently, the principal investigator was willing to consider higher alpha values (greater type I error) and lower power in order to keep the Type I to Type II ratio lower.

Percentage difference between left and right was provided for significant paired differences. Percentage difference was calculated as follows[64]:

$$\text{percentage difference} = \frac{(\text{left mean} - \text{right mean})}{\text{left/right mean}} \times 100$$

where left/right mean = the larger of left or right mean score

Participation in activities other than field hockey was categorized into symmetrical, left hand dominant, right hand dominant, left foot dominant and right foot dominant activities. This classification was based on discussion with coaches and/or therapists in the given activities. The other activities that were listed on the sport participation and their classification can be found in Appendix J. In order to create an interval measurement for contact hours for field hockey and other sports, sport*years were calculated. This method was based on smoking history "pack*years", which is the number of cigarette packs smoked per day x the number of years of smoking. Calculation of sport*years was made in the following manner:

$$\text{Sport*yrs} = \text{\# hours/day} \times \text{years participated, where}$$

$$\text{\#hours/day} = \frac{\text{length of session in hrs} \times \text{frequency/week}}{\text{7 days/week}}$$

$$\text{years participated} = \frac{\text{\# months/year participated} \times \text{\# of years participated}}{\text{12 months/year}}$$

The relationship between IVs and DVs (excluding hand dominance and history of back and thigh injury) was evaluated through bivariate correlation (interval data), spearman's rho (ordinal data), chi square (nominal data) and Kruskal Wallis test ($p < .05$). For bivariate correlation, the Pearson product moment was used for normally distributed data and kendall's tau_b for non-normally distributed data.[54, 55]

RESULTS

Ninety-two (92) individuals enrolled in this study (31 control and 61 field hockey). Some of these 92 participants had missing data. Seven participants did not complete the "other sport" section of the questionnaire. Consequently, these individuals were omitted from the analysis of the effect of other sports on measurements of ROM, strength, and field hockey specific tasks. Forty-seven field hockey participants did not complete the section of the sport participation that dealt with time spent participating at field hockey levels other than university. Consequently, the analysis of this independent variable was not conducted. One individual's questionnaire did not identify handedness when playing hockey. Two control and 20 field hockey participants did not complete all 21 left-right paired tests of ROM, strength and field hockey specific measurements. Of these, 9 were injured, 8 were unable to schedule a section of the testing (e.g. were not able to come on the days when ROM testing was taking place) and 3 arrived late and ran out of time to complete all the tests on that given day. One participant was afraid to perform the side flexion endurance test and one lateral lunge endurance test was disrupted by the Lady Godiva Memorial Band and miniature cannon. All missing data were excluded from statistical analysis.

Average (range) age was 20.9 (18.0 to 26.0) years for the controls and 20.3 (18.0 to 25.0) years for field hockey. Average (range) height was 162.8 (153 to 173.5) cm and 163.4 (141.6 to 174.0) cm for the controls and field hockey participants, respectively. Average (range) body mass was 63.3 (49.5 to 129.0) kilograms (kg) and 62.8 (47.3 to 95.5) kg for the controls and field hockey participants, respectively. No significant difference was found between the two groups for age, height or weight. Only 7 of the 92 participants were found to be left hand and/or left foot dominant (1 control and 6 field hockey). This number did not constitute a large enough group to test findings between right and left hand dominant individuals. Consequently, all significance testing was performed on the right handed and footed individuals only.

The number of participants who reported low back and thigh pain can be found in Tables 4.1 and 4.2, respectively.

Table 4.1. History of Back Injury for Control and Field Hockey Groups

History of Back Injury	Control	Field Hockey
Healthy	19	27
Acute	6	5
Non-significantly limiting	2	17
Significantly-limiting	3	6
Total	30	55

Table 4.2. History of Thigh Injury for Control and Field Hockey Groups

History of Thigh Injury	Control	Field Hockey
Healthy	18	35
Acute	4	11
Non-significantly limiting	7	6
Significantly limiting	1	3
Total	30	55

Analysis via chi-square showed no significant differences between the control and field hockey groups for category of back or thigh injury. However, more than 20% of the category cells had a count of less than 5. Consequently, this result may not be reliable.[55]

Ten participants per group are recommended for ANOVA or non-parametric corollary testing to ensure the reliability of these statistical tests.[54] Consequently, only those back and thigh pain categories with 10 or more participants were used in data analysis. Initial analysis for paired differences and differences amongst groups was performed on the following categories:

1. HC: control subjects with no history of back or thigh injury
2. HFH: field hockey players with no history of back or thigh injury
3. NSLFH: field hockey players with history of non-significantly limiting back pain
4. AFH: field hockey players with history of acute thigh pain.

Due to the limitation of group size, thigh and back pain groups could not be combined (e.g. field hockey players with acute thigh pain and significantly limiting back pain).

The mean left and right measurements and standard deviations for each DV for the different pain categories are shown in Tables 4.3 to 4.6.

Table 4.3. Mean Values for Range of Motion, Strength and Field Hockey Specific Tests for Healthy Control Participants

Movement	N	Left mean (standard deviation)	Right mean (standard deviation)
Range of Motion (degrees)			
2-joint hip extension	13	12 (+/-5)	13 (+/-5)
1-joint hip extension	13	13 (+/-4)	13 (+/-4)
Hip adduction	13	13 (+/-3)	15 (+/-3)
Hip abduction	13	36 (+/-5)	39 (+/-5)
2-joint hip flexion	13	87 (+/-14)	85 (+/-13)
1 joint hip flexion	13	72 (+/-12)	73 (+/-12)
Hip internal rotation	13	42 (+/-7)	42 (+/-6)
Hip external rotation	13	45 (+/-6)	44 (+/-5)
Trunk side flexion	13	19 (+/-5)	19 (+/-5)
Trunk rotation	13	7 (+/-3)	8 (+/-3)
Strength (kilograms)			
Hip flexion	13	39.9 (+/-8.7)	41.7 (+/-9.7)
Hip extension	13	32.3 (+/-10.7)	31.7 (+/-8.4)
Hip adduction	13	20.8 (+/-6.0)	19.5 (+/-4.8)
Hip abduction	13	27.5 (+/-8.1)	25.6 (+/-6.9)
Hip internal rotation	13	12.2 (+/-4.0)	13.0 (+/-3.9)
Hip external rotation	13	10.7 (+/-2.5)	10.6 (+/-2.1)
Trunk side flexion	13	22.7 (+/-6.5)	20.9 (+/-5.9)
Trunk rotation	13	30.1 (+/-11.6)	30.8 (+/-11.8)
Field Hockey Specific (hop = centimetres; endurance tests = repetitions)			
Sideways hop for distance	13	133.5 (+/-25.4)	139.5 (+/-25.7)
Trunk side flexion endurance	13	12.8 (+/-3.1)	12.2 (+/-3.8)

Table 4.4. Mean Values for Range of Motion, Strength and Field Hockey Specific Tests for Healthy Field Hockey Participants

Movement	N	Left mean (standard deviation)	Right mean (standard deviation)
Range of Motion (degrees)			
2-joint hip extension	17	10 (+/-5)	10 (+/-6)
1-joint hip extension	17	9 (+/-4)	10 (+/-4)
Hip adduction	17	12 (+/-2)	13 (+/-3)
Hip abduction	17	41 (+/-5)	39 (+/-5)
2-joint hip flexion	17	82 (+/-11)	82 (+/-11)
1 joint hip flexion	17	68 (+/-14)	69 (+/-12)
Hip internal rotation	17	36 (+/-7)	36 (+/-8)
Hip external rotation	17	44 (+/-5)	41 (+/-6)
Trunk side flexion	17	14 (+/-6)	15 (+/-5)
Trunk rotation	17	5 (+/-2)	6 (+/-3)
Strength (kilograms)			
Hip flexion	18	32.0 (+/-8.6)	32. 3 (+/-9.7)
Hip extension	18	22.9 (+/-6.6)	25.0 (+/-6.4)
Hip adduction	18	17.4 (+/-4.3)	18.8 (+/-4.4)
Hip abduction	18	21.2 (+/-7.2)	22.9 (+/-4. 4)
Hip internal rotation	17	12.6 (+/-3.0)	11.6 (+/-3.1)
Hip external rotation	17	10.0 (+/-1. 8)	10.3 (+/-1.7)
Trunk side flexion	17	17.7(+/-5.4)	16.7 (+/-4.5)
Trunk rotation	18	26.5 (+/-11.7)	25.7 (+/-12.5)
Field Hockey Specific (hop = centimetres; endurance tests = repetitions)			
Sideways hop for distance	16	155.9 (+/-19.7)	154.7 (+/-18.9)
Trunk side flexion endurance	15	15.4 (+/-4.4)	16.0 (+/-6.1)
Lateral lunge endurance	14	121.5 (+/-61.5)	109.6 (+/-61.4)

Table 4.5. Mean Values for Range of Motion, Strength and Field Hockey Specific Tests for Non-significantly Limiting Back Pain Field Hockey Participants

Movement	N	Left mean (standard deviation)	Right mean (standard deviation)
Range of Motion (degrees)			
2-joint hip extension	17	9 (+/-5)	7 (+/-4)
1-joint hip extension	17	10 (+/-5)	8 (+/-5)
Hip adduction	17	12 (+/-3)	14 (+/-4)
Hip abduction	17	40 (+/-6)	39 (+/-5)
2-joint hip flexion	17	81 (+/-12)	78 (+/-11)
1 joint hip flexion	17	72 (+/-7)	69 (+/-8)
Hip internal rotation	17	38 (+/-6)	39 (+/-7)
Hip external rotation	17	45 (+/-6)	43 (+/-7)
Trunk side flexion	17	14 (+/-6)	15 (+/-5)
Trunk rotation	17	5 (+/-2)	5 (+/-2)
Strength (kilograms)			
Hip flexion	17	35.1 (+/-11.0)	36.4 (+/-8.6)
Hip extension	17	28.5 (+/-10.3)	28 (+/-8.8)
Hip adduction	17	19.3 (+/-5.6)	20.1 (+/-6.4)
Hip abduction	17	24.6 (+/-7.6)	25.5 (+/-7.2)
Hip internal rotation	17	11.6 (+/-2.8)	11.9 (+/-3.7)
Hip external rotation	17	9.9 (+/-2.3)	9.8 (+/-2.4)
Trunk side flexion	17	21.2 (+/-7.8)	19.6 (+/-7.3)
Trunk rotation	17	26.5 (+/-8.3)	2.4 (+/-8.6)
Field Hockey Specific (hop = centimetres; endurance tests = repetitions)			
Sideways hop for distance	15	151.5 (+/-15.3)	150.4 (+/-18.6)
Trunk side flexion endurance	15	16.9 (+/-5.3)	16.1 (+/-4.6)
Lateral lunge endurance	15	123.0 (+/-66.0)	104.2 (+/-63.1)

Table 4.6. Mean Values for Range of Motion, Strength and Field Hockey Specific Tests for Acute Thigh Pain Field Hockey Participants

Movement	N	Left mean (standard deviation)	Right mean (standard deviation)
Range of Motion (degrees)			
2-joint hip extension	11	10 (+/-5)	10 (+/-4)
1-joint hip extension	11	10 (+/-6)	10 (+/-6)
Hip adduction	11	14 (+/-3)	14 (+/-3)
Hip abduction	11	40 (+/-6)	41 (+/-5)
2-joint hip flexion	11	85 (+/-12)	82 (+/-13)
1 joint hip flexion	11	73 (+/-7)	73 (+/-10)
Hip internal rotation	11	40 (+/-10)	39 (+/-9)
Hip external rotation	11	44 (+/-5)	40 (+/-5)
Trunk side flexion	11	16 (+/-6)	16 (+/-6)
Trunk rotation	11	6 (+/-1)	5 (+/-2)
Strength (kilograms)			
Hip flexion	11	31.8 (+/-9.9)	30.8 (+/-7.4)
Hip extension	11	20.8 (+/-6.8)	22.4 (+/-6.6)
Hip adduction	11	15.3 (+/-3.1)	16.0 (+/-3.0)
Hip abduction	11	20.6 (+/-5.7)	21.3 (+/-5.8)
Hip internal rotation	9	10.6 (+/-3.3)	10.8 (+/-2.9)
Hip external rotation	9	8.7 (+/-2.0)	9.2 (+/-2.7)
Trunk side flexion	11	16.7 (+/-4.6)	16.8 (+/-5.1)
Trunk rotation	11	24.0 (+/-9.0)	24.2 (+/-8.9)
Field Hockey Specific (hop = centimetres; endurance tests = repetitions)			
Sideways hop for distance	9	156.6 (+/-14.3)	156.4 (+/-14.4)
Trunk side flexion endurance	10	16.4 (+/-5.4)	15.9 (+/-4.7)
Lateral lunge endurance	8	105.0 (+/-51.7)	77.4 (+/-45.1)

Paired sample means testing was performed on all DVs for back and thigh pain categories to investigate differences between left and right. Cohen[65] defined a moderate effect size (ES) as 0.5 and a large ES as 0.8 and above for paired t, Wilcoxan ranks and Mann-Whitney tests. Paired differences between DVs with ES, associated significance, percentage difference and power are shown in Table 4.7. Three groupings of findings across the pain categories are shown. The first grouping has a large ES, significance of $p < .05$ and power between .60 and .86. The second grouping has a moderate to large ES, significance of $p < .10$ and variable power. The third grouping has a moderate ES, significance of $p > .10$ and low power. A more pictorial display of these differences is shown in Appendix K.

Table 4.7. Left versus Right Side (paired samples) for Control and Field Hockey Back and Thigh Pain Categories

Variable	Effect Size	Significance	Percentage Difference	Power*
Healthy Control				
Hip adduction ROM[a]	0.97	.030	-13.9	.65
Hip abduction ROM[a]	0.94	.034	-6.5	.64
Hip external rotation ROM[c]	0.47	.265	3.3	.20
Hip flexion strength[c]	0.63	.148	-4.3	.34
Hip abduction strength[b]	0.77	.088	6.8	.47
Hip internal rotation strength[b]	0.83	.057	-6.4	.67
Sideways hop for distance[a]	1.26	.008	-4.3	.85
Healthy Field Hockey				
Hip adduction ROM[a]	1.00	.012	-12.7	.80
Hip external rotation ROM[b]	0.45	.062	5.2	.36
Trunk rotation ROM[a]	0.86	.006	-23.7	.67
Hip extension strength	0.53	.029	-8.2	.32
Hip adduction strength[b]	0.58	.098	-7.5	.49
Hip internal rotation strength	0.48	.0004	7.6	.27
Trunk side flexion strength[c]	0.59	.121	5.7	.39
Non-Significantly Limiting Back Pain Field Hockey				
2-joint hip extension ROM[c]	0.55	.141	19.7	.34
1-joint hip extension ROM[c]	0.46	.195	17.2	.25
Hip adduction ROM[a]	1.15	.006	-11.0	.86
2-joint hip flexion ROM[b]	0.64	.064	3.5	.43
1-joint hip flexion ROM[a]	0.83	.038	4.7	.65
Hip external rotation ROM[b]	0.62	.083	4.3	.40
Hip adduction strength[c]	0.52	.166	-4.1	.30
Hip abduction strength[c]	0.41	.343	-3.9	.21
Trunk side flexion strength[a]	0.82	.032	7.5	.63
Trunk rotation strength[b]	0.62	.093	5.4	.42
Lateral lunge endurance[a]	0.68	.011	15.3	.41
Acute Thigh Pain Field Hockey				
Hip adduction ROM[c]	0.47	.303	-6.0	.18
2-joint hip flexion ROM[c]	0.70	.182	3.5	.33
Hip external rotation ROM[a]	1.19	.029	9.2	.74
Hip abduction strength[c]	0.54	.348	-3.6	.23
Hip external rotation strength[c]	0.56	.306	-5.0	.24
Lateral lunge endurance[a]	1.54	.012	26.3	.80

*Estimated from Cohen (1988) power tables for t test for means a = 0.05 for significances p < .05 and a = 0.10 for all other values

[a] Large ES, significance of p < .05, power between .60 and .86

[b] Moderate to large ES, significance of p < .10, variable power

[c] Moderate ES, significance of p > .10, low power

Kruskal Wallis testing was performed on all DVs for differences between back and thigh pain groups. For this test, Cohen[65] defined a moderate ES as 0.25 and a large ES as 0.40 and above. Significant differences amongst groups on the DVs with the ES, associated significance, and power are shown in Tables 4.8 and 4.9. As with the paired testing, three groupings can be seen.

Table 4.8. Findings Between Healthy Control, Healthy Field Hockey and Non-significantly Limiting Back Pain Field Hockey

Variable	Effect Size	Significance	Power*
1-joint hip extension ROM[b]	0.28	.078	.54
Hip Abduction ROM[a]	0.38	.042	.63
1-joint hip flexion ROM[b]	0.34	.056	.66
Trunk rotation ROM[c]	0.25	.167	.43
Hip extension strength[c]	0.26	.420	.45
Hip adduction strength[c]	0.31	.172	.57
Hip abduction strength[c]	0.32	.113	.62
Hip internal rotation strength[b]	0.32	.091	.61
Sideways hop for distance[a]	0.40	.024	.67

*Estimated from Cohen (1988) power tables for analysis of variance and covariance a = 0.05 for significances p < .05 and a = 0.10 for all other values

[a] Large ES, significance of p < .05, power > .60

[b] Moderate to large ES, significance of p < .10, variable power

[c] Moderate ES, significance of p > .10, low power

Table 4.9. Findings Between Healthy Control, Healthy Field Hockey and Acute Thigh Pain Field Hockey

Variable	Effect Size	Significance	Power*
Hip abduction ROM[b]	0.38	.081	.65
Trunk rotation ROM[c]	0.30	.181	.50
Hip adduction strength[c]	0.31	.228	.51
Hip abduction strength[c]	0.34	.131	.58
Hip internal rotation strength[b]	0.37	.076	.66
Sideways hop for distance[a]	0.47	.014	.70

*Estimated from Cohen (1988) power tables for analysis of variance and covariance a = 0.05 for significances p < .05 and a = 0.10 for all other values

[a] Large ES, significance of p < .05, power > .60

[b] Moderate to large ES, significance of p < .10, variable power

[c] Moderate ES, significance of p > .10, low power

Post-hoc testing was performed via Mann-Whitney (MW) tests and the p-value was adjusted based on the grouping (for findings with $p < .05$, adjusted MW was $p < .025$; for findings with $p < .10$, adjusted MW was $p < .05$). For findings with $p > .10$, significance levels were coupled with ES to evaluate most significant differences between groups. These post-hoc findings are shown in Tables 4.10 and 4.11.

Table 4.10. Post-hoc Testing Results for Back Pain Group Differences

Variable	Primary group difference (ES, p value)	Secondary group difference (ES, p value)
Large ES, p <.05, power > .60		
Hip abduction ROM	HC vs HFH (0.94, .036)	HC vs NSLFH (0.26, .020)
Sideways hop for distance	HC vs HFH (1.05, .004)	HC vs NSLFH (0.77, .088)
Moderate to large ES, p < .10, variable power		
1-joint hip extension ROM	HC vs NSLFH (0.59, .038)	
1-joint hip flexion ROM	HC vs NSLFH (0.77, .040)	HFH vs NSLFH (0.66, .040)
Hip internal rotation strength	HC vs HFH (0.81, .024)	
Moderate ES, p > .10, low power		
Trunk rotation ROM	HFH vs NSLFH (0.55, .090)	
Hip extension strength	HFH vs NSLFH (0.59, .204)	
Hip adduction strength	HC vs HFH (0.66, .097)	
Hip abduction strength	HC vs NSLFH (0.76, .040)	HC vs HFH (0.70, .100)

Table 4.11. Post-hoc Testing Results for Thigh Pain Group Differences

Variable	Primary group difference (ES, p value)	Secondary group difference (ES, p value)
Large ES, p < .05, power > .60		
Sideways hop for distance	HC vs HFH (1.05, .004)	HC vs AFH (0.83, .060)
Moderate to large ES, p < .10, variable power		
Hip abduction ROM	HC vs HFH (0.94, .036)	
Hip internal rotation strength	HC vs HFH (0.81, .024)	
Moderate ES, p > .10, low power		
Trunk rotation ROM	HFH vs AFH (0.73, .103)	
Hip adduction strength	HC vs HFH (0.66, .097)	
Hip abduction strength	HC vs AFH (0.82, .055)	HC vs HFH (0.70, .100)

Bivariate correlations were performed between IVs and all significant between group findings. In the HC group, 1-joint hip flexion ROM was found to correlate with body mass (r = -0.44, p = .037) and sideways hop for distance correlated with age (r = 0.49, p = .032). In the HFH group, other symmetrical sport*years was found to correlate with hip extension strength (r = -0.41, p = .042) and hip adduction strength (r = -0.55, p = .027). Number of levels of field hockey played (e.g. university, regional, provincial, junior national, senior national) correlated with 1-joint hip extension ROM (r = 0.41, p = .043). Age also correlated with hip adduction strength (r = 0.40, p = .031). Trunk rotation ROM was found to correlate with body mass (r = 0.49, p = .008).

In the NSLFH back pain group, hip abduction ROM correlated with total years of field hockey played (r = 0.46, p = .023). One-joint hip flexion ROM was found to correlate with university field hockey sport*years (r = 0.37, p = .042). Position and playing area were not evaluated due to very small numbers in the respective groups ($1<n<6$). In the AFH thigh pain group, hip abduction ROM correlated with other right hand dominant sport*years ($r = 0.67$, $p = .017$). As no variables consistently correlated over the groups, further multivariate testing was not performed.

DISCUSSION

Thirty seven percent of the control group and 50.9% of the field hockey group reported some history of LBP. Frequencies for at least one episode of field hockey related LBP have been reported at 78%[1], 59%[2] and 53%.[3] Lindgren and Twomey[1] reported that their 78% history of LBP was similar to that of the general population. The present field hockey group had similar findings to Reilly and Seaton,[3] but was lower than other previously published research. The control group had a considerably lower LBP incidence to the general population percentage as reported by Lindgren and Twomey.[1] Two factors may explain this difference. Firstly, during recruitment of the control group, individuals with a history of significant low back pain were discouraged from participating to ensure a large number of healthy participants. Secondly, the average age of the control group was 20.9 yrs. Although Lindgren and Twomey[1] did not state the age of the general population, the average age might have been older than the control group of the present study.

Norms for ROM have been previously established for 1-joint hip extension (10-15°), hip adduction (30°), hip abduction (30-50°), hip internal rotation (30-40°), hip external rotation (40-60°), trunk side flexion (15-20°), and trunk rotation (3-18°).[66] The present findings for ROM for healthy control (HC) and healthy field hockey (HFH) fall within these normal ranges, with the exception of hip adduction (14° and 12°, respectively). It is likely that this difference in finding is due to measurement technique. In Magee's[66] textbook, hip adduction occurs in slight hip flexion while in this study adduction occurred in hip neutral (no added flexion or extension).

Findings of left-right imbalance and differences between groups fell into three groupings, which represented differing confidence in the conclusion of true differences and the potential that the differences would aid in the definition of task appropriate and injury related mechanical imbalances. Statistical significance shows whether there is a sufficiently small probability that the observed difference arose by chance, and $p < .05$ is used by convention.[54] The first grouping of meaningful results (large ES, $p < .05$, power between .60 and .86) represented variables in which there was strong confidence that the left-right imbalances did not occur by chance.

The second grouping of findings (moderate to large ES, $p < .10$, variable power) represented a fairly strong confidence in a level of statistical significance. The third grouping of findings (moderate ES, $p > .10$, low power) represented a low confidence in a level of statistical significance. While statistical significance shows the probability that the finding occurred by chance, clinical significance relates to the actual magnitude of the observed differences and to whether the observed differences are important enough to determine, for example, whether an intervention is effective or whether a patient has changed by an important amount.[54, 67] The second and third groupings are variables that fell into a less stringent statistical significance, but showed actual differences that were similar to the first grouping of findings. As previously stated, no other investigation of left/right differences had been performed in field hockey and very little knowledge existed on what size of muscle imbalance causes LBP. Sample size was a limitation of the present study. Sample size has an effect on observed p-values.[54] Thomas, Salazar and Landers[68] stated that non-significant large ESs from small samples suggest areas for continued research. Given that many of the ESs and percentage differences (Table 4.7) approximated findings of the first group, and given the exploratory nature of this study, the variables in the second and third groupings represented variables that should not be discarded from future research.

Of the findings in paired differences within groups, only 9 variables in the back pain categories and 6 variables in the thigh pain categories showed differences between groups. All 6 variables identified having differences between thigh pain groups overlapped with the 9 variables identified as having differences in the back pain group. Mann-Whitney post hoc analysis of these findings identified the differences in mechanical balance – field hockey task appropriate and injury related – for the 4 back and thigh pain groups.

A task appropriate imbalance was defined when differences existed between HC and HFH groups and between HC and FH pain groups (non- significantly limiting back pain – NSLFH – and acute thigh pain – AFH), but no differences between the field hockey groups (refer to figure 4.8). Hip abduction strength and sideways hop for distance fell into this classification. A task appropriate imbalance was also defined when a difference existed between the HC and HFH groups, but there were no differences between the HC and the field hockey pain groups or between the HFH and the field hockey pain groups. Hip abduction ROM (task appropriate when considering back pain only and task appropriate with potential injury related imbalance when considering thigh pain only), hip internal rotation strength, and hip adduction strength fell into this classification. While a task appropriate difference existed, an injury related imbalance for these variables might also exist. This potential injury related imbalance requires further research.

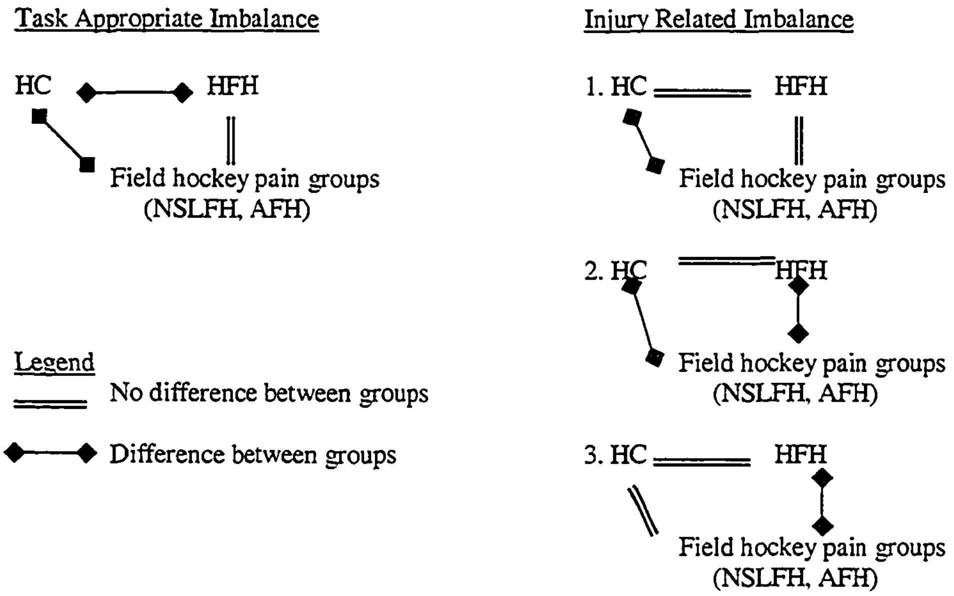
An injury related imbalance was defined when 1 of 3 situations occurred (refer to figure 4.8):

1. No difference occurred between the HC and HFH groups or between the HFH and the field hockey pain groups, but a difference did exist between the HC and field hockey pain groups
2. The HC and HFH groups did not differ, but both differed from the field hockey pain groups
3. The HFH group differed from the field hockey pain groups, but none of the field hockey groups differed from the CH group.

One-joint hip extension ROM, 1-joint hip flexion ROM, trunk rotation ROM, and hip extension strength were defined as injury related imbalances.

For the injury related variables, only trunk rotation ROM and hip abduction strength were related to both the back and thigh pain groups. The rest of the variables were related only to the back pain groups. From this observation, it appeared that back pain may have been the more dominant pain variable, but due to insufficient numbers for multivariate analysis, this conclusion requires further research.

Figure 4.8. Definition of task appropriate and injury related mechanical imbalance



An interesting observation arose regarding the role of mechanical imbalance in the cause of LBP. If mechanical imbalance alone were responsible for LBP, it would be expected that healthy groups (HC and HFH) would not demonstrate significantly paired differences. Results of paired testing demonstrate that this expectation is not the case. Both the HC and HFH groups had significant left-right paired differences in ROM, isometric strength and field hockey specific tests. The mere presence of an imbalance does not indicate impending injury. Rather, the mechanical imbalance must be stressed in some fashion. The present study did not investigate core stability, leg length discrepancy or pelvic asymmetry. Perhaps these factors interact with mechanical imbalance to produce LBP. Perhaps when a mechanical balance is placed into a particular posture or type of movement, such as combined trunk flexion, side flexion and rotation, or when a mechanical imbalance is stressed repetitively, LBP occurs. These interactions of factors require further investigation.

A number of studies have attempted to differentiate between task appropriate and injury related mechanical imbalances. Agre and Baxter[35] investigated leg difference in ROM and strength in soccer players. Just as the present study was concerned that the asymmetrical nature of field hockey might produce left-right imbalance, Agre and Baxter were concerned that the asymmetrical nature of soccer and foot preference for kicking the ball might have produced differences between kicking and non-kicking legs. Agre and Baxter's findings for average hip abduction ROM are similar to the present study.

However, while the present study found a task appropriate imbalance in this movement, Agre and Baxter did not. Agre and Baxter's test for hip flexion ROM was the same as the present study's 1-joint hip flexion ROM. The present study showed a larger ROM than Agre and Baxter. Agre and Baxter found that kicking foot preference did not lead to asymmetry in flexibility and strength in healthy players. Similar to the present study, players who sustained non-traumatic local back strain injuries had significant differences in hamstring flexibility between legs. Years playing organized soccer did not correlate to any findings.[35]

Hamilton, Hamilton, Marshall, and Molnar[36] created a musculoskeletal profile of 28 ballet dancers. The average hip abduction ROM for female dancers was greater than hip abduction for all groups in the present study. The average hip adduction ROM for female dancers was just slightly larger than hip adduction for all the present study groups. There were no left-right differences for flexibility in female dancers. There was, however, a paired compensation. Female dancers had increased hip external rotation and decreased internal rotation; increased abduction and decreased adduction. Similarly, the female dancers showed reversal in strength of abductors (+21%) and adductors (-21%) and significantly stronger right hip and knee muscles than left.[36] The same kind of paired finding does not exist in field hockey nor does a complete dominance of one side. The HC group had right greater than left hip abduction ROM with no difference in adduction ROM. The HC healthy group showed no difference in hip adduction strength but a left greater than right difference in hip abduction. The HFH group showed the opposite – no difference in hip abduction strength and right greater than left hip adductor strength.

Howell[37] created a musculoskeletal profile of 17 lightweight female rowers. As with the present study, not all variables were correlated to injury. In fact, Howell found only lumbar flexibility to be correlated with back pain. In particular, 94% of participants were hyperflexible on the sit and reach test, indicating that excessive lumbar flexibility was needed to be a national caliber rower. However, excessive lumbar hyperflexibility was highly correlated with the incidence of low back pain/discomfort. An observation that the "oarside" latissimus dorsi was tighter than the non-oarside latissimus dorsi demonstrated left-right asymmetry in rowing. Similar to the present study, not all independent variables were related to the findings. Number of years rowed was not related, but there was a high negative correlation between adherence to a regular stretching program and the incidence of low back pain/discomfort.[37]

Nadler et al. performed two studies on strength of the hip extensor (gluteus maximus) and hip abductor (gluteus medius) muscles and their relation to LBP.[64, 69] Both studies involved 160 to 230 NCAA Division I athletes and employed a hand held dynamometer fixed onto a specifically designed anchoring station, very similar to the present study. The first study[64] investigated the cause and effect relationship of hip strength asymmetry and future LBP. Average and maximum values for hip extension and abduction and side-to-side differences were computed. Athletes were then followed for 1 year for incidents of non-traumatic LBP. Unfortunately, Nadler et al.'s first study did not differentiate between sports. They found that female athletes without LBP had left hip extensors 5.5% stronger than right and female athletes with LBP had left extensors 15%

stronger than right. The present study found that HFH had the right hip extensor 8% stronger than the left and the NSLFH group had no significant difference. Hip extensor strength, however, was in the group of variables needing further research. Nadler et al. found no difference in hip adduction strength while the present study found a greater right than left difference for the HFH group. Nadler et al. found that neither the hip extensor strength difference nor the hip abductor strength difference were predictive for episodes of LBP. Of note, 46% of athletes who required treatment had previous history of LBP and had significant strength differences.[64]

Nadler et al.'s[69] second study investigated the impact of a core strengthening program on the incidence of LBP and its influence on strength balance of the proximal hip musculature. Hip abduction and extension strength was measured over 2.5 years. Over the first year, athletes were tested pre-season and then monitored for non-traumatic LBP. Over the second year, athletes were tested preseason and then given a core strengthening program and followed for non-traumatic LBP. Finally, athletes were tested preseason of the last year. The core strengthening program consisted of 30-45 min 4-5 times per week of sit ups, pelvic tilts, squats, lunges, leg press, dead lifts, hang cleans, and roman chair back extension. For athletes involved over the first two testing periods, no significant difference was seen in paired differences in hip abduction and extension strength. However, athletes involved in the core strengthening had an increase in right hip extension strength. For female athletes, a significant increase in left hip abductor strength occurred and was inversely correlated with a decrease in LBP treatment need [69]. Interestingly in the present study, NSLFH had a right greater than left hip abduction strength difference, but no difference existed for HFH. Perhaps this difference in hip abduction strength is related to LBP in field hockey as well. A limitation for both studies was the small number of athletes requiring treatment for LBP.[64, 69] The series of musculoskeletal profiles discussed demonstrate that activity specific imbalances occur and that these patterns differ between activities.

Although the Agre and Baxter,[35] Hamilton, Hamilton, Marshall, and Molnar,[36] and Howell[37] studies all tried to account for the independent variables that might be correlated to the strength and ROM findings, none were found. In a similar attempt to these three studies, Teitz, O'Kane, Kind, and Hannafin[70] attempted to define potential etiological factors associated with back pain in rowing. Questionnaires were sent to individuals who had graduated over a 20-year span and collected information pertaining to anthropometric measures (height, weight) and training experience (competitive rowing before age 16, trained in an indoor tank, trained with free weights, trained with a weight machine, trained with an ergometer, ergometer cable position, ergometer duration – less than 30 min and 30 to 60 min, oar type, and rowing position). Nine hundred and thirty-six men and 694 women responded. Average height and weight of rowers increased over the 20-year span and this increase was positively correlated with LBP for men and women. In the present study, only HC 1-joint hip flexion ROM and HFH trunk rotation ROM was found to correlate with body mass ($r = -0.44$, $p = .037$ and $r = 0.49$, $p = .008$, respectively). Teitz, O'Kane, Kind, and Hannafin[70] initially performed bivariate analysis for all variables. Competitive rowing prior to age 16 was significantly associated with LBP during intercollegiate rowing. Rowing can be performed in a symmetrical (sculls) or asymmetrical (sweep) fashion. No significant differences in the incidence of LBP were found as a result of scull or sweep rowing actions. Athletes who had trained with 3 to 4 techniques (e.g. weight machines, free weights, indoor track, ergometer) showed significantly higher rates of LBP than those who trained with two or less techniques. Bivariate analysis by decade found that only ergometer training greater than 30 minutes and the use of free weights were consistently associated with LBP. Multivariate analysis examining predictor variables to back pain by the age of participants showed only ergometer training greater than 30 minutes as the most consistent and significant predictor of LBP.[70]

Similar to the musculoskeletal profiles of Agre and Baxter,[35] Hamilton, Hamilton, Marshall, and Molnar, [36] and Howell[37] and the rowing study of Teitz, O'Kane, Kind, and Hannafin,[70] the present study did not show a consistent correlation between independent variables (IVs) and the task appropriate and injury related variables. It was hypothesized that the longer an athlete was exposed to field hockey, the longer the training effect and the greater the potential left-right difference. However, total field hockey years played only correlated significantly with hip extension strength and university field hockey sport*years only correlated with 1-joint hip flexion ROM, both in the NSLFH group only. Number of levels played correlated with 1-joint hip extension ROM, but only in the HFH group. Since incomplete data was collected for total sport*years at all levels of field hockey played (e.g. university, provincial, national teams), it is possible that the addition of this information might clarify the findings. While all field hockey participants may be training and playing for similar amounts of time at the university level, there might be significant differences in participation at the provincial and national levels. These differences might lead to differences in the correlations between total sport*years and left-right imbalance.

In Canada, the majority of field hockey players are introduced to the sport relatively late in life compared to many athletes (introduced for some in grades 7 and 8 and for the majority not until grade 10). Consequently, participation in other activities may have affected the development of a purely field hockey specific imbalance. As the length of time required to develop a task appropriate or injury related imbalance is unknown, as is how long such an imbalance may last, the influence of other sports as confounders to the development of a purely field hockey task appropriate imbalance is a concern. Other symmetrical sport*years correlated only with hip extension strength and hip adduction strength in the HFH group ($r = -0.41$, $p = .042$ and $r = -0.55$, $p = .027$, respectively) and other right handed asymmetrical sport*years correlated only with hip abduction ROM in the AFH group ($r = -0.67$, $p = .017$).

Teitz, O'Kane, Kind, and Hannafin[70] state that changes in type and intensity of training, in equipment, in the age at which competitive rowing begins, and in rowing physique made interpretation of some bivariate findings in their study difficult. While the present study does not have these exact concerns that arise with a 20-year study, differences between different university training techniques could confound the results. Examination of differences between pain groups based on the university attended was difficult to ascertain due to small groups. However, when all right-handed athletes were considered, significant differences between universities existed between 2-joint hip extension ROM (p = .009), 1-joint hip extension ROM (p = .019) and hip flexion strength (p = .012). Therefore, it is possible that some findings are affected by different training techniques between universities.

Limitations

Small sample size did not allow for certain analyses, particularly the effect of position played and area on the field on paired differences, and differences between universities. Although the original sample size was quite large in comparison to other musculoskeletal profiles, it was not large enough to provide meaningful results when subgroups based on pain were created. This issue is not unusual for sport studies, especially elite sport studies. This limitation may be corrected through the future use of longitudinal studies.

Some participants were in both the NSLFH and AFH groups. Because of the small subgroup numbers, it was not possible to investigate the influence that back and thigh injuries exert on each other and on injury related imbalance.

Forty-seven field hockey participants did not complete the section of the sport participation questionnaire that dealt with time spent participating at field hockey levels other than university. Consequently, the analysis of this independent variable was not conducted. These lack of information may account for the lack of clear relationship between years played and injury.

No matter what methodology is used to develop a musculoskeletal profile, limitations exist on the ability of the measurement tool to adequately represent functional activity. The methodology chosen for the present study had this limitation. Standard clinical measurements of ROM and isometric strength employ an inductive approach, where the function of isolated muscle groups is assessed and extrapolated to the function of the whole body.[71] This approach assumed that isolated areas will work the same whether in isolation or in combination with other areas of the body, which may not be the case. Activity (or sport) specific tests employ a deductive approach, where the whole body is assessed while a task is being performed.[71] Even activity specific tests could not completely duplicate the skill performed in a practice or game, especially with respect to speed of movement. The proposed methodology for the present study was selected with the recognition of this limitation. To provide as much clinical application as possible, methodology was selected to reflect the measurement tools and techniques frequently used by clinicians.

The generalizability of the present study was limited strictly to female intercollegiate field hockey players. While the techniques and principles used to develop the musculoskeletal profile may be transferred to other sports, specific findings related solely to the study groups.

CONCLUSIONS

The purpose of the present study was to investigate the potential presence of a left/right task appropriate imbalance of the trunk and hip region in Canadian female interuniversity field hockey players, employing measures that could be easily used in a field or clinical setting, and to differentiate between these and injury-related mechanical imbalances. The present study was descriptive and exploratory in nature. As such, it was important to ensure that differences, although not statistically significant by convention ($p = .05$), would not be discarded from future research. Consequently, significance in findings was related to a combination of ES, type I error and power. Findings were grouped: 1) variables in which there was strong confidence in the findings of statistical significance ($p < .05$); 2) variables in which there was fairly strong confidence in a level of statistical significance ($p < .10$, a moderate effect size that might have clinical significance toward the delineation of task appropriate and injury related imbalance, and the percentage difference within the ranges of group 1), and; 3) variables in which there was low confidence in a level of statistical significance, but the ES similar to groups 1 and 2. The variables in groups 2 and 3 require future research.

It was hypothesized that left/right task appropriate muscle imbalances would exist in field hockey and that this imbalance would differ from a healthy control group and from players with a history of low back or thigh pain. This hypothesis was supported, but there was limited statistical significance. Task appropriate differences between the HC group and the field hockey groups were seen in sideways hop for distance, hip abduction ROM, hip internal rotation strength, hip adduction strength, and hip abduction strength. Three of these variables (hip abduction ROM, hip internal rotation strength, and hip adduction strength) may also have injury related imbalances, and this potential requires further research. Injury related imbalances were detected in 1-joint hip extension ROM, 1-joint hip flexion ROM, trunk rotation ROM, and hip extension strength.

The delineation of task appropriate and injury related imbalances might prove helpful in the rehabilitation of injured field hockey players. The differences seen in sideways hop for distance were statistically strong. In the rehabilitation of a female field hockey player following either back or thigh injury, sideways hop for distance must be the same for both legs. A statistically strong difference was noted in hip abduction ROM between HC and NSLFH, but a slightly less strong difference was seen between HC and AFH. However, given the strength of the left-right paired difference in hip abduction in the CH group and the lack of any paired difference in the HFH, NSLFH and AFH groups, hip abduction ROM must be the same for both legs when rehabilitating a female field hockey player following either back or thigh injury. Unfortunately, because the rest of the task appropriate and injury related variables require further investigation, definitive recommendations regarding rehabilitation of these variables would be premature.

A number of independent variables were identified and measured in hopes that they might help explain the differences seen in task appropriate and injury related imbalances. Unfortunately, due to small subgroup sizes and lack of consistent IV influence, this analysis was not possible. Although they correlated with different dependent variables, total field hockey years played, university field hockey sport*years, and number of levels played all seemed to play a role in the difference scores of some variables. Incomplete data was collected for total sport*years for all levels of field hockey played (e.g. university, provincial, national teams). It is possible that this missing information might have provided the link between these independent variables.

FUTURE DIRECTIONS

Although injury related differences were found, results of this study could not ascertain whether these differences caused or were caused by back or thigh injury. It is likely that because the injury history of the participants was collected retrospectively, the differences were caused by injury. Future epidemiological studies could be undertaken to prospectively track injuries in athletes with the different imbalances to investigate the impact of these imbalances on injury occurrence. Using either the retrospective or prospective data, intervention programs that combat the injury related imbalances could then be developed and investigated for effectiveness in reducing chronic low back pain.

The effect of sports played concurrently or prior to participation in field hockey needs to be determined. Associated with this is the need to identify how long a mechanical imbalance takes to develop and how long it lasts once an individual has finished participating in the given activity.

Finally, small sample sizes have plagued many studies on elite athletes. In order to provide greater numbers and stronger statistical power, longitudinal studies and/or serial case studies need to be performed.

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CHAPTER 5: LOW BACK PAIN RISK FACTORS IN CANADIAN INTERUNIVERSITY FIELD HOCKEY – CONCLUSION

SUMMARY OF RESULTS

The overall goal of this dissertation was to investigate and identify factors that could be related to low back pain (LBP) in field hockey. In order to accomplish this goal, three separate, yet linked studies were conducted on elite female hockey players. The first study, entitled "Repetitive Movement Patterns in Field Hockey and Their Relation to Low Back Pain", sought to identify mechanical exposure factors that might be related to LBP, and to quantify these factors for women and men in game and practice environments. Field hockey is best characterized as a sport with frequent movements in and out of lumbar spine forward flexion, rotation, and side flexion. When all movements that combined lumbar spine forward flexion, rotation and side flexion ("up and down movements") were totaled, both women and men, on average, will reach the 400-repetition threshold associated with high risk for back injury[1,2] within the course of a tournament and women, on average, will reach this threshold in 3 hours of practice. The strong side movements that combine knee, hip, and lumbar spine flexion with rotation and side flexion are known to be poorly tolerated in the lumbar spine and carry the highest injury potential.[3] The most frequently occurring ball propulsion movements (strong side push and strong side drive) all involved rapidly and forcefully rotating the trunk through constrained positions of extreme right to extreme left rotation combined with lumbar spine flexion. Similar constrained postures are also found in lunge tackles and receptions. In the most frequently occurring ball propulsion movements (stationary pushes and drives and running feet sideways strong side pushes), participants lunged to the left significantly more than to the right. The muscle force generated to propel the ball occurred through asymmetric movement. Overall, a significant difference for all games and practices was found in the total number of left versus right lunges. In addition to the repetition of asymmetric movement increasing the effect of the other risk factors, it is possible that over time these asymmetric movement patterns might create a mechanical imbalance, an intrinsic risk factor associated with low back injury.

The second study, entitled "Clinical Measures to Detect Mechanical Imbalance: a Pilot Study", sought to: 1) create a testing battery to investigate left-right mechanical imbalance of the low back and hip in field hockey players; 2) develop tests that allow practical application to clinical practice, and; 3) establish the reliability and validity for this testing battery. The majority of range of motion (ROM) and strength tests in the testing battery reported excellent intrarater reliability, while the functional tests produced less reliable results that may have been due to local muscular fatigue. With suggested modifications, the functional tests should produce valid and reliable results. As ROM and isometric strength tests are already standard procedures in clinical practice, they have obvious clinical application. The functional tests were modified to fit field hockey and are easy to perform in the clinical setting.

The third study entitled, "A Musculoskeletal Profile of Canadian Interuniversity Female Field Hockey Players", sought to investigate the potential presence of a left/right task appropriate imbalance of the trunk and hip region in Canadian female interuniversity field hockey players, employing measures that could be easily used in a field or clinical setting, and to differentiate between these and injury-related mechanical imbalances. Task appropriate differences between the healthy control group and the field hockey groups were seen in sideways hop for distance, hip abduction ROM, hip internal rotation strength, hip adduction strength, and hip abduction strength. Three of these variables (hip abduction ROM, hip internal rotation strength, and hip adduction strength) may also have injury related imbalances, and this potential requires further research. Injury related imbalances were detected in 1-joint hip extension ROM, 1-joint hip flexion ROM, trunk rotation ROM, and hip extension strength. A number of independent variables (IV) were identified and measured but, due to small subgroup sizes and lack of consistent IV influence, further analysis was not possible. Although they correlated with different dependent variables, total field hockey years played, university field hockey sport*years, and number of levels played all seemed to play a role in the difference scores of some variables. Because incomplete data was collected for total sport*years for all levels of field hockey played (e.g. university, provincial, national teams), it is possible that this missing data might have provided the link between these independent variables.

STUDY OUTCOMES RELATED TO CAUSE OF INJURY

The combined outcomes of the 3 studies contained in this dissertation shed some light on the potential causes of LBP in field hockey. In particular, discussion has revolved around static muscle loading, type of movement, posture, repetition and fatigue, asymmetric activity and mechanical imbalance factors. A diagrammatic version of the interconnection of these previously described mechanical and individual factors is found in Figure 5.1.

Static Muscle Loading

When most people think of field hockey, the first reaction is "you're always bent over the stick". The task description showed that this is not the case. Rather, ball handling and prolonged forward flexion, which occur on average for approximate 4 seconds per bout and for a total of approximately 2 minutes per game, are unlikely to be a major risk factor for low back pain in field hockey.

Type of Movement and Posture

The predominant movements in field hockey involve a combination of knee, hip, and lumbar spine flexion combined with rotation and side flexion. These movements are poorly tolerated in the lumbar spine and carry the highest injury potential.[3] As such they are likely to be a contributing factor to the incidence of field hockey related LBP.

The most frequent ball propulsion movements of strong side push and strong side drive all involve rapidly and forcefully rotating the trunk from extremes of right to left rotation with the lumbar spine flexed, and can be considered constrained postures. Constrained postures are also found in lunge tackles and receptions. The force required to propel or contest the ball is intertwined with the postural stresses of the extreme position of forward flexion and left and right rotation. These may be linked with field hockey related LBP.

Repetition and Fatigue

The questionnaire results from the task description showed that local muscular fatigue occurred during defensive skills, running or sprinting with the ball, dribbling drills and lunging/lateral movement drills without the ball. The repetition of these movements, combined with the repetitive squat and lunge movements of ball propulsion and contesting for the ball, for the duration of a tournament or a week's practice schedule may put players at high risk for LBP.

Asymmetric Activity

The predominance of strong side activities that move through extremes of combined low back flexion, rotation and side flexion, fatiguing movements predominantly in forward flexed positions, repetition of hip and back forward flexion with trunk rotation and side flexion all have a worse effect in the presence of asymmetrical loading.

The asymmetric nature of field hockey is demonstrated by the significant differences found between plant foot (left greater than right) for ball propulsion, between strong side and reverse squat receptions, and between left versus right lunges.

Mechanical Imbalance

Mechanical imbalance was found in some movements of the hip and low back in field hockey. Some differences (sideways hop for distance, hip abduction ROM, hip internal rotation strength, hip adduction strength, and hip abduction strength) were task appropriate. Others (1-joint hip extension ROM, 1-joint hip flexion ROM, trunk rotation ROM, and hip extension strength) were injury related. The task appropriate differences should allow for improved performance whereas the injury related imbalances might be the cause or a result of low back or thigh injury.

Figure 5.1. Interconnection of factors related to injury.

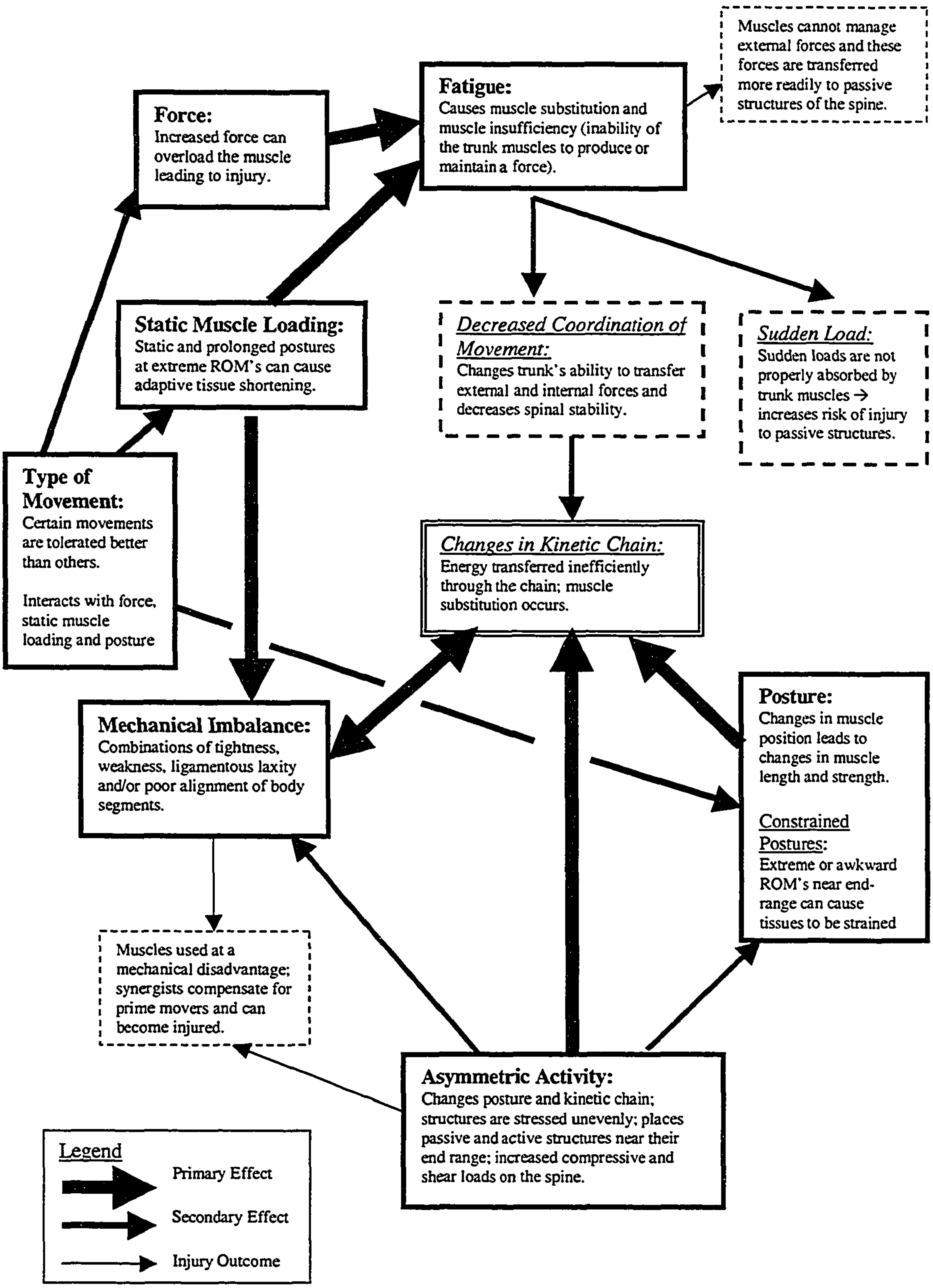

Figure 5.1 illustrates the interaction of the risk factors for low back pain. The following statements can be made regarding how the findings from the 3 studies on elite field hockey fit into this model. Static muscle loading does not seem to be a major factor in fatigue; repetition of movement, however, does seem to be a major factor. The fatigue of repetitive movement may cause muscle insufficiency in the dampening of external forces created by the forceful movements of the sport, and decreased coordination of movement, affecting the kinetic chain. The most common movements involve combined lumbar spine flexion and rotation, a movement pattern known to be poorly tolerated.[3] These poorly tolerated types of movement interact with posture, and may cause tissue damage and alter the kinetic chain. The inherent nature of the sport is asymmetrical, and in and of itself, may cause insufficiencies in the kinetic chain. However, given that both task appropriate and injury-related imbalances exist in female field hockey players, and given that both the healthy control and healthy field hockey groups had significant differences in left-right balance, it is unlikely that the mere presence of an asymmetry will cause injury. Rather, some other factors cause performance-enhancing asymmetries to become injury-related in some players. While the series of studies did not investigate the interaction of other causes of injury with mechanical imbalance, nor the sequencing of the creation of an injury-related mechanical imbalance, it is suspected that repetition of movement and fatigue play a significant role.

IMPLICATIONS TO INJURY PREVENTION

Based on the assumption that mechanical imbalance caused by asymmetry of movement does not, alone, cause injury, but rather that the activity somehow stresses the imbalance to a point where tissue becomes injured, two possibilities for injury prevention exist based on the risk factors identified in this dissertation. The first possibility rests with type of movement. Forceful, dynamic movements combining trunk flexion, side flexion, and rotation are common in field hockey, but known to be poorly tolerated.[3] Injury prevention could involve changing these predominant movements. This intervention, unfortunately, is unlikely to happen. In fact, field hockey techniques are tending to become more constrained (i.e. increased forward flexion) as the sweep hit and drag flick become more popular in the sport.

If the types of movements used in field hockey cannot change, prevention must involve preparing athletes for the activity. Tudor Bompa[4] has written a number of books on the theory of conditioning. He states that, on average, athletes take 6 to 8 years to reach the elite level in their sport. For field hockey athletes who reach the elite level at average ages of 20 to 25 years, Bompa states that "athletic formation" training, emphasizing body weight and light equipment exercises for the hips, low back and abdomen, needs to start between the ages of 11 and 14 years.[4] This type of preparatory training does not happen currently in Canada.

Field hockey demands repetition of submaximal muscular contractions.[5, 6] Methods to rehabilitate muscular endurance are poorly described in therapy textbooks.[5, 7] Most therapists base their rehabilitation plan for strength on the DeLorme system (3 sets of 10 repetitions with decreasing intensity of the exercise), the daily adjustable progressive resistance exercise system – DAPRE (4 sets of 6 to 10 repetitions with adjusted resistance based on the individual's daily abilities), or current strength and conditioning principles (3 sets of 10 to 15 repetitions).[8, 9] The general belief is that athletes with greater strength exhibit greater muscular endurance.[9]

Bompa[6] states that strength training of 15 to 20 repetitions for sports where muscular endurance is a component is grossly inadequate. The task description demonstrated 400 repetitions of trunk and hip flexion with trunk rotation and side flexion occurring within 3 hours of practice. It is quite likely that this repetition of movement is one of the factors that creates an injury related imbalance from a task appropriate one. Bompa[6] advocates 3 to 6 sets of 20 to 30 repetitions to develop muscular endurance. The introduction of this type of training for the most repetitive movements in field hockey may reduce injury.

LIMITATIONS

Specific limitations for each study have been previously reported in each of the 3 chapters. This discussion pertains to limitations that encompass all of the studies.

Insufficient time existed in this dissertation process to gather data on all of the possible risk factors associated with LBP in field hockey. For example, anecdotally, the researcher was aware that many field hockey athletes experience more difficulty performing core stability exercises on one side of their body than the other. This observation may support the potential presence of asymmetry in core stability muscles. The study on mechanical imbalance did not collect data on core stability, leg length discrepancy or pelvic asymmetry due to logistical and practical limitations. Consequently, some data is gathered in isolation and conclusions must be attempted with missing information. This limitation, however, also provides the opportunity to realize the exciting avenues of research still to be pursued.

Limitations in sample size have been found in many previously reported sport injury cause studies. Although the number of athletes enrolled in all 3 studies was comparable to many similar studies published to date, small sub-group sample size did not allow for certain analyses. This limitation may be corrected through the future use of longitudinal studies.

No matter what the methodology used to develop a musculoskeletal profile, limitations exist on the ability of the measurement tool to adequately represent functional activity. Information gathered in the three studies of this dissertation needs to be linked to performance measures and injury data to fully assess the functional effect of the findings.

FUTURE DIRECTIONS

More information is needed on the length of time a mechanical imbalance takes to develop and how long it lasts once an individual has finished participating in the given activity. Biomechanical studies on the predominant movement patterns would add a great deal of information to knowledge of the kinetic chain function in field hockey. Future prospective epidemiological studies need to be undertaken linking repetitive movement, mechanical imbalances (including core stability) to injury rates.

Interventions, such as asymmetric strength training or an increased muscular endurance component in the training programs of field hockey players needs to be assessed. Investigations of how to efficiently train asymmetrically need to be undertaken.

To gain large sample sizes, 10 to 20 year longitudinal studies and/or serial case studies need to be performed.

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APPENDIX A: QUESTIONNAIRE OF TIRING ACTIVITIES IN FIELD HOCKEY

Faculty of Physical Education and Recreation

Instructions: The following 6 questions ask you to write down things you do in field hockey practices and games that you find tiring for your heart and lungs or for your muscles. If you list more than one thing, please rank them in order from hardest to less hard (hardest = 1).

Example: During **PRACTICES**, what makes your muscles really tired?

Answer: (2) repetitive one on one's
(1) repetitive push passing

1. During PRACTICE, what do you do that tires out your heart and lungs? That is, what makes you breath really hard or lose your breath? (For example, the 30 minute drill, 1 minute one on one drill, etc.)

2. During GAMES, what do you do that tires out your heart and lungs? That is what makes you breath really hard or lose your breath? (For example, running back on defence, dribbling with the ball, pressuring the ball, etc.)

3. During PRACTICE, what do you do that tires out your muscles? That is, what makes your muscles ache? (For example, repetitive hitting drills, stopping on the penalty corner, bounding drills, cone drills, etc.)

4. During GAMES, what do you do that tires out your muscles? That is, what makes your muscles ache? (For example, dribbling around lots of people, running with the ball, etc.)

5. In **GAMES** or **PRACTICES**, what muscles get tired or ache? (For example, calves, quads, hamstrings, low back, abdominals, shoulder, forearm)

6. Are there any body positions that you use in **games** or **practices** that really tire out your muscles? That is, are there any body positions that make your muscles ache? (For example, the dribbling position, penalty corner push out position, penalty corner stopping position, ready stance, etc.)
   If yes, what is the position(s) and what muscles get tired?

APPENDIX B: FATIGUING MOVEMENTS IN FIELD HOCKEY

Appendix B Table 1. Muscularly Fatiguing Movements in Games – Women

Identified Movements	Frequency of Response	Total
Movement Without the Ball		64
-defensive skills (low position, marking, pressuring the ball, footwork, lunging, channelling)	36	
-change of direction/ transition from offence to defence	7	
-sprinting back on defence	5	
-sprinting	5	
-just playing	4	
-number one runner on penalty corner (repetitive)	3	
-support running on offence	2	
-body contact in the circle	1	
-diving	1	
Movement With the Ball		31
-running/sprinting with the ball	16	
-dribbling (under pressure)	13	
-passing (give and go) up the field	1	
-frequently swinging the ball around the backfield	1	
Receiving and Ball Propulsion		4
-hitting	2	
-reverse hitting	1	
-penalty corner stopping	1	
"Nothing makes me tired"	1	1
		100

Appendix B Table 2. Muscularly Fatiguing Movements in Games - Men

Identified Movements	Frequency of Response	Total
Movement Without the Ball		18
-defensive skills (marking, 1 versus 1 defence)	5	
-sprinting back on defence	4	
-change of direction/ transition from offence to defence	3	
-long runs	3	
-just playing	3	
Movement With the Ball		6
-running/sprinting with the ball	6	
		22

Appendix B Table 3. Muscularly Fatiguing Movements in Practice - Women

Identified Movements	Frequency of Response	Total
Movement Without the Ball		47
-lunging drills	13	
-footwork/agility/speed drills	12	
-sprints	11	
-bounding drills	7	
-channelling drills (running with stick onthe ground)	2	
-running to tip on penalty corners	1	
-diving	1	
Movement With the Ball		29
-running drills with stick work or dribbling	16	
-cone drills	10	
-stick circuit (full field stick work and running drills)	3	
Game-like Skills/Contending for the Ball		18
-1 versus 1	10	
-tackling drills	6	
-small game (mini hockey, 2 versus 2)	2	
Receiving and Ball Propulsion Drills		33
-repetitive hitting	12	
-penalty corner pull outs	8	
-shooting	4	
-penalty corner stopping	3	
-hit and receive drills (push or drive)	3	
-penalty corner hits	1	
-strokes	1	
-stopping/receiving drills	1	
		127

Common Theme:
"anything repetitive when you are bent over and no chance to stand up and stretch"

Appendix B Table 4. Muscularly Fatiguing Movements in Practice - Men

Identified Movements	Frequency of Response	Total
Movement Without the Ball		10
-sprints/long runs	5	
-lateral movement drill/lunging/being low	4	
-footwork	1	
Movement With the Ball		8
-dribbling/bounding/cone drills	5	
-continuous bending	3	
Game-like Skills/Contending for the Ball		2
-1 versus 1	1	
-small game (mini hockey)	1	
Receiving and Ball Propulsion Drills		2
-repetitive drag push	1	
-low trapping	1	
		22

Appendix B Table 5. Muscles that Fatigue in Games or Practices - Women

Identified Muscles	Frequency of Response	Total
Lower Back	35	35
Pelvis/Thigh		103
-quadriceps	38	
-hamstrings	37	
-buttocks (gluteals and piriformis)	20	
-hip flexors	4	
-adductors/groin	2	
-iliotibial band	2	
Leg/Foot		35
-calves	24	
-anterior shin (tibialis anterior)	7	
-feet	2	
-posterior shin (tibialis posterior)	1	
-ankles	1	
Upper Back/Neck		5
-back of the neck	3	
-in between shoulder blades	2	
Shoulders		8
-trapezius	7	
-deltoids	1	
Arm/Hand		14
-forearms	11	
-biceps	1	
-triceps	1	
-thumb muscles	1	
		200

Appendix B Table 6. Muscles that Fatigue in Games or Practices - Men

Identified Muscles	Frequency of Response	Total
Lower Back	10	10
Pelvis/Thigh		26
-quadriceps	8	
-hamstrings	15	
-buttocks (gluteals)	1	
-hip flexors	1	
-adductors/groin	1	
Leg/Foot		6
-calves	6	
Neck	1	1
Shoulders	1	1
Trunk		1
-abdominals	1	
		45

Appendix B Table 7. Fatiguing Body Positions in Games or Practices - Women

Identified Position	Frequency of Response	Total	Muscles Listed
Knees/Hips/Back Flexed		61	
-dribbling	21		lower back, buttocks,
-defensive stance/ready position	15		quadriceps, hamstrings forearms, latissimus
-penalty corner stop	8		dorsi
-low tackle	8		
-lunge	7		
-channelling	2		
Twisting with Knees/Hips/Back Flexed		22	
-penalty corner pull out	13		adductors, low back,
-penalty corner hit	3		latissimus dorsi, triceps,
-driving	2		quadriceps, upper back
-flick	2		
-reverse drive	1		
-drag flick	1		
		83	

Appendix B Table 8. Fatiguing Body Positions in Games or Practices - Men

Identified Position	Frequency of Response	Total	Muscles Listed
Knees/Hips/Back Flexed		14	
-dribbling	8		lower back, quadriceps,
-defensive stance/ready position	2		hamstrings, gluteals, neck, calves
-low running (back on defence/ rebounding)	2		
-tackle	1		
-lunge	1		
Twisting with Knees/Hips/Back Flexed		5	
-penalty corner pull out	4		groin, low back,
-drag flick	1		quadriceps
		19	

APPENDIX C: TEMPLATE FOR VIDEO ANALYSIS

STATIONARY			PROLONGED FORWARD FLEXION			
Strong side			*Total time*			
	Push					
	Drive					
	Sweep					
	Flick					
Reverse						
	Push		SQUAT POSITIONS			
	Drive		*Tackle*			
	Flick			Strong side		
PC pull out				Reverse		
High flick			*Reception*			
Stroke				Strong side		
Drag flick				Reverse		
			Tipping/Bounce Pass			
RUNNING				Strong side		
FEET FORWARD				Reverse		
Strong side						
	Push		LUNGE POSITION			
	Drive		*Tackle*			
	Sweep			Strong side		
	Flick				Left	
Reverse					Right	
	Push			Reverse		
	Drive				Left	
	Flick				Right	
			Reception			
FEET SIDEWAYS				Strong side		
Strong side					Left	
	Push				Right	
	Drive			Reverse		
	Sweep				Left	
	Flick				Right	
Reverse			*Tipping/Bounce Pass/One Time Hit*			
	Push			Strong side		
	Drive				Left	
	Flick				Right	
				Reverse		
MOVEMENT WITH THE BALL					Left	
Total time					Right	
			PC Stop			
					Left	
					Right	

APPENDIX D: PICTORIAL REPRESENTATION OF DISCRETE MOVEMENTS

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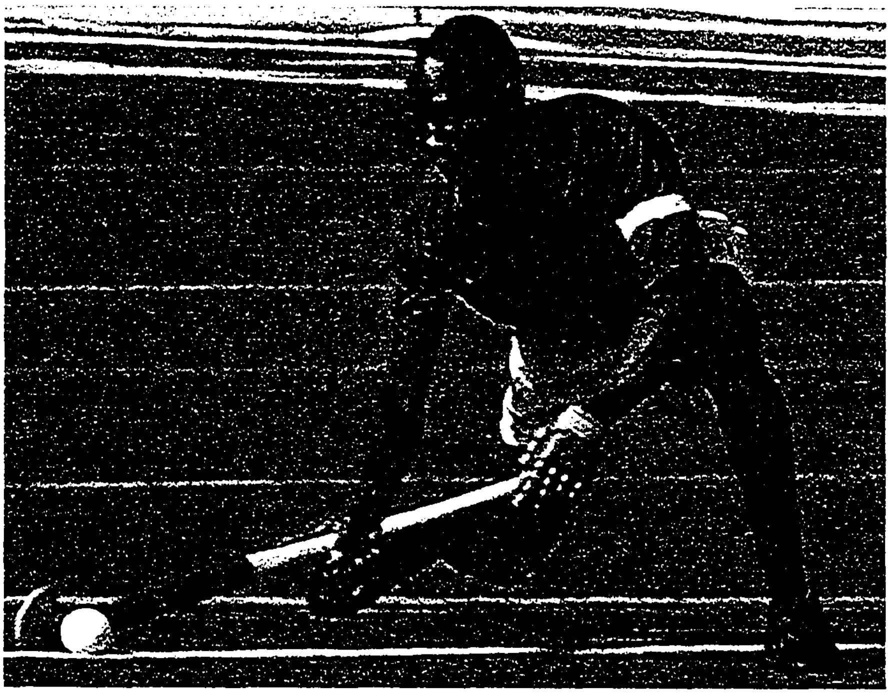
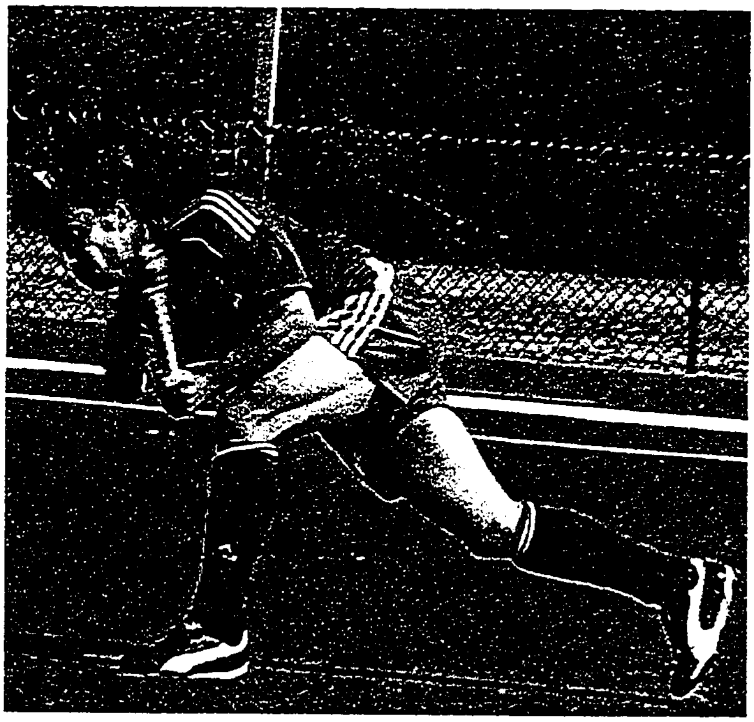
Appendix D Figure 1. Stationary strong side push (left plant foot).



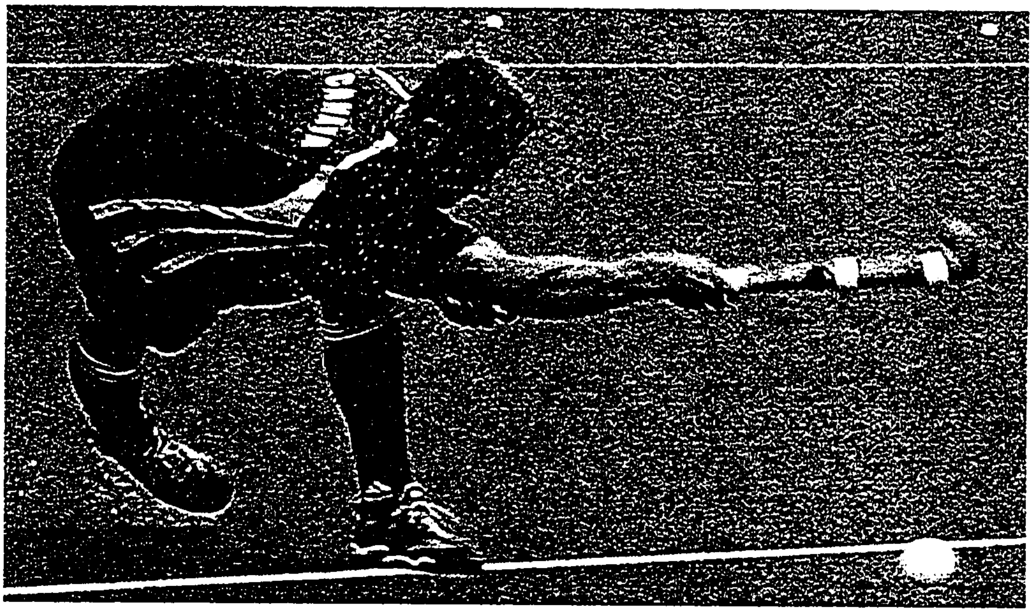
Appendix D Figure 2. Stationary strong side drive end position (left plant foot).

Appendix D Figure 3. Stationary strong side flick end position (left plant foot).

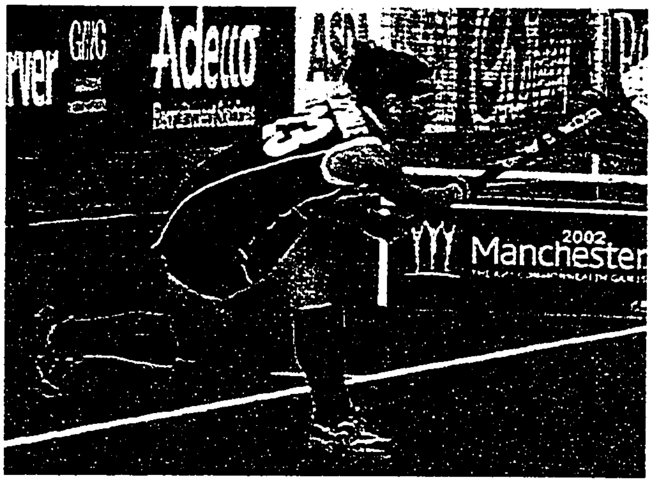


Appendix D Figure 4. Penalty stroke (left plant foot).

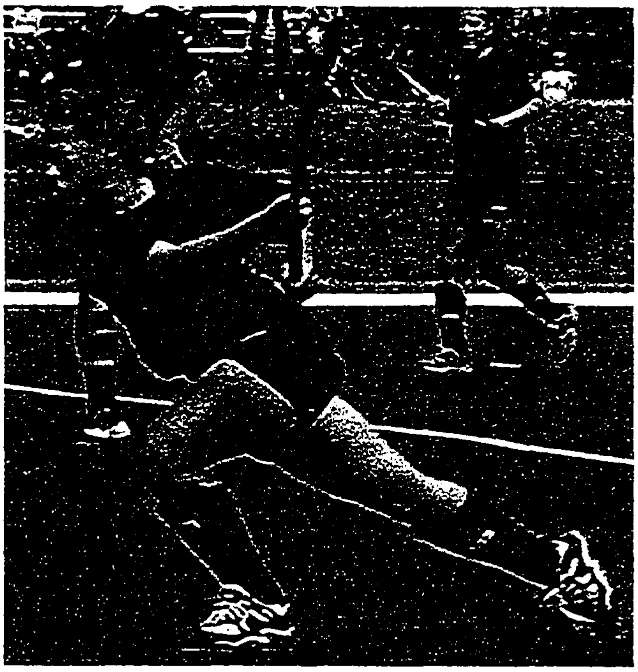
Appendix D Figure 5. Drag flick end position (left plant foot).



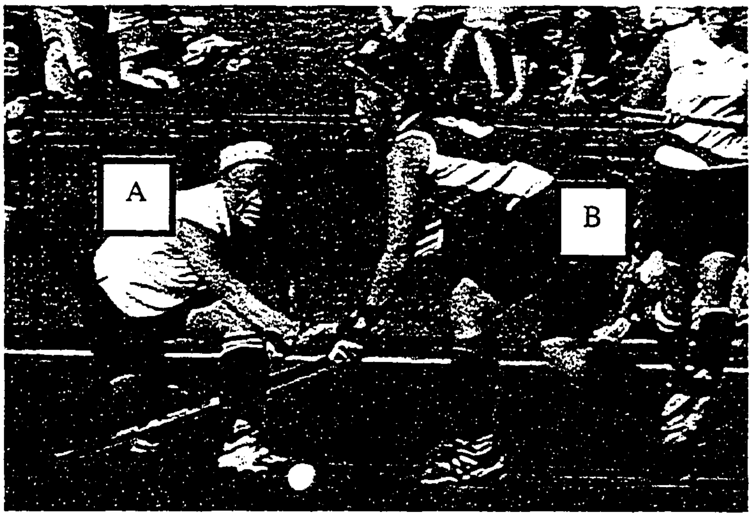
Appendix D Figure 6. Penalty corner pull out end position.



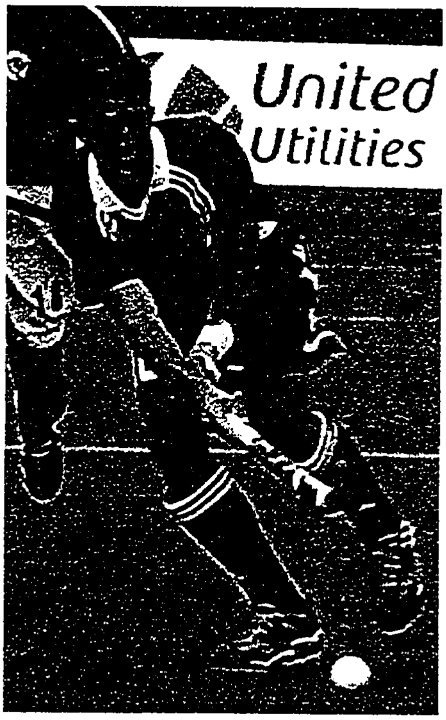
Appendix D Figure 7. Running feet forwards strong side push end position (left plant foot).



Appendix D Figure 8. Strong side push and tackle. Running feet forward strong side push; B. Left lunge strong side tackle.



Appendix D Figure 9. Running feet sideways strong side push (right plant foot).



Appendix D Figure 10. Running feet sideways strong side drive.

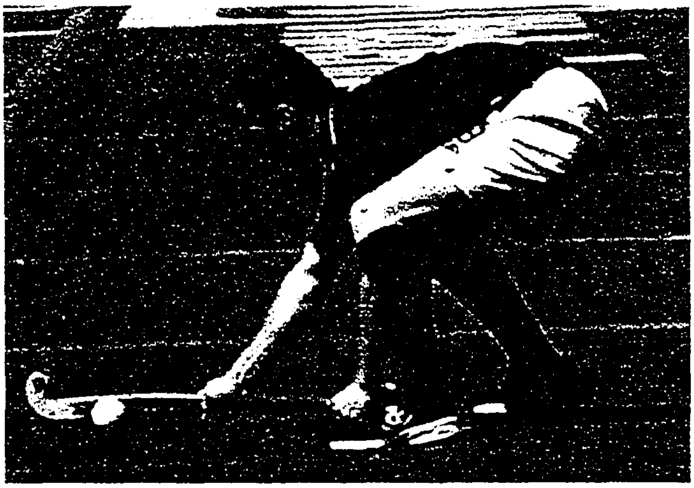
A. Start position (left plant foot).

B. End position (left plant foot).

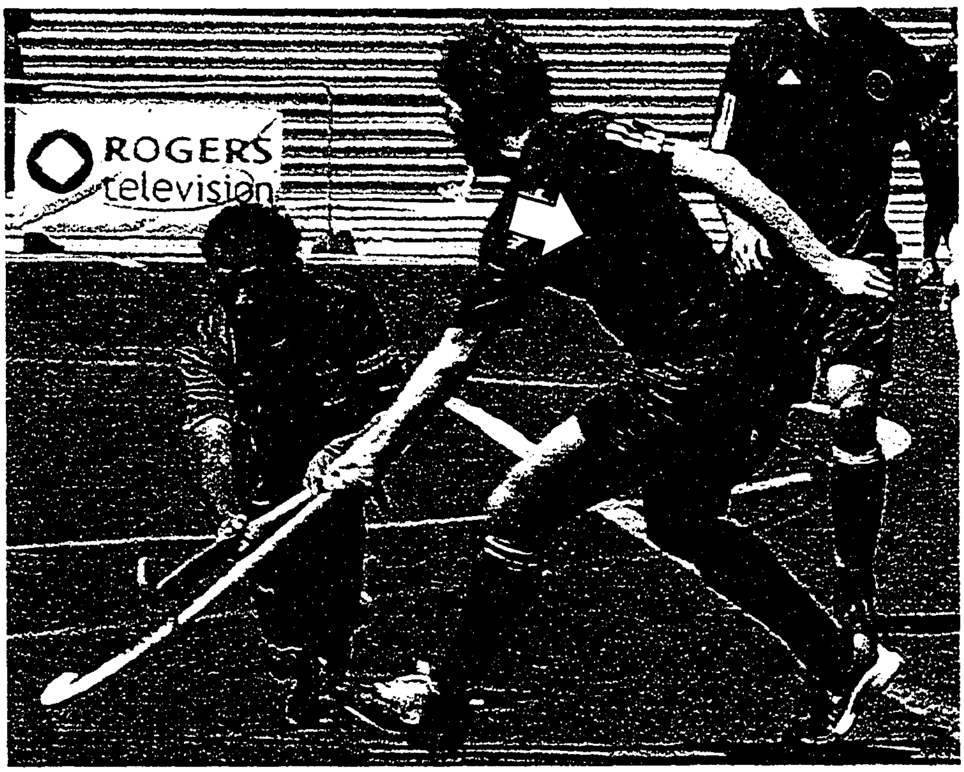
Appendix D Figure 11. Running feet sideways strong side sweep (left plant foot).

Appendix D Figure 12. Running feet sideways reverse drive (right plant foot).

Appendix D Figure 13. Squat reception.



Appendix D Figure 14. Left lunge strong side tackle (marked with arrow).



Appendix D Figure 15. Right lunge strong side tackle (marked with arrow).

Appendix D Figure 16. Left lunge strong side reception.

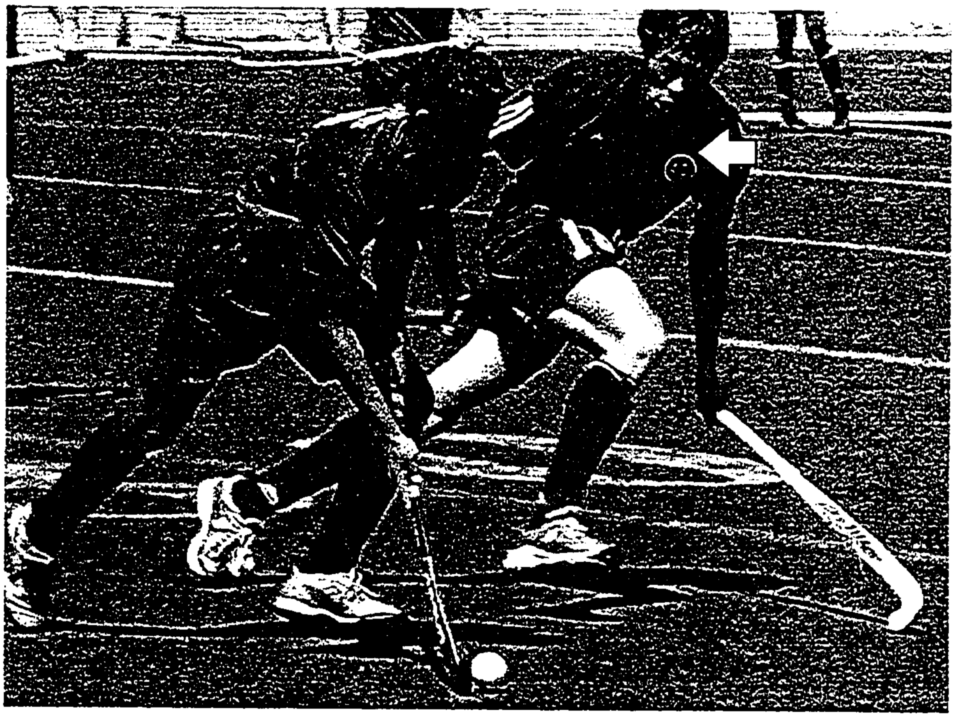
Appendix D Figure 17. Right lunge strong side reception.

Appendix D Figure 18. Right lunge reverse reception.

Appendix D Figure 19. Various positions of prolonged forward flexion.

Appendix D Figure 20. Movement with the ball.

Appendix D Figure21. Channelling (marked with arrow).



APPENDIX E: SIGNIFICANT DIFFERENCES OF DISCRETE MOVEMENTS

Appendix E Table 1. Significant Differences of Discrete Movements between Women's and Men's Games

Movement	p (Mann-Whitney)
Stationary strong side push off right	.004
Stationary reverse push	.023
Running feet forward strong side push off right	.028
Running feet sideways strong side sweep	.006
Total time of prolonged forward flexion per player	.001
Frequency of prolonged forward flexed positions	.002
Average time per prolonged forward flexion position	.002
Left lunge strong side tipping/bounce	.026
Right lunge strong side tackle	.009
Right lunge strong tipping/bounce	.023

Appendix E Table 2. Significant Differences of Discrete Movements between Women's Games and Practices

Movement	p (Mann-Whitney)
Stationary strong side push off right	.003
Stationary strong side sweep	.005
Strokes	.003
Running feet forward strong side sweep	.016
Running feet sideways strong side drive	.000
Running feet sideways strong side sweep	.001
Running feet sideways strong side flick off right	.026
Running feet sideways reverse push off right	.008
Running feet sideways reverse flick off right	.001
Total time of ball handling	.038
Squat reverse tackle	.026
Squat strong side reception	.009
Squat strong side tipping/bounce	.001
Left lunge strong side tackle	.048
Right lunge strong side tackle	.029
Total frequency of lunges	.010
Total frequency of left lunges	.008

APPENDIX F: SIGNIFICANT DIFFERENCES OF LEFT/RIGHT LUNGE AND STRONG SIDE/REVERSE ACTIVITIES

Appendix F Table 1. Significant Differences of Left/Right Lunge and Strong side/Reverse Activities – Women's Games

Movement	p (Sign Test)
Stationary strong side push and strong side push off right	.000
Stationary strong side drive and strong side drive off right	.000
Running feet sideways strong side push and strong side push off right	.000
Squat strong side tackle and reverse tackle	.000
Squat strong side reception and reverse reception	.000
Left lunge reverse reception and right lunge reverse reception	.015
Total frequency of left lunges and total frequency of right lunges	.000

Appendix F Table 2. Significant Differences of Left/Right Lunge and Strong side/Reverse Activities – Men's Games

Movement	p (Sign Test)
Stationary strong side push and strong side push off right	.000
Stationary strong side drive and strong side drive off right	.031
Stationary reverse push and stationary reverse push off right	.016
Running feet sideways strong side push and strong side push off right	.019
Running feet sideways strong side sweep and strong side sweep off right	.008
Squat strong side reception and reverse reception	.000
Left lunge reverse tackle and right lunge reverse tackle	.003
Total frequency of left lunges and total frequency of right lunges	.000

Appendix F Table 3. Significant Differences of Left/Right Lunge and Strong side/Reverse Activities – Women's Practices

Movement	p (Sign Test)
Stationary strong side push and strong side push off right	.002
Stationary strong side drive and strong side drive off right	.031
Running feet sideways strong side push and strong side push off right	.021
Running feet sideways strong side drive and strong side drive off right	.012
Running feet sideways strong side sweep and strong side sweep off right	.031
Squat strong side reception and reverse reception	.001
Squat strong side tipping/bounce and reverse tipping/bounce	.031
Total frequency of left lunges and total frequency of right lunges	.012

APPENDIX G: SPORT PARTICIPATION QUESTIONNAIRE

Completed by researcher:

Height ____________ Weight ____________ Age ____________

Completed by athlete. Pease answer each question as fully as possible. Where given a choice of answers, please circle the most appropriate answer.

1. Which hand do you write with? Left Right Both

2. Which foot do you kick a ball better with? Left Right Neither

3. How many years have you played field hockey? ____________
   From month/year ____________ to month/year ____________.

4. Please indicate the level(s) at which you have played and the approximate number of years for each level you have played.

Level	Number of Years Played
University	____________
Regional (e.g. Ontario, Alberta, B.C. Summer Games)	____________
Provincial (e.g. U-18, U-21, Senior National Championships; Canada Games)	____________
National Team/Squad Junior	____________
National Team/Squad Senior	____________

5. For any team indicated above, please list the length of the season in the space provided below.
   (e.g. University: End of August to November)

6. For your **university team**, is there a position you play 80% or more of the time? Yes No

   If *Yes*, please name the position. ____________

   What part of the field is this position on? Left Centre Right

   If *No*, please complete the following chart in the space below.

Position Played	Left, Centre or Right	Percentage of Time

7. If you play for any other field hockey teams, do you play any other position than listed above?

Yes No

If *Yes*, please complete the following chart in the space below.

Team	Position Played	Left, Centre or Right?	Percentage of Time

8. For your **university team**, what is the average number of practices per week? ________

9. For your **university team**, what is the average length of one practice? ____________

10. If you play for any other field hockey teams, please complete the chart below.

Team	Average Number of Practices per Week	Average Length of Practice

11. Have you ever, or do you now, play **any other sports** that practice, compete and/or train outside of practice (when these three aspects are combined) 2 times or more per week?

Yes No

If Yes, please complete the following chart.

Sport	Number of Years Played	Length of Season	Average Number of Sessions per Week (practice, games, other training)	Average Length of one session

Thank you for your participation!

APPENDIX H: INJURY HISTORY QUESTIONNAIRE

1. Have you ever had pain, discomfort or any other trouble with the lower part of your back? Yes No

2. Have you had pain, discomfort or any other trouble with the lower part of your back in the last twelve months? Yes No

3. Have you had pain, discomfort or any other trouble with the lower part of your back in the last three months? Yes No

4. Are you having pain, discomfort or any other trouble with the lower part of your back today? Yes No

If you answered yes to any of the questions above, please continue with questions 5 through 11. If you <u>did not</u> answer yes to any of these questions, please go to question 12.

5. Please describe your lower back pain, discomfort or trouble in the space below.

6. Do you have your lower back pain, discomfort or trouble every day or only occasionally through the week or month? Please explain.

7. Have you sought medical attention (physician or therapist) for this lower back pain or trouble? Yes No

8. Has your lower back pain been given a diagnosis (e.g. disc herniation)? Yes No

   If *Yes*, what is the diagnosis? ______________________________

9. Does your lower back pain, discomfort or trouble only occur near or during your menstruation? Yes No

10. Has this lower back pain, discomfort or trouble caused you to miss practice/games? Yes No

    If Yes, how many? ______________________

11. Has this lower back pain, discomfort or trouble caused you to modify the way you play? Yes No

    If *Yes*, please explain how in the space below.

    Are you still modifying the way you play? Yes No

12. Have you ever had pain, discomfort or any other trouble with your hips or thighs? Yes No

13. Have you had pain, discomfort or any other trouble with your hips/thighs in the last twelve months? Yes No

14. Have you had pain, discomfort or any other trouble with your hips/thighs in the last three months? Yes No

15. Are you having pain, discomfort or any other trouble with your hips/thighs today? Yes No

If you answered yes to any of the questions above, please continue with the remaining questions. If you did not answer yes to any of these questions, thank-you for your participation!

16. Please describe your hip/thigh pain, discomfort or trouble in the space below.

17. Do you have your hip/thigh pain, discomfort or trouble every day or only occasionally through the week or month? Please explain.

18. Have you sought medical attention (physician or therapist) for this hip/thigh pain or trouble? Yes No

19. Has your hip/thigh pain been given a diagnosis (e.g. arthritis)? Yes No

If *Yes*, what is the diagnosis? ______________________________

20. Has this hip/thigh pain, discomfort or trouble caused you to miss practice/games? Yes No

If Yes, how many? ______________________

21. Has this hip/thigh pain, discomfort or trouble caused you to modify the way you play? Yes No

If *Yes*, please explain how in the space below.

Are you still modifying the way you play? Yes No

Thank-you for your participation!

APPENDIX I: NON-NORMAL VARIABLES IN THE MUSCULOSKELETAL PROFILE

Controls:

ROM

Left 2 joint hip extension
2 joint hip extension difference
Hip adduction difference
Left hip abduction
Left 2 joint hip flexion
Right 2 joint hip flexion
Left 1 joint hip flexion
1 joint hip flexion difference
Hip external rotation difference
Trunk rotation difference

Strength

Hip external rotation difference
Trunk side flexion difference
Left trunk rotation
Right trunk rotation
Trunk rotation difference

Field Hockey Specific

Left trunk side flexion endurance

Independent Variables

Other sport years (all categories)

Field Hockey:

ROM

Left hip adduction
Hip abduction difference
Left 2 joint hip flexion
Right 2 joint hip flexion
Left 1 joint hip flexion
1 joint hip flexion difference
Right hip internal rotation
Left hip external rotation
Left trunk rotation
Right trunk rotation

Strength

Left hip flexion
Left hip ext
Right hip extension
Hip extension difference
Left hip abduction
Left hip internal rotation
Left hip external rotation
Hip external rotation difference
Left trunk side flexion
Trunk side flexion difference
Right trunk rotation

Field Hockey Specific

Right lateral hop
Left trunk side flexion endurance
Right trunk side flexion endurance
Trunk side flexion endurance difference
Left lateral lunge endurance
Right lateral lunge endurance
Lateral lunge endurance difference

Independent Variables

Total years played
University sport*years
Other sport*years (all categories)

APPENDIX J: CATEGORIZATION OF SPORT PARTICIPATION

Symmetrical*

Cheerleading	Football (touch)	Running	Swimming
Cycling (mountain)	Gymnastics	Skate (in-line)	Track
Cycling (road)	Horseback riding	Ski (downhill)	Triathlon
Dance	Karate	Ski (Nordic)	Weight training
Football (flag)	Rugby	Soccer (uses both feet equally)	Wrestling

Asymmetrical – Right Hand Dominant*

Basketball	Tennis
Hockey	Ultimate
Portside row (oar on rower's right)	Waterpolo

Asymmetrical – Left Hand Dominant*

Ringette	Starboard row (oar on rower's left)

Asymmetrical – Right Foot Dominant*

Snowboard (lead with right foot)	Soccer

Asymmetrical – Left Foot Dominant*

None listed

* only sports identified in questionnaires are listed above; for sports that could have left or right dominance (e.g. basketball), sports placed in left or right dominance as indicated by respondent

APPENDIX K: DIAGRAMMATIC REPRESENTATION OF LEFT-RIGHT DIFFERENCE PATTERNS FOR ALL BACK AND THIGH PAIN GROUPS

HEALTHY CONTROL		HEALTHY FIELD HOCKEY		NON-SIGNIFICANTLY LIMITING BACK PAIN FIELD HOCKEY		ACUTE THIGH PAIN FIELD HOCKEY	
Left greater	Right greater	Left greater	Right greater	Left greater	Right greater	Left greater	Right greater
		Trunk side flexion strength		**Trunk side flexion strength**			
			Trunk rotation ROM				
				Trunk rotation strength			
				2-joint hip flexion ROM		2-joint hip flexion ROM	
				1-Joint hip flexion ROM			
	Hip flexion strength						
				2-joint hip extension ROM			
				1-joint hip extension ROM			
			Hip extension strength				
	Hip adduction ROM		**Hip adduction ROM**		**Hip adduction ROM**		Hip adduction ROM
			Hip adduction strength		Hip adduction strength		
	Hip abduction ROM						
Hip abduction strength							Hip abduction strength
	Hip internal rotation strength	**Hip internal rotation strength**					
Hip external rotation ROM		Hip external rotation ROM		Hip external rotation ROM		**Hip external rotation ROM**	
							Hip external rotation strength
	Sideways hop for distance						
				Lateral lunge endurance		**Lateral lunge endurance**	

Bold = Large ES, significance of $p < 0.05$, power between 0.60 and 0.86
Underlined = Moderate to large ES, significance of $p < .10$, variable power
Regular = Moderate ES, significance of $p > 0.10$, low power

APPENDIX L: STUDY 1 ETHICS DOCUMENTS

Faculty of Physical Education and Recreation

PHYSICAL CHARACTERIZATION OF FIELD HOCKEY

Principal Investigator:
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A study is being done at the 2002 Senior National Tournament in London, Ontario to list movements in field hockey, to find out how often these movements happen and to find out what movements athletes feel are really tiring. Results from this study will be used to fulfill the partial requirements of a Ph.D. in the Faculty of Physical Education and Recreation, University of Alberta.

The results from this study will be used to create testing methods for a future study on the muscle imbalances that happen in field hockey. The data collected from this future study will hopefully be used to decrease injury in field hockey. The results may also be helpful for coaches to develop sport specific training programs.

The study consists of two parts – a videotape part and a questionnaire. For the videotape part, the principle investigator will choose one athlete per half game to be videotaped for the entire half. The video camera will be put in the stands. To ensure confidentiality, the investigators (the principle investigator and her supervisory committee) will not tell anyone who has been videotaped and no one except the investigators will be able to watch the completed videotapes. **No coaches, umpires, spectators or tournament organizers will be allowed to view the videotapes.**

For the questionnaire, the investigator will choose ½ of the athletes to answer questions about what movements in field hockey are really tiring. The investigator will find the athlete at a time that does not interfere with his/her competition and ask if he/she would answer the questions. The athlete can say "no" without any consequences. The questions will take about 10 minutes to answer. The principle investigator will be the only person to know which athletes have been asked and the only peerson to hand out and collect the questionnaires. There will be no name or signature on the questionnaire to identify the athlete.

The videotapes and questionnaires will be kept in a locked office for 5 years after the results have been published, after which they may be destroyed. The investigators will be the only people who can look at the videotapes and questionnaires.

The videotaping has no physical risk to the athletes and, as athletes are frequently videotaped in field hockey by opposing teams, there should also be no psychological risk. There is a very slight chance that answering questions about tiring movements in field hockey might make the athlete feel uncomfortable. If this happens, the athlete can say he/she doesn't want to answer the questions without consequence.

If you have concerns about this study, you may contact Dr. Wendy Rodgers, Chair of the Faculty Ethics Committee, at 492-5910. Dr. Rodgers has no direct involvement with this project.

Sincerely,
Tija Westbrook, M.Sc., B.Sc.(P.T.), C.A.T.(c.)
Faculty of Physical Education and Recreation
University of Alberta

Faculty of Physical Education and Recreation

PHYSICAL CHARACTERIZATION OF FIELD HOCKEY

Principal Investigator:
Tija Westbrook, M.Sc., B.Sc.(P.T.), C.A.T.(c.)
Faculty of Physical Education and Recreation
University of Alberta
Edmonton, Alberta, Canada

Research Supervisor:
Dan Syrotuik, Ph.D.
Faculty of Physical Education and Recreation
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Edmonton, Alberta, Canada
(780) 492-1018

A study is being done at the 2002 Senior National Tournament in London, Ontario to list movements in field hockey, to find out how often these movements happen and to find out what movements athletes feel are really tiring. Results from this study will be used as part of a Ph.D. program in the Faculty of Physical Education and Recreation, University of Alberta.

The results from this study will be used to make testing methods for a future study on the muscle imbalances that happen in field hockey. The results from this future study will hopefully be used to lower field hockey injuries. The results from this study may also be helpful for coaches to make sport specific training programs.

I would like you to finish this questionnaire that asks you what movements in field hockey you think are really tiring. I am asking about ½ of the athletes at this tournament to answer these questions. You can say "no" without any problems. Just give the questionnaire back to me if you don't want to do it. The questions will take about 10 minutes to answer. The principle investigator is the only person who knows which athletes are answering the questionnaire. To keep your answers anonymous, ***DO NOT*** put your name anywhere on the questionnaire.

The questionnaires will be kept in a locked office for 5 years after the results have been published, after which they may be destroyed. The investigators (the principle investigator and her supervisory committee) will be the only people who can look at the questionnaires.

There is a very slight chance that answering questions about tiring movements in field hockey might make you feel uncomfortable. If this happens, just give me back the questionnaire. There will be no problems if you give it back.

If you have problems with this study, you may contact Dr. Wendy Rodgers, Chair of the Faculty Ethics Committee, at 492-5910. Dr. Rodgers has no direct involvement with this project.

Sincerely,

Tija Westbrook, M.Sc., B.Sc.(P.T.), C.A.T.(c.)

APPENDIX M: STUDY 2 ETHICS DOCUMENTS

INFORMATION LETTER

Pilot project: reliability and validity of testing measures to be used to create a musculoskeletal profile of interuniversity field hockey players.

Principal Investigator:
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Faculty of Physical Education and Recreation
University of Alberta
Edmonton, Alberta, Canada

Research Supervisor:
Dan Syrotuik, Ph.D.
Faculty of Physical Education and Recreation
University of Alberta
Edmonton, Alberta, Canada
(780) 492-1018

Purpose: A study is being done to establish reliability and validity of a series of tests that will be used in a future study to look at muscle imbalances in field hockey players. Results from this study will be used to fulfill the partial requirements of a Ph.D. in the Faculty of Physical Education and Recreation, University of Alberta.

Benefits: This pilot project will accomplish the following: establish reliability and validity of the tests; streamline the testing techniques, and; establish the number of participants needed for the future muscle imbalance study. The data collected from this muscle imbalance study will hopefully be used to decrease injury in field hockey. The results may also be helpful for coaches to develop sport specific training programs. Sports therapists, when treating field hockey athletes, can use the testing procedures evaluated in this pilot project and can use the information about muscle imbalances to treat low-back pain.

Procedures: If you agree to participate, you will complete 2 questionnaires and 3 groups of tests that measure flexibility, strength, power and endurance of the muscles of the low back and hip. Proper technique will be explained and demonstrated by the researcher. The researcher is a certified Athletic Therapist and a licensed Physical Therapist. Two groups of people will be involved in this study – former elite field hockey players and student therapists.

The first questionnaire asks you about your age, dominant hand and leg and field hockey experience. Everyone will answer questions about age and dominant hand and leg. Only the field hockey athletes will look at the rest of this questionnaire. They will be asked to comment on any areas of the questionnaire that they feel is too long or is difficult to understand. Your height and weight will be taken when the questionnaire is given back to the researcher.

The second questionnaire asks you about your previous injuries. Everyone will be asked to complete an injury questionnaire. Again, you will be asked to comment on any areas of the questionnaire that you feel is too long or is difficult to understand.

Flexibility will be tested using inclinometers. An inclinometer is a circular fluid filled disk with a weighted gravity pendulum, something like a compass. It will be attached to your leg above and below the knee using a Velcro strap. For measurements of the back, two inclinometers will be placed on different parts of your back. Your shirt will need to be tucked into your bra for measurements of the back. The tests take place lying on a therapy table and sitting in a chair. Padding will be put between you and the straps anywhere where you are uncomfortable. For the lying tests, the researcher will move the leg. For sitting tests, you will move your trunk as far as you can. Each test will be performed 5 times per test per leg/ direction.

Strength will be tested with a push-pull dynamometer. A push-pull dynamometer is something like a hanging scale for vegetables at the grocery store. The push-pull dynamometer will be attached to your leg or chest with a harness over your clothing. The tests take place standing in a specially built walker and sitting in a chair. You will be strapped to the walker or chair to ensure that other body parts do not move and change the test. Padding will be put between you and the straps anywhere where you are uncomfortable. You will be asked to pull as hard as possible against the dynamometer. All the strength tests will follow a general 5- minute warm-up on a bike. Each test will be performed 5 times per test per leg/direction.

Power and endurance will be tested with 3 sport specific tests. All sport specific tests will follow a general 5-minute warm-up on a bike. This test will be performed 3 times per side.
Trunk Side Flexion:
This test will take place lying on a table. You will be strapped to the table to ensure that other body parts do not move and change the test. Padding will be put between you and the straps anywhere where you are uncomfortable. You will be asked to do as many sideways sit-ups as possible in 5 minutes. This test will be performed 3 times per side.
Single-Leg Hop:
This test is a standing broad jump test done one leg at a time. The researcher will measure how far you can hop forward once on one leg. This test will be performed 5 times per leg.
Lateral Lunge:
Only field hockey athletes will do this test. You will be asked to go into a field hockey "ready" stance holding a stick. You will be asked to lunge diagonally forward on a 45° angle to do a poke tackle. You will do as many poke tackles as possible in 5 minutes. This test will be performed 3 times per leg.

Time Commitment:
Anthropometric Data Questionnaire: 5 min for student therapists
15 min for field hockey athletes
Injury History Questionnaire: 5 to 20 min depending on your injury history
Height and Weight: 5 min
ROM Testing: 65 min
Isometric Strength Testing: 3 hours
Activity Specific Testing: 1.5 hours for student therapists
2.5 hours for field hockey athletes

Total Time Commitment: 7 to 8 hours

This time commitment can be broken into 3 sections and scheduled at your convenience.
Questionnaires, Height and Weight, ROM: 1.5 to 2 hours
Isometric Strength Testing: 3 hours
Activity specific Tests: 1.5 to 2.5 hours

Risks:
The risk of injury through flexibility testing is very low. The movements are done either by you or the researcher. The researcher stops the movement of the leg at the first feeling of stretch, well below the range where you could become injured. You control the movement of the back and can

stop if you feel uncomfortable. The strength, power and endurance tests require a maximal effort or going to exhaustion of the muscle. With this type of exercise there may be some health risk. During and after the test it is possible to experience symptoms such as abnormal blood pressure, fainting, light-headedness, muscle cramps or strain and nausea. While serious risks to healthy participants are highly unlikely, they must be acknowledged, and you willingly assume the risks associated with very hard exercise. The researcher will administer all the tests and is a licensed Physical Therapist and Athletic Therapist with additional certifications in CPR and advanced first aid. The researcher has extensive emergency care training.

Confidentiality:
To ensure anonymity, personal information will be coded and stored in a locked office to which only the principle investigator and research advisors have access. Normally, information is retained for a period of five years post publication, after which it will be destroyed.

Freedom to Withdraw:
You are free to refuse to participate or to withdraw from the study at any time without consequence. If you decline to continue or you withdraw from the study your information will be removed from the study upon your request.

Additional Contacts:
If you wish to speak with someone who is not involved with this study, please call Dr. Wendy Rodgers, Chair of the Faculty Ethics Committee, at 780-492-5910.

Pilot project: reliability and validity of testing measures to be used to create a musculoskeletal profile of interuniversity field hockey players.

Principal Investigator:
Tija Westbrook, M.Sc., B.Sc.(P.T.), C.A.T.(c.)
Faculty of Physical Education and Recreation
University of Alberta
Edmonton, Alberta, Canada

Research Supervisor:
Dan Syrotuik, Ph.D.
Faculty of Physical Education and Recreation
University of Alberta
Edmonton, Alberta, Canada
(780) 492-1018

Please complete the following:

Do you understand that you have been asked to participate in a research study?	Yes	No
Have you received a copy and read the attached information sheet?	Yes	No
Do you understand the benefits and risks involved in taking part in this study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate, or to withdraw from the study at any time, without consequence, and that your information will be withdrawn at your request?	Yes	No
Has the issue of confidentiality been explained?	Yes	No
Do you understand who will have access to your information?	Yes	No

This study was explained to me by: ______________________________

I agree to take part in this study.

________________________________ ____________ ____________________
Signature of Athlete Date Witness

________________________________ ____________________
Printed Name Printed Name

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate

________________________________ ____________
Signature of Investigator or Designee Date

APPENDIX N: STUDY 3 ETHICS DOCUMENTS

INFORMATION LETTER

A Musculoskeletal Profile of Canadian Interuniversity Female Field Hockey Players

Principal Investigator:
Tija Westbrook, M.Sc., B.Sc.(P.T.), C.A.T.(c.)
Faculty of Physical Education and Recreation
University of Alberta
Edmonton, Alberta, Canada

Research Supervisor:
Dan Syrotuik, Ph.D.
Faculty of Physical Education and Recreation
University of Alberta
Edmonton, Alberta, Canada
(780) 492-1018

Purpose: A study is being done on the potential existence of a left/right sport specific imbalance of the trunk and hip region in female interuniversity field hockey players. Results from this study will be used to fulfill the partial requirements of a Ph.D. in the Faculty of Physical Education and Recreation, University of Alberta.

Benefits: The results of this muscle imbalance study will be used to decrease injury in field hockey, may help coaches develop sport specific training programs and may help provide testing procedures and norms for sports therapists to evaluate and treat low-back pain.

As this study will attempt to create norms, individual or grouped team results from the testing will be meaningless until all the data has been collected. Consequently, individual results will *not* be provided. However, should there be an obvious test result that leads the researcher to believe that the participant may be at risk for future injury in their activity, the researcher will tell the participant and the participant may ask for her results. Coaches will *never* be given individual results, but they may ask for grouped results for their team only.

Procedures: If you agree to participate, you will complete 2 questionnaires and 3 groups of tests that measure flexibility, strength, power and endurance of the muscles of the low back and hip. Proper technique will be explained and shown by the researcher. The researcher is a certified Athletic Therapist and a licensed Physical Therapist. Two groups of people will be in this study – 1. elite field hockey players, and 2. University of Alberta students and members of the public (volunteers).

The first questionnaire asks you about your age, dominant hand and leg and sport experience. Everyone will answer questions about age and dominant hand and leg and non-field hockey activity. Only the field hockey players will finish the rest of this questionnaire. Your height and weight will be taken when the questionnaire is given back to the researcher. (Time commitment: 5 min for volunteers; 15 min for field hockey players)

The second questionnaire asks you about your previous injuries. Everyone will finish this questionnaire. (Time commitment: 5 to 20 min depending on your injury history)

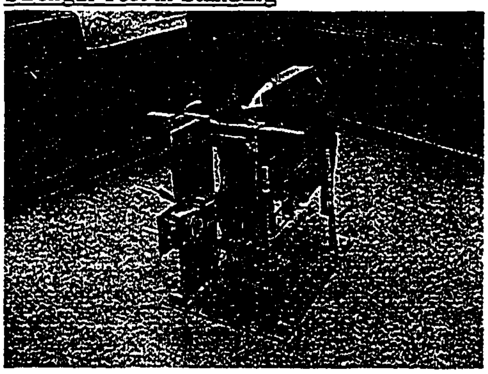
Flexibility

Flexibility will be tested using inclinometers and compasses. An inclinometer is a circular fluid filled disk with a weighted gravity pendulum, something like a compass. It will be attached to your leg or placed on your back. Your shirt will need to be tucked into your bra for measurements of the back. The tests take place lying on a therapy table and sitting on a stool. You will be strapped to the table or stool to ensure that other body parts do not move and change the test. For the lying tests, the researcher will move the leg. For sitting tests, you will move your trunk as far as you can. Each test will be done 2 times per test per leg/ direction. (Time commitment: 40 min)

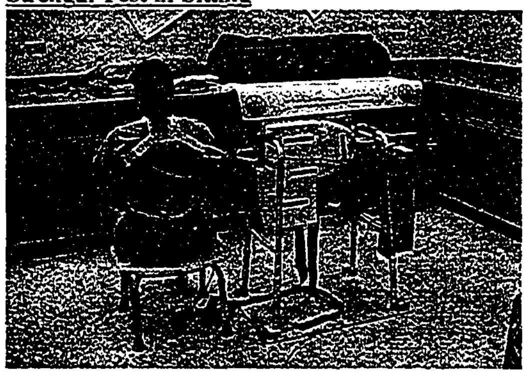
Flexibility Tests

Strength
Strength will be tested with a push-pull dynamometer. A push-pull dynamometer is something like a hanging weigh scale for vegetables at the grocery store. The push-pull dynamometer will be attached to your leg or chest with a harness over your clothing. The tests take place standing in a specially built frame and sitting on a stool. You will be strapped to the frame or stool to make sure that other body parts do not move and change the test. You will be asked to pull as hard as possible against the dynamometer. All the strength tests will follow a general 5- minute warm-up on a bike. Each test will be done 2 times per test per leg/direction. (Time Commitment: 2 hours)

Strength Test in Standing



Strength Test in Sitting



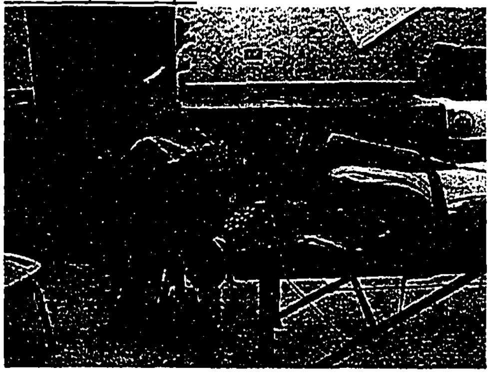
Power and Endurance
Power and endurance will be tested with 3 sport specific tests. All sport specific tests will follow a general 5-minute warm-up on a bike. (Time commitment: 45 min for volunteers; 1.25 hours for field hockey players)

Sideways Sit-Up:
For this test, you will be secured to a massage table and you will do as many sideways sit-ups as you can. This test will be done 1 time per side.

Single-Leg Hop:
This test is like a standing broad jump test done one leg at a time. The researcher will measure how far you can hop sideways on one leg. This test will be done 2 times per leg.

Lateral Lunge:
Only field hockey players will do this test. From a field hockey "ready" stance holding a stick, you will lunge diagonally forward on a 45° angle to do a poke tackle. You will do as many poke tackles as you can. This test will be done 1 time per leg.

Sideways Sit-Ups



Lateral Lunge

Total Time Commitment: *4 to 5 hours*
This time commitment will be broken into 3 sections.
Questionnaires, Height and Weight, Flexibility: 1 hour
Isometric Strength Testing: 2 hours
Sport Specific Tests: 45 min to 1.25 hours

Note: for strength and sport specific tests, a large portion of the time commitment is rest between repetitions. This rest allows the muscles enough time to produce maximum effort for each test.

Risks:
The risk of injury through flexibility, strength and power testing is very low. The flexibility movements are done either by you or the researcher. The researcher stops the movement of the leg at the first feeling of stretch, well below the range where you could become injured. You control the movement of the back and can stop if you feel uncomfortable. The strength and power tests are standard therapy and fitness assessments specifically designed to be low-risk. The endurance tests require going to exhaustion of the muscles. Participants involved in a trial run of the lunge and sideways sit-ups tests experienced mild to moderate muscle soreness that went away within 2 days.

Confidentiality:
To ensure anonymity, personal information will be coded and stored in a locked office to which only the principle investigator and research advisors have access. Normally, information is kept for a period of five years post publication, after which it will be destroyed. Results from this study will published as grouped data, *not* as individual data. Your coach will *not* be given individual results for any player.

Freedom to Withdraw:
You are free to refuse to participate or to withdraw from the study at any time without consequence.
If you decline to continue or you withdraw from the study your information will be removed from the study upon your request.

Additional Contacts:
If you wish to speak with someone who is not involved with this study, please call Dr. Wendy Rodgers, Chair of the Faculty Ethics Committee, at 780-492-5910.

A Musculoskeletal Profile of Canadian Interuniversity Female Field Hockey Players

Principal Investigator:
Tija Westbrook, M.Sc., B.Sc.(P.T.), C.A.T.(c.)
Faculty of Physical Education and Recreation
University of Alberta
Edmonton, Alberta, Canada

Research Supervisor:
Dan Syrotuik, Ph.D.
Faculty of Physical Education and Recreation
University of Alberta
Edmonton, Alberta, Canada
(780) 492-1018

Please complete the following:

Do you understand that you have been asked to participate in a research study?	Yes	No
Have you received a copy and read the attached information sheet?	Yes	No
Do you understand the benefits and risks involved in taking part in this study?	Yes	No
Have you had an opportunity to ask questions and discuss this study?	Yes	No
Do you understand that you are free to refuse to participate, or to withdraw from the study at any time, without consequence, and that your information will be withdrawn at your request?	Yes	No
Has the issue of confidentiality been explained?	Yes	No
Do you understand who will have access to your information?	Yes	No

This study was explained to me by: ________________________

I agree to take part in this study.

________________________ ____________ ________________
Signature of Athlete   Date   Witness

________________________ ________________
Printed Name   Printed Name

____
Signature of Parent/Guardian if under 18 years of age

I believe that the person signing this form understands what is involved in the study and voluntarily agrees to participate

________________________ ____________
Signature of Investigator or Designee   Date