The Effects of Aerobic and Localized Fatigue on Jump Shot Kinematics and Kinetics in Team Handball Players

by

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Abstract

Team handball has become a very popular sport throughout the world and according to the International Handball Federation over 30 million athletes in 183 countries currently play the sport. The purpose of this project was to determine the influence of aerobic fatigue as well as localized fatigue on jump shot kinematics and kinetics. Pelvis rotation significantly decreased at MER following localized fatigue from -13.08° to -2.57°. At FC of the jump shot, significant differences were observed for pelvis lateral flexion, pelvis rotation, and trunk flexion. The pelvis was positioned with greater contralateral, lateral flexion following aerobic fatigue (-1.25 ± 3.41° to -3.39 ± 4.14°). Increased contralateral pelvis rotation was also observed in the jump shot following aerobic fatigue (-43.07 ± 12.92° to -50.79 ± 12.26°). Pelvis lateral flexion towards the contralateral side was also significantly greater at BR following aerobic fatigue (-21.90 ± 5.99° to -25.55 ± 7.79°). The trunk had greater flexion at FC following aerobic fatigue. Trunk rotation significantly increased from -6.80 ± 10.07° to -12.55 ± 10.97° at MER following fatigue. It is likely, that while few changes were observed in this study, cumulative fatigue would have a greater effect on range of motion, isometric strength, and the kinematics and kinetics of throwing in in team handball players than what was observed after a single bout of fatigue. If these fatiguing protocols were performed on consecutive days then more significant differences in jump shot kinematics would likely have been observed.

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Table of Contents

List of Tables

List of Figures

List of Abbreviations

BPM	Beats Per Minute
BR	Ball Release
FC	Foot Contact
FLP	Fatigue Landing Protocol
GIRD	Glenohumeral Internal Rotation Deficit
HRMax	Heart Rate Max
MER	Maximum External Rotation
MIR	Maximum Internal Rotation
NCAA	National Collegiate Athletic Association
ROM	Range of Motion
RPE	Ratings of Perceived Exertion
SAFT	Soccer-Specific Aerobic Fatigue Test
$Vert_{max}$	Maximum Vertical Jump Height
VO2max	Maximal Oxygen Uptake
WOSI	Western Ontario Shoulder Instability Index

CHAPTER 1

INTRODUCTION

Team Handball is a dynamic sport that requires the athlete to not only have well developed aerobic fitness, but also master movements such as running, jumping and throwing. The purpose of this project was to determine the influence of aerobic fatigue as well as localized fatigue on throwing kinematics and kinetics. This chapter presents a brief introduction that is divided into 4 sections. Section 1 addresses the sport of team handball while section 2 discusses previous work on the role of fatigue on the kinematics of selected dynamic movements. Section 3 presents research on range of motion and lastly, section 4 will present the hypothesis and glossary of terms.

Team handball has become a very popular sport throughout the world.[1,2] According to the International Handball Federation, over 30 million athletes in 183 countries currently play team handball. While the sport is vastly popular in Europe and many other countries, it is relatively unknown in the United States. Yet grassroots programs are beginning to be developed in an effort build interest in this Olympic sport. As participation in team handball increases the need for scientific data describing the key skills and injury risk factors involved in the sport are needed.

Of the limited data on team handball, it has been reported that team handball players make approximately 48,000 throws in a season at a median throw speed of 130 km/h[3] with the jump shot being the most common shot (73-75%).[4,5] While the jump shot is the most frequently performed, the kinematics and kinetics associated with this shot are scarce.[5,6] The jump shot in team handball involves the execution of a vertical jump off of the contralateral leg following a three stride run-up.[4] This throwing motion is different from most typical overhead throwing sports. The essence of having to throw while in the air results in a loss of kinetic energy that can be generated from the ground. This loss in energy could in turn cause biomechanical compensation. In contrast, the stride leg remains in contact with the ground during the set shot and baseball pitch, allowing the pelvis, trunk, and throwing arm to accelerate over the leg, which aids in kinetic energy transfer.[4]

Fatigue is a complex and multi-faceted physiological response that is difficult to quantify.[7] Fatigue has been defined as any reduction in maximal force generating capacity, irrespective of the force required for a specified task.[7-9] Force production, movement coordination, motor control precision, muscle reaction times and proprioception have all been negatively affected by fatigue.[7,10,11] These decrements in performance contribute to injury risks such as the inability to attenuate forces, bone bending stresses, and stabilize joints.[7,12] The compromised ability of the muscles to protect the body from large forces due to fatigue hinders the body's ability to protect itself from injury.[7]

The sport of team handball is unique in that it requires a combination of dynamic movements throughout the course of a game. These movements include running, jumping, landing, throwing, catching, and cutting. How these movements are altered once a player fatigues have yet to be examined, however, the effects of fatigue on both static and dynamic activities have been extensively examined in the literature in other sports.[7,10,11,13-30] Based on the results of these previous studies it is evident that kinematic alterations occur following fatigue. Kinematic alterations during dynamic movements may place a joint in a comprised position that increases the risk of injury. Localized fatigue from throwing and aerobic fatigue from running may contribute to altered kinematics such as decreased humeral elevation, elbow flexion, scapula protraction, trunk flexion, jump height, increased plane of elevation, trunk lateral flexion; and kinetics such as shoulder distraction and elbow valgus forces.

Kinematic changes that result from fatigue can place a joint in a vulnerable position during dynamic movements. Understanding kinematic changes that occur with fatigue is paramount for the creation of injury prevention protocols. While little research has aimed to examine kinematic differences in upper extremity movement patterns following fatigue, the literature available on the lower extremity has identified potential flawed mechanics that increase the risk of injury.[14,31,32] For instance, movements that involve sudden change of direction, landing from a jump, and rapid stops are all non-contact mechanisms of injury that are greatly affected by lower extremity kinematics.[11] Because these movements have previously been identified as common injury mechanisms great effort has been taken to understand how lower extremity kinematics are affected by fatigue,[11,13-16,21,23,26,31-37] yet the application of the same methodology to the upper extremity has gone mostly unconsidered.

In addition to kinematic alterations that may occur following fatigue, changes in range of motion are also likely to occur following fatiguing. It is evident from the literature that range of motion is altered in upper extremity dominant athletes due to repetitive overhead movements.[3,38-59] Examining range of motion in team handball players will improve the understanding of the acute effects of fatigue on range of motion. Significantly altered range of motion in professional baseball pitchers has been observed 24 hours post pitching performance.[60] Baseball pitchers usually only pitch competitively once every five days and have more recovery time than team handball players are allotted, therefore, changes in range of motion may be exacerbated in team handball players.

It has been reported in baseball [43,45,47,58,60-63], that shoulder range of motion is a critical factor in upper extremity injury incidence.[64,65] Therefore, the available range of motion of the shoulder and hip may be a factor that significantly contributes to upper extremity injury in team handball players. Due to the repetitive nature of overhead throwing, athletes often develop adaptive changes at the glenohumeral joint such as an increase in external rotation and decrease in internal rotation compared to the non-throwing shoulder, known as glenohumeral internal rotation deficit (GIRD).[3,54,65-69] GIRD is believed to be the result of a contracture of the posterior capsule and the inferior glenohumeral ligaments [3,64,70-72] as well as torsion to the humeral head.[3,54,65-69]

In addition to changes in the shoulder range of motion, research is beginning to point to the importance of the hip as a contributor to shoulder dysfunction. Adequate hip range of motion and strength are crucial for energy transfer from the proximal segments to the distal segments of the kinetic chain during throwing.[59] Dysfunctional hip characteristics may alter upper and lower extremity kinematics and kinetics thus decreasing performance and increasing the risk of injury.[59,73] The literature examining range of motion characteristics of the shoulder[3,51,54,62,64-69,72,74-77] in upper extremity dominant athletes is far more prevalent than at the hip.[48,58,59,78] The repetitive nature of throwing can cause large rotational stresses about the hip, which can alter range of motion and result in injury.[78] Ellenbecker et al.[78] have reported no significant differences in active hip range of motion between the dominant and non-dominant hips in elite tennis players and professional baseball pitchers. Even though no side-to-side differences were observed, 17% of pitchers had greater than 10° difference in internal rotation and 42% had greater than 10° difference in external rotation between sides.[58,78] Hip and shoulder range of motion has been found to be important indicators of injury potential in certain overhand throwing athletes, but limited work has been done in this area for team handball.

Purpose

Thus, the purpose of this study was to examine the effects of localized fatigue of the throwing arm as well as aerobic fatigue on jump on jump shot kinematics and kinetics in team handball players. In addition to examining the effects of localized and aerobic fatigue on the jump shot, this study endeavored to determine shoulder and hip range of motion and isometric strength profiles in team handball players. This study also aimed to determine how range of motion and isometric strength profiles change following each fatiguing protocol and if these changes were still present after 24-hours.

Significance

By addressing the role of localized fatigue from throwing and aerobic fatigue on the jump shot this study will add to the literature in two ways. First, there is little research examining the results of fatigue on upper extremity movement patterns. Second, the research compares kinematic changes from localized fatigue as well as aerobic fatigue on jump shot kinematics and range of motion in team handball players. As a result, this study attempts to fill the research void on the role of fatigue on throwing mechanics.

Hypotheses

H01: Kinematic differences at the pelvis, trunk, shoulder and elbow during the jump shot will be present following both the aerobic and localized fatigue protocols.

H02: Fatigue will increase the kinetics about the shoulder and elbow during throwing.

H03: There will be decreased glenohumeral internal rotation and increased external rotation immediately following and 24 hours following each fatiguing protocol.

H04: Isometric muscle strength in the shoulder and hip will be decreased from baseline values immediately following each fatiguing protocol but will return to baseline within 24 hours.

Limitations

Limitations in this study are below:

1. Data for this study were collected on a small sample of elite team handball players on the same team.

Delimitations

Delimitations for the current study are below:

1. Shoulder and hip range of motion were measured passively thereby greater values were expected compared to active range of motion measurements.
2. Aerobic fatigue was induced running on a treadmill at 80% HRMax to fatigue.
3. Shoulder and hip internal and external rotation strength was measured using a hand held dynamometer.
4. Kinematic data were collected using a tethered electromagnetic tracking system.
5. Data collection occured in a controlled laboratory setting inside the Auburn University Sports Medicine and Movement Laboratory.

Definitions

Range of Motion: The amount of motion available at a specific joint is considered a joints range of motion.

Glenohumeral internal rotation deficit (GIRD): An adaptive change at the glenohumeral joint that includes an increase in external rotation and decrease in internal rotation in the dominant shoulder compared to the non-dominant shoulder.

Kinematics: A branch of mechanics that describes the motion of an object without regard to the factors that cause the motion. These include linear and angular displacements, velocities, and accelerations.

Kinetics: A branch of mechanics that examines the effects of forces on the motion of an object. Kinetics includes both forces and torques acting on an object.

Kinetic Chain: A series of linked, interdependent segments of the body that function in a proximal-to-distal sequence to impart a desired action on the most distal segment of the chain.[79]

Summation of Speed Principle: The speed of each body segment should be faster than that of the more proximal segment and each segment initiates independent movement when the adjacent proximal segment reaches its maximum angular velocity.

Lumbopelvic-Hip Complex: The area encompassing the pelvis and supporting the torso.[80]

Lumbopelvic Stability: The ability to prevent postural collapse of the vertebral column and return it to a stable position following movement.[80]

CHAPTER II

REVIEW OF LITERATURE

The purpose of this study was to examine the effects of fatigue on throwing kinematics, kinetics, and shoulder and hip range of motion in team handball players. Project objectives were, first, to establish baseline shoulder and hip range of motion patterns and isometric strength in team handball players as well as following aerobic and localized fatiguing protocols, and 24-hours following each fatiguing protocol. The second objective was to evaluate kinematic and kinetic changes during the performance of a team handball jump-shot following aerobic fatigue and localized fatigue protocols. The following chapter presents relevant literature pertaining to the appropriate facets of this project. Specifically, the following chapter was divided into seven sections while examining injury, fatigue, range of motion, isometric strength, proximal to distal sequencing, throwing velocity and accuracy, and movement variability during throwing.

Injury

Upper extremity injury epidemiology literature in team handball is lacking as most studies focus on acute lower extremity injuries.[81-87] In one of the few studies examining upper extremity injury, Seil et al. (1998) identified the shoulder as the most frequent site to experience overuse symptoms over the course of a year. Additionally, shoulder pain in elite German team handball players accounted for 40% of time lost injuries over a six-month period.[88,89] Based on the few studies that have examined upper extremity injury, it is clear that overuse symptoms affecting the shoulder occur in team handball players. The identification of the shoulder as a common site of pain can now lead researchers to further examine the kinematics of throwing and other common sport specific movements in an effort to understand the etiology of injury.

In one of the most recent injury studies, self-reported shoulder pain in 179 Norwegian female team handball players was examined.[88] The participants completed the Fahlström questionnaire, which assesses current perceived level of pain, previous pain, and pain on testing day on a Likert scale. Players who reported pain on testing day were also given the Western Ontario Shoulder Instability Index (WOSI) questionnaire. Results revealed that 36% of team handball players had current pain, 22% previously had shoulder pain, and 41% reported never having pain. Of those currently experiencing pain, 75% described their pain as gradual onset. While this study does provide insight into the prevalence of shoulder pain, a major limitation was that testing was performed during the preseason. Preseason practices are focused more on general conditioning rather than shooting on goal, which would place greater stress on the shoulder and most likely increase the prevalence of pain in team handball players.

Team handball injuries in players competing in the Men's Asian Handball championships in 2008 provides insightful data regarding injury mechanism and injury data by position.[1] This study tracked injury in teams from Iran, China, Qatar, and Lebanon, over the course of a year and had a sample size of 40 players. The incidence of injury was 20.7 per 1000 hours of competition while 0.96 injuries occurred per 1000 hours of training. The occurrence of acute injuries (82.54%) was significantly higher than chronic injuries (17.46%), with the ankle (23.8%) and the knee (15.9%) being the most commonly injured joints in this study. Though previous literature has demonstrated that the lower extremity is the most common injury site, it should be noted that these are acute injuries. Further, the most recent study has begun to suggest that the shoulder needs future research. Examining the underlying pathomechanics during sport-specific tasks are necessary to decrease the incidence of injury in team handball players. Fatigue may play a significant role in altering mechanics and leading to an increase in injury risks.

Fatigue

The effects of fatigue during both static and dynamic activities have been extensively examined in the literature.[7,10,11,13-30] However, the process of understanding the mechanical changes due to fatigue is hindered by the plethora of different fatiguing protocols used throughout the literature. Protocols can encompass isolated muscle fatigue, high intensity fatigue, central or localized muscle fatigue, and aerobic fatigue. Isolated fatiguing protocols do not address neuromuscular changes that occur and high-intensity protocols produce fatigue effects due to lactate buildup.[11] These fatiguing protocols are problematic because they do not adequately replicate the demands placed on the body during a sports match. Therefore this review of literature will focus on studies using functional, central body fatiguing protocols to better determine the most appropriate protocol to implement in an attempt to simulate the fatigued encountered by team handball players.

Currently the effects of fatigue on the kinematics of team handball movement patterns such as throwing are unknown. Functional central fatiguing protocols[7,10,11,13-15,19,21-24,29,30,90] are implemented more frequently than local fatiguing protocols recently. However there is very little consistency in the methods implemented when attempting to fatigue research participants. This lack of consistency makes it difficult to extrapolate the results across studies. The implementation of two fatiguing protocols that examine the effects of repetitive throwing and aerobic fatigue will help to determine the degree to which each of these factors effects jump shot kinematics and kinetics.

The effects of a short-term functional fatiguing protocol on lower extremity kinematics during a stop-jump and sidestep cutting task was recently examined in NCAA Division I soccer players by Cortes et al.[26] Kinematic and ground reaction force data were collected while participants performed five unanticipated stop-jumps and five sidestep cutting maneuvers prior to and immediately following a fatiguing protocol. Testing was implemented to produce unanticipated movement by using a software program that randomly generated the athletic task that alerted participants on which task to perform for a given trial. The participants were alerted of the chosen task once they ran past a laser beam two meters from the force plate upon which the chosen athletic task was to be performed. The fatiguing protocol was comprised of step-ups onto a box, L agility drill, and five countermovement jumps at 18-22% of their maximum vertical jump height.[26] The fatiguing protocol began with the step-ups and participants were required to step-up onto a box, 30 cm high, for 20 seconds at a pace of 200 beats per minute (bpm).[26] Next, the L agility drill was performed followed by five consecutive countermovement jumps. The final step of the protocol was performance of agility ladder drills at a pace of 220 bpm. This entire process was repeated 3 additional times with no rest in between sets. Participants reaching a heart rate of at least 85% of their estimated maximum heart rate were determined to be fatigued. The results of this study indicated that participants had significantly increased knee and hip extension between the tasks and that ground reaction forces were significantly different between the jump-stop and side-step tasks and fatigue conditions following fatigue. Knee rotation at initial contact also increased significantly following fatigue for both tasks. The authors propose that observed decrements in performance may be related to surpassing the anaerobic threshold as participants were at or above 86% of their maximum heart rate during the fatiguing protocol.[26] This suggests that lactic acid accumulation may have adversely affected performance in the tasks following fatigue. Fatigue for this study was induced within a 6-minute time frame and resulted in altered lower extremity kinematics. The ability to induce fatigue that alters kinematics, in such a short period of time is concerning. Team handball games are composed of two 30-minue halves and it is unknown if and when fatigue occurs and the resultant effects that fatigue has on the body and kinematics of performance.

One recent innovative fatigue study utilized a 90-minute soccer-specific aerobic fatigue test (SAFT) to examine hamstring and quadriceps maximal contraction.[10] Participants performed three dominant leg, maximal voluntary concentric contractions of the quadriceps and hamstrings as well as three eccentric hamstring contractions prior to and following fatigue. The SAFT is based on data obtained from match play in order to best replicate the fatigue response experienced by players during competition and was validated by Lovell et al.[91] This protocol consisted of two 45-minute periods with a 15-minute rest period between the two periods to simulate half time. The design of the agility course was centered around a 20 m shuttle run, with the incorporation of four positioned poles that the participants were required to navigate using agility movements.[10] The protocol required participants to either backpedal or sidestep around the first pole and then running forwards through the course while navigating the three poles positioned in the middle of the course. Protocol intensity was controlled through verbal cues on a CD and participants completed 1269 changes in speed and 1350 changes in direction throughout the duration of the protocol. A significant difference in peak eccentric hamstring torque by 16.8% and a 15% decrease in the strength ratio between eccentric hamstring and concentric quadriceps torque were observed following fatigue. The decline in eccentric hamstring strength from fatigue is commonly associated with muscle strain risk.[10,92,93] Therefore the results of this study may have implications for a predisposition of hamstring injuries late in soccer matches.[94]

Additionally, the effects of fatigue on technical performance have also been analyzed and suggest that fatigue decreases performance.[21,95,96] Russell et al.[21] examined the effects of 90-minutes of soccer-specific exercise on skill performance in 15 youth players. A multistage fitness test was performed to calculate running speeds that would be used during the soccer match simulation fatigue protocol and 15-meter sprint speeds were also measured on the first two visits. Participants were tested at the same time of day throughout the study and also performed the same 20-minute warm up consisting of running, dynamic stretching, and ball skills. The soccer match simulation protocol incorporated shooting, passing, and dribbling directed by audio signals. Participants completed three 4.5-minute blocks of three 20 meter walks, an alternating 15 meter sprint or 20 meter dribble test, a four second passive recovery period, five 20 meter jogs at 40% VO2max, one backwards jog at 40% VO2max, and two 20 meter strides at 85% VO2max.[21] A 1-minute passing test was measured prior to exercise, at half time, 15, 30, 45, 60, 75, and 90 minutes of exercise to assess performance. Passes from distances of 4.2 meters and 7.9 meters to a target in the center of the goal. Shooting consisted of 4 shots at a randomly assigned target in the corners of the goal. The dribbling task was comprised of dribbling around 7 cones as fast and accurately as possible. Throughout the protocol heart rate was monitored and ratings of perceived exertion were measured at the end of each block of exercise. Heart rate was divided into 4 zones based on intensity. Zone 1 was <70% HRmax, zone 2 70-79% HRmax, zone 3 80-89% HRmax, and zone 4 90-100% HR max. Water was provided to participants 10 minutes before the end of each half and after 15, 30, 60, and 75 minutes of exercise.[21] Statistical analyses revealed that shooting accuracy decreased by 25.5% following exercise and successful shooting percentage remained at 70% through the duration of testing. Passing precision was not significantly different following testing however the speed of the passes was significantly decreased by 7.8%. The protocol did not significantly alter dribbling procedure in this sample of participants. Whether similar results to this study would be observed in team handball is yet to be determined. It is likely that performance decrements in team handball specific movements would be observed following fatigue and therefore it is critical to examine the extent of fatigue on performance measures such as throwing.

Whereas the previous soccer study examined the effects of fatigue on soccer skill performance, it is also important to understand the changes in kinematics of common movements utilized in soccer as well. Up to 70% of anterior cruciate ligament injuries are non-contact in nature and side cutting has been identified as one of the most common mechanisms.[97] Fatigue related changes in lower extremity during sidestep cutting was analyzed in female soccer players by Sanna et al (2008). This study required participants to take part in three separate testing days with one week of rest scheduled in between the testing days. The first session was dedicated to having the participants perform a 20-meter progressive shuttle run to exhaustion. This test was used to determine the speeds necessary during the fatiguing protocol. The next session was a practice session in which participants performed maximal effort countermovement jumps and sidestep cutting maneuvers to become familiar with these movements for the testing session. The final session was the testing session in which kinematic data were collected and the fatiguing protocol was implemented. The testing protocol consisted of five sidestep cutting maneuvers and three countermovement jumps prior to and following the 60-minute fatigue protocol. The fatiguing protocol was implemented as a shuttle run divided into three blocks of 15 minutes and one final block of 10 minutes. Each block of testing included the following tasks: three walks, one sprint, three jogs, and three cruises. These tasks were repeated until time expired. The speeds at which the participants completed these tasks were monitored. Walking, jogging, and cruising speeds were monitored as 35%, 55%, and 95% of the VO2max speed, respectively and were measured using a stopwatch.[11] The last block only consisted of jogging and cruising alternatively. A rest period of three minutes was allotted to participants between each block.

Ratings of perceived exertion were recorded after each block of exercise. Following the completion of the protocol, three countermovement jumps were performed as a determinant of fatigue. The results of this study revealed that lower extremity kinematics during sidestep cutting are only partially altered as a result of this fatiguing protocol. These changes were most notable in transverse plane kinematics of the knee with increased internal rotation being observed. These fatigue affects were more subtle than the authors expected and while the participants reported RPE of fatigue and decreased countermovement jump power, they may have retained enough ability to complete the sidestep cutting maneuver because this task did not require maximum force to complete. The authors speculate that greater differences may have been observed if the cutting maneuver was unanticipated in nature.

Proprioception plays an important role in maintaining joint stability during movement. [15] Deterioration of proprioception due to fatigue may be a risk factor for injury in athletes.[15] Whole-body, and local fatigue effects on knee proprioception were previously examined by Miura et al.[15] in an effort to better understand the relationship between these variables. This study recruited 27 healthy male volunteers to reproduce knee joint position at a preselected flexion angle between 10-80°. Absolute error was calculated between passively and actively positioned knee angle over eight trials. These trials were completed prior to and following both fatiguing protocols. The local fatigue protocol consisted of 60 consecutive maximum concentric and eccentric contractions on an isokinetic dynamometer at 120°/second whereas general fatigue was elicited through five minutes of treadmill running at 10 km/hr at 10% grade.[15] The local fatigue protocol was implemented in the first testing session and then the general load protocol was performed two weeks later to eliminate the learning effects associated with the joint reposition trials. Local fatigue was assessed by peak torque changes and general fatigue was measured by heart rate. The general load fatigue protocol produced greater change in absolute angular error (57%) compared to the 13.3% error following the local fatigue protocol. The greater difference from general fatigue may be the result of deficiency in central processing of proprioceptive signals from central fatigue. Additionally, central fatigue may reduce motor control precision, interrupt muscle-stabilizing activity when resisting joint forces, and put the knee at risk for injury.[15] A limitation of the study was that only heart rate was used to assess general fatigue whereas blood lactic acid level or VO2max may have provided additional information on the status of fatigue. Heart rate was chosen to limit the time between fatigue and post-test knee angle reproduction.

The effects of localized and whole-body fatigue have also been examined during single-leg balance.[19] In a study of 10 healthy male and 10 healthy female participants to also see if gender differences in balance occurred following fatigue. Testing included three sessions and each were separated by a period of a week. The three sessions were control, localized muscle fatigue, and whole-body fatigue. During each session the participants performed 10, 10-second single leg balance tasks prior to each fatigue condition and five afterwards. Localized fatigue was invoked in the participants through repeated consecutive heel raises on a 20° slant board through the participants full range of motion. Participants performed the heel raises until they could no longer move through the range of motion and the same investigator throughout testing determined termination. The whole-body fatigue protocol was performed on a rowing ergometer to volitional fatigue. Participants were required to row at a pace of 66 beats/minute and fatigue was determined based on the participants' inability to maintain this cadence. The final protocol (control) required the participants to sit for five minutes before post-test balance could be re-measured. Both fatiguing protocols resulted in increased center of pressure displacement.

Medial/lateral sway was similar between fatiguing protocols however anterior/posterior sway was more sensitive to the whole-body fatiguing protocol. These results indicated that whole-body exercise is just a detrimental to balance as single-leg exercise and the authors suggest central processing plays a critical role in these observed differences.

As postural stability is an important factor to athletic performance, there is continued need to understand how this is affected by fatigue. The Balance Error Scoring System (BESS) is a valid and reliable postural stability test that is frequently implemented in concussion testing. Scores on this assessment have been shown to decrease following a fatiguing protocol of squat jumps, sprints, and treadmill running in club-level athletes.[98 22] Wilkins et al.[22] examined BESS performance following a functional fatiguing protocol in Division I athletes. All nine conditions of the BESS protocol were performed prior to and following the fatiguing protocol. These conditions included: double-leg balance, single-leg balance, and tandem stance on firm, foam, and tremor box surfaces. The conditions were counterbalanced for each participant so the effects from exertion would not be greater for one condition than the other.[22] The fatiguing protocol consisted of a circuit of seven exercises around a basketball court. Stations 1 and 7 required participants to moderately jog around the court for 5 minutes and 2 minutes, respectively. Stations 2 and 6 were three minutes of continuous straight-line sprint work. The final three stations (3-5) consisted of 2 minutes of push-up, 2 minutes of sit-ups, and 3 minutes of 12-inch step-ups. Ratings of perceived exertion were reported in an attempt to quantify exertion. These ratings were assessed before, at the midpoint, and after the fatiguing protocol exercises were completed. More errors were reported in the fatigue group than the control group, which was expected. Fatigue affected the tandem stance balance the most and it is evident from these results that postural stability was negatively affected by fatigue. Both central and localized fatigue may have altered the balance scores observed in this study even though the goal was to elicit central fatigue. It is possible that localized fatigue of certain muscles did result from some of the exercises utilized in the fatiguing protocol. When developing a fatiguing protocol it is necessary to be cognizant that central and localized fatigue may both factor in to decreased task performance.

Functional and isokinetic (localized) fatigue have also been examined for dynamic stabilization during a jump landing.[30] Time to stabilization (TTS) was measured to assess neuromuscular control during the jump landings. This is a quantifiable measure of postural stability that assesses postural sway when transitioning from a dynamic to static state.[30,99] In addition to TTS, peak ground reaction force and selected lower extremity kinematics were also examined. This study required three testing sessions with the first session collecting demographic information and assessing maximum vertical jump height ($Vert_{max}$) using a Vertec vertical jump tester. During the next testing session the participants performed three single-leg landing tasks before and after fatigue. The height at which they jumped was 50% of their $Vert_{max}$ as measured in the first session. The participants were instructed to begin the task 70 cm behind the force plate and to land from their vertical jump in the center of the force plate. When landing on the force plate the participants had to land on their stance leg, which was defined as the leg that they did not prefer to kick a ball with. Next, one of the two fatiguing protocols was implemented in a randomized and counterbalanced manner. The isokinetic fatiguing protocol required the participants to perform concentric and eccentric plantar flexion and dorsi flexion at speeds of $30°/s^{-1}$ and $120°/s^{-1}$ respectively until fatigue. When plantar flexion and dorsi flexion torques decreased below 50% for three consecutive repetitions then the protocol was complete. The functional fatigue protocol was comprised of the following 6 stations: Southeast Missouri

Agility drill, plyometric box jumps (height 31, 46, and 61 cm), side-to-side bounds (30 lateral jumps a distance of 0.6 meters), mini-trampoline jumps (30 repetitions), co-contraction arch, and a hop sequence. The time to complete this course was measured at baseline and for each time that the participants ran through. When the time to complete the course increased from 50% from the baseline, fatigue was considered reached. Post testing was then completed within one minute following completion of the last trial of the fatigue course. No significant differences in TTS, kinematics, and ground reaction forces were observed between fatiguing protocols. Peak vertical ground reaction force and TTS increased following both fatiguing protocols. Increased vertical ground reaction force may be the result of participants landing in a position of extension, as this has been associated with increased ground reaction forces.[99] Overall these results may indicate the need for a more strenuous fatiguing protocol and additional measures of fatigue in order to detect additional neuromuscular changes.[99]

The musculoskeletal system is responsible for attenuation mechanical shock during landing.[14] The inability of the musculoskeletal system to attenuate high loads during landing increases the probability of injury.[14,100] Decreased ability to attenuate large loads may occur once fatigue is present and this may lead to compensatory changes in joint mechanics. Coventry et al.[14] examined the changes in shock attenuation and joint mechanics previously in eight male participants. Kinematic and ground reaction force data were collected for a series of three maximal effort two-leg and three single-leg countermovement jumps onto a force plate. The highest value for the two-leg jumps was considered the participant's maximum jump height for the fatigue landing protocol (FLP). After these jumps were completed the participants were instructed to practice the FLP to become familiar with the landing tasks. The FLP consisted of two repeated cycles of landing exercises with each cycle lasting approximately 25 seconds.

Cycle one required the participants to hang from an overhead bar that was positioned at a height of 80% of their maximal jump height. The participants then let go of the bar and landed on their dominant leg. After landing, five maximal effort single-leg countermovement jumps were performed. The second cycle of exercise was comprised of 5 single-leg squats performed to 90° of knee flexion. This protocol was performed until the participants felt they could not 'stick' the next landing. Ratings of perceived exertion were recorded following each countermovement jump using a modified Borg category-ratio scale.[14] In addition, whole-body power output for the single-leg jumps were calculated for each cycle that the participant completed to assess general fatigue. From baseline to post-fatigue the amount of work performed at the hip decreased by 31% ($p = 0.08$), 59% at the knee ($p < 0.05$), and 35% at the ankle ($p < 0.05$). The amount of flexion at the hip and knee increased in the post-fatigue trials by 5.2° and 5.8°, respectively. These results differed from the study by Wikstrom et al.[30] in which the hip and knee were observed to be in a position of increased extension during landing. The increased hip and knee flexion observed in the current study likely contributed to the decreased peak ground reaction force following fatigue. Though landing strategy did change following fatigue, shock attenuation remained the same. While we know that lower extremity landing kinematics change following fatigue we do not know how these changes may affect upper extremity throwing mechanics.

The contributions that certain muscle groups make to movement performance following fatigue can be beneficial for researchers when selecting an appropriate fatiguing protocol. Reimer III et al.[23] examined the effects of ankle and hip muscle fatigue on single-leg postural control in healthy recreational athletes. This study was designed as three separate testing sessions separated by one-week intervals to limit learning effects from the testing. Session one was used to familiarize the participants with the testing protocol and collect demographic information.

Five practical postural control trials in which participants maintained single leg balance, while standing on a Biodex Stability System, were recorded. Immediately following these trials one-repetition maximum strength trials were performed for a single-leg squat and single-leg calf raise. Participants were allowed to select the starting weight for these trials and then weight was increased 10-20% until participants could only complete 5-7 repetitions of the exercise.[23] The second session involved testing postural control prior to and following either the proximal or distal muscle fatiguing protocol. The order of the fatiguing protocol was assigned by a coin flip for the first participant and then counter balanced for the subsequent participants.[23] The second fatiguing protocol was then performed during session three. For each fatiguing protocol the participants had to lift 65% of their estimated one repetition maximum until fatigue. Fatigue was reached when the participants could not maintain the standardized pace for three consecutive repetitions. For the ankle fatiguing protocol the pace was 33 beats/minute and for the hip fatiguing protocol the pace was 45 beats/minute. Fatigue of the ankle and hip musculature both resulted in significant changes in anterior/posterior stability and medial/lateral stability. Functional fatiguing protocols do not isolate specific muscle groups because of the closed kinetic chain nature and therefore neither muscle group examined in this study provided greater contribution to balance.[23] The inability to isolate specific muscle groups in functional protocols could be considered a negative factor when attempting to elicit fatigue for certain studies.

In addition to the effects of fatigue on kinematic data there is also a great need to understand the kinetics associated with fatigue. Altered kinetic patterns can further contribute to injury risk factors during dynamic activities. Landing from a jump is a common maneuver for athletes involved in many sports, including team handball. Madigan et al.[7] previously examined the role of fatigue on single leg landing kinematics and kinetics. The fatiguing protocol was designed to impart fatigue on multiple muscle groups and also be functional in nature so that it could better relate to activities outside a laboratory setting. Thus, the authors implemented a fatiguing landing activity (FLA). The FLA required alternating sequences of two single-leg landings and three single-leg squats.[7] Participants performed these activities until they felt their knee would collapse on the next landing. Following fatigue the results of this study revealed that decreased ground impact forces and increased knee flexion occurred during landing. These changes were speculated to be due to the fact that different fatigue patterns result in different biomechanical adaptations/compensations to enhance the stability of a joint.[7] These compensations may be related to a neuromuscular protective mechanism that alters kinematics to modulate impact forces during landing.[7] Changes in lower extremity kinematics following fatigue also likely contribute to upper extremity mechanics. As team handball involves both lower and upper extremity repetitive movements, detrimental changes in lower extremity mechanics may result in altered upper extremity mechanics.

Changes in landing mechanics have also been examined in participants with and without patellofemoral pain following fatigue.[13] Landing mechanics in participants with patellofemoral pain are of interest because the mechanics utilized may contribute to this condition. Peak isometric force was examined prior to and following exertion for lateral trunk flexion, hip abduction, and hip external rotation. Next, kinematic and kinetic data were collected as participants performed five consecutive single-leg jumps as high as they could. A functional fatiguing protocol was implemented immediately after the first five jumps and this protocol was comprised of a repetitive series of 10 single leg squats and five single-leg jumps. For the squat to count the participant was required to reach at least 60° of knee flexion and participants were instructed to jump as high as possible for the jump trials. Ratings of perceived exertion were obtained throughout the fatiguing protocol and a rating of 17 or greater was used to indicate fatigue. Following fatigue, lateral trunk flexion and hip external rotation strength decreased by 10% and hip abduction strength by 21%. Contralateral pelvic drop following fatigue was significantly greater in participants with patellofemoral pain than the control group ($p = 0.003$). Participants with patellofemoral pain also exhibited increased hip flexion and adduction but decreased hip internal rotation following fatigue compared to the control group. These changes in strength and landing kinematics in participants with patellofemoral pain following fatigue may increase their risk for lower extremity injury. In addition, these altered landing mechanics may not only be specific to this population but also populations with other lower extremity ailments as well. Team handball players competing with similar ailments to patellofemoral pain may exhibit altered kinematic patterns throughout the kinetic chain that are exacerbated once they reach fatigue. With a majority of kinetic energy production during dynamic overhead movement patterns being created at the lower extremity, any kinematic changes due to fatigue will alter the energy available at the upper extremity.

While the literature is largely focused on lower extremity fatigue, upper extremity fatiguing protocols are sparsely reported. In one of the few studies examining upper extremity fatigue, Tripp et al.[29] examined the effects of functional fatigue on multi-joint position reproduction in competitive baseball players. Multi-joint position reproduction was measured using an electromagnetic tracking device with the sensors attached to the sternal notch, deltoid tuberosity, and the third metacarpal of the dominant arm. Data were recorded for three different predetermined arm positions that the participants were asked to reproduce. The first position was the arm-cocking position at the point the forward acceleration of the arm would begin. Position two involved holding the arm at the position where ball release should occur and position three was the finishing point of the throwing motion. Participants were assigned to either the fatigue group or non-fatigue group initially however later in the day the non-fatigue group returned and completed the fatiguing protocol. The functional fatiguing protocol consisting of throwing a baseball 20 feet from a single-knee position at maximal effort every five seconds until fatigue. If the participant's velocity fell under 90% they were encouraged by the investigators to throw harder. Fatigue was measured, after every 20 throws, using the Borg ratings of perceived exertion scale and participants were deemed fatigued when they reached an exertion level of 15. This level of exertion has previously been deemed highly correlated with the metabolic responses of fatigue such as respiratory exchange, heart rate, oxygen consumption and blood lactate.[101] Participants reached or exceeded 15 after 61.5 ± 15.1 throws. Following fatigue, the error scores increased 10.5 ± 8.3. From an arm position standpoint the arm-cocked position produced significantly higher scores than the follow-through position ($p = 0.02$). Based on these results it is evident that sensorimotor system acuity decreased following fatigue. During prolonged training sensorimotor changes may be observed and therefore athletes should be monitored in an effort to decrease the risk of upper extremity injury.

Seliga et al. (1991) examined the relationship between exercise intensity and RPE values and found that scores increased significantly with a corresponding workload increase. The values of RPE that corresponded to a light workload were 9-10, a moderate workload was 11-12, and a heavy workload was 14-16. Additionally, RPE has been correlated with percentage of ventilatory threshold or VO2max.[22,102,103] RPE values ranged from 12-14.2 at 70% VO2max, 15.4-16 at 80%, and 18-18.2 at 90% VO2max in healthy, physically active males.[22,102] These findings suggest that A heart rate of at least 85% of the estimated heart rate max[26] and a RPE of at least 17[13] should be utilized to indicate fatigue in team handball players.

It is evident from the reviewed literature that fatigue can cause decrements in movement performance, postural stability, kinematics, and kinetics. The numerous protocols that have been used to induce central fatigue provide a wide variety of options for designing a protocol for team handball. The fast-paced, high-intensity sport of team handball will likely require an equally taxing protocol to induce fatigue in these athletes. Based on the reviewed literature it is evident that both a local and global/whole body protocol are needed to investigated the influence of fatigue on throwing kinematics and range of motion and muscle strength.

Range of Motion

The importance of range of motion in throwing has been thoroughly examined in the sport of baseball however the literature is lacking evidence for team handball. Due to the repetitive nature of overhead throwing, athletes participating in throwing sports often develop adaptive changes at the glenohumeral joint. Specifically, an increase in external rotation and decreased internal rotation compared to the non-throwing shoulder and this common phenomenon is known as glenohumeral internal rotation deficit (GIRD).[3,54,65,67-69,104] Shoulder adaptive changes have been speculated to be due to a contracture of the posterior capsule and the inferior glenohumeral ligaments[3,64,70-72] as well as retroversion to the humeral head.[3,54,65-68,105]

In one of the few studies assessing range of motion in team handball players the relationship between glenohumeral range of motion and throwing related shoulder pain was investigated.[3] A cross-sectional design involved 64 club league handball players and these players were divided into pain and non-pain groups. The pain group was classified as pain greater than one month and reproducible pain of at least 3 out of 10 and the non-pain group had no pain within the past three months. A significant difference between internal and external rotation between limbs was observed in the pain and non-pain groups. The non-pain group had significantly greater internal rotation of the throwing arm (39.4 ± 11.1°) compared to the pain group (33.3 ± 9.2°). Significantly greater throwing arm external rotation was recorded in the pain group compared to the non-pain group (108.0 ± 9.8° vs 102.4 ± 10.6°). GIRD in the pain group was 15° and external rotation gain was 10.3 and in the non-pain group GIRD was 6.7° while external rotation gain was 4.8°. No significant differences in non-throwing arm range of motion were observed between the pain and non-pain groups. Internal rotation in the pain group was 48.3 ±16.8° and 46.1 ± 11.2° for the non-pain group. External rotation of the non-throwing arm was 97.7 ± 8.0° for the pain group and 97.6 ± 6.2° for the non-pain group. The amount of GIRD observed in team handball players in this study was below the ranges previously reported in overhead athletes[3,51,54,62,74-76] with the pain group having 15 ± 12.6° while the non-pain group had a deficit of 6.7 ± 5.1°. In asymptomatic overhead athletes GIRD has been reported as 10-15° [3,51,54,62,74-76] and in symptomatic athletes 19-25°.[3,64,76,77]

Range of motion has also been assessed in elite Norwegian team handball players and significant differences between the dominant and non-dominant shoulders for both internal and external rotation were observed.[88] Total range of motion between the dominant and non-dominant shoulder were not significantly different in this sample. The Norwegian team handball players were classified into groups based on history of pain, however no significant range of motion differences between groups existed. While no significant differences were observed between groups it is important to understand range of motion values in team handball players for comparison purposes. Dominant arm internal rotation was 44.5 ± 8.5° in the group with no pain (n = 74), 45.0 ± 8.2° for the group with previous pain (n = 40), and 43.6 ± 7.1° (n = 65) in those team handball players currently experiencing pain. Non-dominant arm internal rotation values were slightly greater than the dominant arm for each group. Non-dominant arm internal rotation was 47.8 ± 8.8° in the group with no pain, 49.0 ± 6.3° for the group with previous pain, and 48.2

± 6.7° in those team handball players currently experiencing pain. External rotation in the dominant arm for the group with no pain was 106.1 ± 9.5°, 105.0 ± 8.1° for the group with previous pain, and 103.6 ± 8.9° for the players with current pain. As expected non-dominant arm external rotation was less than that of the dominant throwing arm with the no pain group displaying 102.7 ± 9.0°, previous pain 100.1 ± 7.4°, and current pain 101.5 ± 9.2°. Further research is needed to better understand range of motion and injury etiology in team handball players with special attention focused on the role of humeral retrotorsion in team handball athletes and its effect on range of motion. In addition to more data regarding glenohumeral range of motion, hip range of motion data should also be obtained.

As a compensation for range of motion deficits at the hip, greater forces at the shoulder may occur.[48,106] Therefore restricted hip range of motion may have implications on the range of motion at the shoulder. Hip range of motion has been examined in baseball, softball, and tennis players but has not been reported in team handball players. Scher et al.[107] examined the relationship between hip and shoulder range of motion and shoulder injury in professional baseball players. Data were collected on twenty-nine pitchers and 28 position players who played baseball at least three days per week. Range of motion data were collected prior to the season using a goniometer with a bubble level. Goniometric measurements are the gold standard method for collecting range of motion data, when performed by the same tester.[43,47,48,63,108-112] The measures tested were randomized and included shoulder internal rotation, shoulder external rotation, hip internal rotation, hip external rotation, and hip extension. All shoulder range of motion and hip extension range of motion were collected with the participants supine while hip internal and external rotation was collected with the participant in a seated position. Injury data were collected through a questionnaire that included questions regarding past medical history of shoulder, hip or elbow injury, skill level, throwing arm, and positions played. For the purpose of this study an injury was defined as a problem within the previous year that required more than two days of non-play or being on the disabled list and restricted from throwing.[48] When comparing hip and shoulder range of motion between baseball pitchers and position players, with and without a history of shoulder injury, the only significant difference observed between the groups, was non-dominant hip internal rotation in position players.[48] Position players without a history of shoulder injury had approximately 5° greater non-dominant hip passive internal rotation than players with a history of injury. The authors speculated the difference to be from the throwing methods used by position players and the internal rotation of the non-dominant leg helping to slow the player's body during the follow through phase. It was hypothesized that decreased non-dominant hip internal rotation dissipates less force through the trunk therefore increasing the forces at the shoulder.[48]

Range of motion at the hip and hip abduction strength have similarly been examined in healthy baseball pitchers and position players by Laudner et al.[59] Forty baseball pitchers and 40 position players, injury free for the past two years participated in this study. A digital inclinometer was used to measure range of motion for hip internal and external rotation and a hand held digital dynamometer was used to measure gluteus medius strength. The lead leg was defined as the leg opposite to the throwing arm. Hip range of motion was measured with the participant seated on a table with an examiner stabilizing the femur while another examiner passively rotated the participant's shank. The end of range of motion was the first sign of tissue resistance.[59] Gluteus medius strength was obtained with the participant side-lying and the leg in slight hip abduction, extension, and external rotation. Force was applied by the examiner, in a downward direction of adduction, against the participant as they attempted hip abduction.

Maximal gluteus medius contraction took place until the examiner was able to break the test position. The results found that position players had greater hip internal rotation and gluteus medius strength in the trail leg compared to pitchers. Internal rotation of the trail hip is necessary to prepare for positioning of the lead leg.[59] Limited internal rotation of the trail leg may lead to a player throwing across their body while limiting the use of energy from the lower extremity.[59,73] The gluteus medius functions to prevent downward tilt of the contralateral pelvis and generating force to propel the body towards the target and lengthening the stride during throwing. Similar range of motion patterns may be observed between positions in team handball. Back court players (right, center, and left back) may have altered range of motion compared to the wing players and furthermore those players with a history of upper extremity injury may have different patterns of range of motion than their non-injured counterparts.

Similar internal rotation results in the stance (trail) leg were originally observed in 16 college baseball pitchers as well.[113] Both hip internal rotation and extension were significantly greater in the stance leg compared to the kick leg ($p < 0.01$). During the wind-up of the baseball pitch, the stance leg externally rotates to position the kick (lead) foot so that the pelvis and trunk can rotate over the kick leg. As the pelvis and trunk rotate over the kick leg there is internal rotation about the stance leg. Internal rotation of the stance leg provides efficient kinetic energy transfer to the trunk, and arm.[113] It is currently unknown if increased internal rotation exists in the stance leg of team handball players as it does in baseball pitchers. Team handball is a fast-paced game with players having to make quick passes and shots on goal. This decreased time to pass and shoot may result in different patterns of range of motion compared to baseball pitchers who do not have the same time and/or movement constraints.

With the asymmetric hip loading patterns that are present in pitching it is expected that sport-specific and extremity-specific range of motion adaptations are likely.[78] Ellenbecker et al.[78] examined hip internal and external range of motion in 147 elite tennis players and 101 professional baseball pitchers. Range of motion was measured actively and utilized reflective markers during digital photography. Dominant hip internal rotation in the pitchers was 23 ± 8.3° and 22 ± 8.9 in the non-dominant hip. External rotation of the dominant hip was 35 ± 9.1° and 34 ± 10.6° for the non-dominant hip in the professional pitchers. Even though no side-to-side differences were observed, 17% of pitchers had greater than 10° difference in internal rotation and 42% had greater than 10° difference in external rotation between sides.[58,78] These data reveal that there is significant variability between extremities however these differences are consistent with normal range of motion values. In uninjured pitchers, bilateral hip range of motion should be symmetrical. Range of motion values that are asymmetrical may indicate hip osteoarthritis or injury.[78,114] Bilateral hip range of motion may be altered in team handball players as a result of the repetitive jumping and other large loading patterns present in the sport.

Large mechanical loads are placed on the hip joint in team handball due to cutting movements, rapid stopping, and acceleration.[114] These movements may lead to osteoarthritis of the hip, which is characterized by reduced range of motion, pain, and disability.[114] L'Hermette et al.[114] examined passive range of motion, the prevalence of hip osteoarthritis, and hip pain in retired elite team handball players. A match control group, by age and weight, were selected for comparison. Risk factor data were obtained through a questionnaire that included questions such as date of birth, first official elite game, retirement from elite team handball, lifetime occupational loading, years and hours/week of training, lower limb pain or injury, family medical history, and current medical conditions of lower limb joints.[114] Weight bearing radiographs were taken on all participants to determine if osteoarthritis was present in their hips. Passive hip flexion, extension, medial (internal) rotation, and lateral (external) rotation measurements were also examined to determine if range of motion is altered in participants with osteoarthritis. Results indicated that hip osteoarthritis was high in former elite team handball players with 60% of the participants suffering from this condition compared to 13% of the control group. The high rate of osteoarthritis in team handball players is greater than the occurrence presented in other high risk sports such as soccer (32%), fencing (35%), rugby and tennis (16%).[114] The results of this study support the theory that the type of sport, length of playing time, and playing level all contribute to early osteoarthritis. Decreased range of motion was noted in hip flexion and internal rotation in participants with osteoarthritis. These values along with increased hip extension, abduction, and lateral rotation are likely due to the repetitive movement specific to team handball. It is evident that hip range of motion is altered in team handball players and these alterations may be early indicators of osteoarthritis in this population of athletes.

Sprinting, jumping and kicking in soccer place high loads and torsional forces on the hip joint and its surrounding stabilizing structures.[115] Degenerative changes in the hip, such as osteoarthritis, are caused by low-grade repetitive trauma and early signs of osteoarthritis may be present in non-injured/pain-free players. Osteoarthritis causes reduced hip range of motion and may therefore be an indicator of this condition. Early degenerative changes and hip joint range of motion have been examined in professional youth and senior team football (soccer) players with age-matched controls to better understand range of motion adaptations. Range of motion was measured bilaterally for hip internal rotation, external rotation, flexion, abduction, and extension in 20 youth footballers, 20 senior team players. Hip range of motion was observed to be similar between both groups of football players with football players exhibiting reduced internal rotation and abduction, which may indicate that this pattern of range of motion is sport specific. Hip internal rotation was lowest in the senior players groups compared to all of the other groups and the authors believe that this may indicate early degenerative changes in the joint. The hip joint capsule may also have increased tightening due to microtrauma associated with increased time playing the sport.[115] While the true etiology of range of motion differences is unknown it is believed that if these changes are not corrected players may be pre-disposed to abnormal hip cartilage degeneration. Because abnormal range of motion patterns at the hip can predispose an athlete to abnormal degradation, analyzing range of motion regularly may allow for clinicians to address these deficiencies by restoring normal patterns of motion. Examining range of motion patterns in team handball players prior to, immediately following, and 24-hours post fatigue will allow for improved training programs to be developed that address common motion patterns at the hip.

Hip disorders are prevalent among elite athletes especially those in power sports and throwers.[58,114] During overhead throwing the hip is the primary joint that initiates spinal rotation[58] therefore any deficiency in hip motion can also affect the transfer of energy through the spine. Robb et al.[58] examined the relationship between hip range of motion, pitching biomechanics and ball velocity in 19 professional baseball pitchers. Passive range of motion data was collected for hip adduction, abduction, internal rotation, and external rotation. The right hip was defined as the dominant hip for each right handed pitchers. Kinematic data were collected using digital cameras and reflective markers and the parameters analyzed were maximum pelvic angular velocity, upper torso angular velocity, and trunk separation.[58] Range of motion was significantly less in the non-dominant hip compared to the dominant hip for all measures except abduction in this sample of pitchers. This difference suggests a femoroacetabular rotational deficit similar to GIRD in the shoulder.[58] These results contradict Ellenbecker et al.[78] in that they observed no differences in range of motion bilaterally in baseball pitchers and tennis players. However their study examined active range of motion instead of passive hip range of motion. Passive range of motion assesses the entire physiologic range of the hip, leading to the identification of abnormal arthrokinematics and soft tissue tightness.[58] Active range of motion only assesses functional range of motion about a joint and results in smaller values of measurement. Non-dominant hip rotation that is less than the dominant may result in compensatory and excessive motion in the spine and shoulder to allow for motion and maintain arm and ball velocity.[58] Total hip arc of rotation (internal rotation + external rotation) was significantly correlated with ball velocity ($r = 0.50$, $p = 0.04$). Significant correlations between hip range of motion and trunk separation velocity, pelvic orientation, and stride length were also observed. The significant relationship between hip range of motion and trunk separation velocity suggests the larger ranges of hip motion facilitate increased pelvis angular velocity. More range of motion in the dominant hip resulted in an opened orientation of the pelvis at foot contact potentially resulting in premature transfer of kinetic energy up the kinetic chain.[58]

Alterations in shoulder range of motion due to throwing may have injury implications.[60] Range of motion profiles in upper extremity athletes have been thoroughly examined in the literature however changes in range of motion following throwing are just beginning to be examined.[60] Reinold et al.[60] were the first researchers to examine shoulder and elbow range of motion values in baseball pitchers prior to and following pitching. Data were collected on 67 professional baseball pitchers during the first two days of spring training. Passive shoulder internal and external rotation and elbow flexion and extension were the measures examined in this study. Measurements were taken prior to warm-up and then after a standardized warm-up and throwing protocol. The protocol included 5 minutes of jogging, generalized full-body stretching for 15 minutes, long toss (27.4 m) for 10 minutes, and then full intensity pitching for 50-60 pitches. Measurements were then completed again within 30 minutes of the conclusion of pitching and a final time 24 hours after the initial testing. The results indicated a decrease in dominant shoulder internal rotation (-9.5°), total motion (-10.7°), and elbow extension (-3.2°) after pitching that remained at 24 hours.[60] These results are thought to be explained by soft-tissue adaptations from the high level of eccentric muscle contractions during pitching.[60] The authors speculated that the decreased range of motion may be a normal physiological response to pitching and if pitching continues before values return to baseline the pitchers may be more susceptible to shoulder injury. By gaining an understanding of the acute effects of throwing in team handball injury prevention stretching programs can be designed to address any subsequent deficits that occur following practice or a game. Furthermore, identifying how long after activity decrements in range of motion persist will be valuable for training protocol development.

Only one study to date has examined range of motion over the course of an athletic season in any sport.[116] Dwelly et al.[116] examined glenohumeral range of motion in collegiate baseball and softball players at three time periods over the course of an athletic season. The three time periods were pre-fall (last week of September), pre-spring (second week of January), and post-spring (first week of May). Glenohumeral internal and external rotation was measured twice bilaterally using an inclinometer and the average was then calculated to determine range of motion. No significant differences were observed in internal rotation across the three time periods however a trend in decreased internal rotation was observed between pre-spring and post-spring. External rotation increased 11° in the dominant arm from pre-fall to post-spring. The increased external rotation gains are believed to be a secondary result of the external rotation demands during throwing. Maximal external rotation occurs during the late cocking phase and is required to maximize internal rotation velocity of the shoulder.[64,116] The results of this study are clinically relevant because monitoring changes in range of motion may identify throwing athletes at risk for upper extremity injury.

Range of motion adaptations that are present in the shoulder are one of the causes of shoulder pain in overhead athletes.[3,54,105,117,118] It is believed that repetitive overhead movements lead to microtrauma and resultant contracture of the posterior capsule and inferior glenohumeral ligament of the shoulder, which results in GIRD.[3,64,70,75,76] While the two previous studies examining the prevalence of GIRD in team handball players have produced conflicting results[3,88] no current study has aimed to examine changes in range of motion of the hip and shoulder following aerobic fatigue or localized fatigue of the arm from throwing. Furthermore, range of motion data for the hip in team handball players has not been reported in the literature.

Isometric Strength Profiles

Decreased shoulder range of motion and muscle strength is believed to be contributing factors to shoulder injury in overhead athletes.[119-121] The role of the external rotators during follow through of an overhead movement is to slow the arm and maintain the humeral head in the glenoid fossa.[119] The role of shoulder isometric strength in overhead movements such as serving or throwing may provide clinicians with valuable data to improve strength and conditioning programs. Shoulder rotation range of motion and isometric strength in elite badminton player have previously been examined.[119] Passive shoulder internal and external rotation measures were obtained with the shoulder abducted to 90° using a standard goniometer. Shoulder internal and external rotation strength was measured using a hand held dynamometer.

The participant was positioned supine on a table with their shoulder abducted to 90° and 0° of rotation in the scapular plane. The elbow was flexed to 90° and the examiner stabilized the proximal humerus during measurement. To measure external rotation strength the participant was supine with the shoulder positioned at mid-range external rotation and they externally rotated against a hand held dynamometer that was located proximal to the ulnar styloid. The same methods were utilized to measure internal rotation strength except the participant internally rotated their shoulder to produce an isometric contraction. An isometric contraction was required to last 5-6 seconds at maximal effort. In order to reduce the effects of fatigue a rest period of 20-30 seconds was allotted between each of the three testing trials. The mean of three trials was recorded and used for statistical analysis. The results indicate that total range of motion was reduced on the dominant side compared to the non-dominate side with males having less internal rotation and females having decreased external rotation. Excessive or reduced range of motion may contribute to shoulder instability and impingement therefore understanding range of motion patterns is paramount for developing injury prevention protocols in athletes. From a strength perspective, male badminton players were stronger than females in all measurements except dominant side internal rotation. The female players had a tendency to be weaker in external rotation in their dominant arm compared to their non-dominant arm however this difference was not statistically significant. The gender differences observed were believed to be due to insufficient external rotation strength training in elite female players compared to their male counterparts. While the focus of the proposed study is to examine male team handball players, the differences in strength between genders in badminton may limit the generalizability of the proposed study results to female players.

The shoulder experiences high loads during throwing and the ability to use strength measurements to identify risk for injury could be critical.[122] Byram et al.[122] examined prone shoulder internal and external rotation strength as well as seated internal and external rotation strength in professional baseball pitchers. Type of injury and treatment were also tracked throughout the season for each participant using an ordinal scale of no injury (0), injury not requiring surgery (1), or injury requiring surgery (2).[121,122] Only injuries linked to kinetic chain dysfunction during throwing were analyzed. Median strength measurements for the sample of pitchers were 35 kg for internal rotation, 36 kg for prone external rotation, 26 kg for seated external rotation, and 28 kg for the supraspinatus strength. No significant associations between preseason strength and overall likelihood of injury were present. However, the estimate of injury requiring surgery decreased significantly between players at the 5th and 95th percentiles for prone ($p = 0.003$) and seated external ($p = 0.048$) rotation and supraspinatus strength ($p = 0.006$).[122] The internal and external rotators of the shoulder help to provide stability to the inherently unstable shoulder joint. During the deceleration phase of the throwing motion the external rotators must eccentrically contract to dissipate the kinetic energy that is generated from the internal rotators during the cocking and acceleration phases of throwing.[122] Maintaining balance between the internal and external rotators helps provide stabilization to the shoulder and training the relatively weak external rotators and supraspinatus can improve muscular balance in pitchers.[122] It is clear that the shoulder external rotator muscles are inherently weaker in baseball pitchers and the same may be true in the dominant shoulders of team handball players. In addition, if muscular strength imbalances exist in team handball players then they may be more susceptible to upper extremity injury.

Professional baseball pitchers experience high loads about the shoulder and strength of the stabilizing musculature is critical for injury prevention. While previously described research has identified weakness in the external rotators compared to the internal rotators, strength and range of motion have also been compared in professional baseball pitchers.[123] Decreases in both range of motion and strength are believed to be due to repetitive microtrauma and eccentric overload and the resultant muscle-tendon injury that occurs.[123] Donatelli et al.[123] examined passive shoulder internal and external rotation range of motion as well as internal rotation, external rotation, supraspinatus, serratus anterior, and lower trapezius muscle strength in minor league baseball players. Significant differences in internal and external rotation were observed bilaterally in minor league baseball pitchers. External rotation was greater and internal rotation was decreased in the dominant arm. Decreased internal rotation has been linked to increased anterior and superior translation of the head of the humerus.[123,124] While external rotation increased in the dominant arm the strength of the external rotators was weaker than the non-dominant arm ($p < 0.01$). The combined range of motion and strength differences observed in the dominant arm of pitchers may further contribute to upper extremity injury. Decreased external rotation strength and internal rotation range of motion is believed to cause the large tensile forces that act on the rotator cuff musculature leading to tears. The tensile forces act about the shoulder during the follow-through phase of throwing as the shoulder attempts to resist distraction, horizontal adduction, and internal rotation.[123]

Range of motion, muscular strength, and injury have also been examined in adolescent baseball pitchers to establish if adaptations exist in the dominant arm and if these adaptations differ between pitchers with and without injury.[75] Twenty-three adolescent baseball pitchers had upper extremity strength and range of motion measured prior to and following their baseball season. Isometric muscular strength was measured for the lower trapezius, middle trapezius, rhomboids, latissimus dorsi, supraspinatus, internal rotators, and external rotators using a handheld dynamometer. Active glenohumeral external and internal rotation range of motion was measured bilaterally using a goniometer. Following the conclusion of the baseball season, participants completed a questionnaire to assess playing statistics and injury incidence. The information gained from the questionnaire was the following: number of games pitched, number of games pitched with shoulder or elbow pain, magnitude of pain, percentage of practices with shoulder or elbow pain, pain during non-baseball activities, if pain affected performance or mechanics in a game, and if the pain required medical attention.[75] In adolescent pitchers, significantly greater external rotation (11 ± 10°) and less internal rotation (13 ± 11°) were observed in the dominant arm. Range of motion did not differ in pitchers with or without pain however pitchers experiencing pain had 4° less total range of motion about the shoulder. From a strength prospective, pitchers with prior pain had greater internal rotation strength than those without pain and lower relative strength in the supraspinatus and middle trapezius.[75] The results are believed to indicate that pain is associated with muscle strength imbalances between the internal rotators and the muscles responsible for slowing the arm and stabilization of the shoulder.[75] These data support previous theories that increased internal rotation strength without rotator cuff and scapula stabilizing muscle strengthening places the shoulder at risk for injury.[120] By establishing the relationship between range of motion and strength adaptations in the dominant throwing arm is different in pitchers with and without injury, deficits may be able to be identified early to reduce the risk of injury in throwing athletes. Similarly, team handball players who exhibit muscular imbalances between the internal and external rotators of the shoulder may need to be prescribed additional strengthening exercises to help reduce the risk of shoulder injury.

Team handball players make numerous throws throughout practices and games however it is currently unknown how shoulder and hip strength change following performance. Upper and lower extremity muscle strength and range of motion has been examined following fatigue in baseball pitching.[125] One to two days prior to pitching, range of motion and isometric strength testing was performed for each participant. Strength testing was performed as break tests with a hand held dynamometer for shoulder flexion, abduction, adduction, scaption, internal rotation; external rotation, hip flexion, abduction, adduction; middle trapezius, lower trapezius, rhomboids; and grip strength. The pitchers pitched in a live game before post-test measurements were taken to determine if range of motion and strength change after pitching. The results revealed that supraspinatus strength in the dominant arm was 12.6% less than the non-dominant arm and internal rotation was 9.9% greater. No significant differences in supraspinatus or external rotation strength were observed following pitching leading the authors to believe that this muscle is fatigue resistant due to the repetitive eccentric contractions that are made during pitching. While no differences were observed in the supraspinatus and external rotators, all other shoulder strength tests showed decreases following pitching. The greatest observed difference was in the internal rotators, which decreased 18%. This decrease in strength following pitching indicates that the internal rotators experience high performance demands during pitching.[125]

It is clear from the literature that decreases in muscular strength of the shoulder occur following extended throwing performances, however, strength profiles of the hip have been largely ignored. Measuring isometric shoulder and hip strength profiles will advance the purpose of this study by providing normative data for team handball players that can be used in future studies as a comparison across different levels of competition. These data will also provide normative data for strength changes that may occur as a result of running and throwing to fatigue. If shoulder and hip strength profiles decrease once fatigue has been reached a player may be vulnerable to injury as other muscles may be required to provide increased activation and force production to maintain desired athletic performance.

Proximal-To-Distal Sequencing

Sequential segmental timing of movement plays a key role in producing efficient upper extremity motion during throwing. Proximal-to-distal sequencing is the most efficient sequencing pattern in activities such as pitching, kicking, and overhead serves. Research has begun to delve into the sequencing patterns in team handball throwing [126-129] to see if similar patterns exist and varied results have been reported. Ideally, with proximal-to-distal sequencing, the kinetic energy developed in the proximal segments of the kinetic chain (legs, hips and trunk) should be transferred to the more distal segments of the shoulder, elbow, wrist, and hand. Proximal-to-distal sequencing should follow the summation of speed principle introduced by Bunn[130] in which a segment begins moving apart from the more proximal segment, at the instant of greatest speed of the preceding segment and reaches a maximum speed greater than that of its preceding segment.[131] The earlier studies by Jöris et al.[126] and Herring & Chapman[129] reported temporal proximal-to-distal sequencing in the team handball throw.[132] However recent research has questioned those findings and reported proximal-to-distal sequencing does not exist in the team handball throw because maximum linear velocity of the shoulder occurs following the maximum velocity of the elbow. [127,128,133]

Fradet et al.[127] examined proximal-to-distal sequencing in six male team handball players performing a standing throw from 9-meters. In this sample of players, upper torso rotation reached maximal velocity after the arm began moving forward. To obtain maximal arm velocity, the humerus should begin accelerating once the torso reaches maximal velocity. [127] The authors speculate that proximal-to-distal sequencing may not exist in the team handball throw as it does in other throwing activities. The altered sequencing may, in part, be due to the conditions that team handball players are subjected to during competition such as opposition from defensive players and a goalkeeper. Many team handball players are not instructed by coaches on throwing technique and are required to figure out the best way to effectively throw on their own which may also help to explain the lack of proximal-to-distal sequencing observed. [127]

A study by van den Tillaar and Ettema[132] was performed to better examine proximal-to-distal sequencing while taking into account both segment and joint movements of the entire body during the standing throw. This study examined throwing mechanics in 11 top and first division Norwegian team handball players with 13 ± 3.3 years of experience. Based on the maximal angular velocity of the joint movements proximal-to-distal sequencing did not occur during the standing throw. Knee extension angular velocity occurred after pelvis rotation and some trunk movements during the standing throw. Maximal wrist flexion angular velocity occurred prior to elbow extension and shoulder internal rotation as well as shoulder horizontal adduction occurred before movement of the trunk further supporting that proximal-to-distal sequencing does not occur in this type of throw. The early wrist flexion velocity prior to elbow extension is speculated to be the result of the bi-articular characteristics of the wrist flexors in that these muscles also contribute to elbow flexion as well.[132] Therefore elbow extension may initiate early wrist flexion.[132,134] The timing sequence of maximal linear velocity also did not follow proximal-to-distal sequencing with the sequencing going from the lower extremity, arm, trunk, forearm, hand and finger. The initiation of joint movements however almost followed a pattern of proximal-to-distal sequencing. Knee extension was the only variable that did not occur at the proper time as it occurred late in the throw. The sequencing began with trunk movement, followed by shoulder movement, internal rotation of the shoulder, elbow extension and movement of the hand. The authors believe that even though the initiation of sequencing was slightly altered with knee extension occurring later in the motion, that this alteration is irrelevant because the knee is likely extending to help stabilize the leg and hip. The timing of hip negative acceleration and maximum knee extension velocity occurred almost at the exact time (0.136 ± 0.025 s and 0.137 ± 0.02 s respectively), which is why the author believes these two factors are related and that knee extension velocity can be ignored in the sequencing of events.

Proximal-to-distal sequencing has also been examined across skill levels during the standing throw with a three-step run-up.[135] This study divided 24 participants into three groups: less experienced players (1.6 ± 0.9 years of experience), experienced players (6.6 ± 2.0 years of experience), and elite players (13.4 ± 2.1 years of experience). The standing throw with run-up was chosen to best represent throws that backcourt players commonly make during the course of a game.[136] Maximal angular velocity of pelvis rotation occurred before maximum trunk rotation and trunk flexion angular velocity. [135] Also of interest is that maximum angular velocity of the pelvis, for all skill levels, occurred 0.10-0.12 s prior to ball release. Both elite and experienced players displayed proximal-to-distal sequencing for pelvis rotation, trunk rotation, trunk flexion, shoulder internal rotation, and forearm pronation. Maximal elbow extension velocity (0.009-0.015 s before ball release) occurred prior to shoulder internal rotation (0.003-0.009 s after ball release), wrist flexion and forearm pronation occurred simultaneously.[135] A significant difference was found between elite and less experienced players for timing of maximum pronation of the forearm and the authors speculate that the pronation that occurs closer to ball release improves momentum transfer to the ball.

Proximal-to-distal sequencing with the sequence of event going from the lower extremity, arm, trunk, forearm, hand and finger maximizes ball velocity. The most recent studies examining sequencing in the standing team handball throw have not observed proximal-to-distal sequencing. Nevertheless, the initiation of joint movements followed a pattern of proximal-to-distal sequencing. Proximal-to-distal sequencing has yet to be examined during a jump shot, which will likely exhibit different sequencing and initiation patterns than the standing throw because a majority of the shot is performed in the air. This study will not only assess proximal-to-distal sequencing patterns in the jump shot but will also determine if sequencing patterns are affected by fatigue.

Throwing Velocity

Ball velocity when throwing a team handball has been examined frequently in the literature because this factor has been identified as keys in successful throwing.[5,128,137-142] Ball velocity is the result of throwing technique, segmental timing, and muscular strength and power.[6,126,138,141,143] While ball velocity is important to scoring a goal in team handball, many of the previous studies did not take into account the role a defender has on the offense shooting at the goal. Throwing velocity and accuracy may not be the only alteration during a shot, but the kinematics a shooter implements may be altered as well when a defender is present.[141] Rivilla-Garcia et al.[141] examined the effects of opposition on jump throw velocity in elite, amateur, and adolescent team handball players. Each participant completed maximal velocity shots on goal with varying degrees of difficulty. The experimental situations included a jump throw from 9 m with and without opposition from the goalkeeper and a defensive player. Ball velocity without opposition was 3.9% faster than with the goalkeeper present and 8.6% faster than the throwing velocity when a goalkeeper and defensive player were present. The relationship trade off between accuracy and velocity, when the information processing demand is increased, may explain decreased velocities when opposition was present.[141] The authors believed the increased visual stimuli when the goalkeeper and defensive player were present increased the amount of information that the players had to process in order to make a successful shot on goal.

As similar study examined throwing capacity between senior and U-18 men team handball players.[144] The testing procedure for this study included throwing a heavy medicine ball (3 kg), a light medicine ball (0.8 kg), throwing a standard size team handball without opposition, and throwing a standard sized team handball with the opposition of a goalkeeper. The medicine ball throw trials were used to measure distance of the throws while the other two throwing conditions were focused on velocity. As expected, the senior players values for all tasks were greater than the U-18 players. Throwing velocity for the senior players without opposition was 25.19 ± 2.14 m/s and the U-18 was 21.67 ± 2.08 m/s. When a goalkeeper was present, the senior players had a throwing velocity of 23.22 ± 2.63 m/s and the U-18 threw 20.58 ± 2.06 m/s. The authors speculated the increased velocity in the senior players was the result of better conditioning and a more experienced throwing technique.

The main kinematic contributors for throwing velocity have been reported to be shoulder internal rotation and elbow extension[138,139] and better throwers have higher shoulder internal rotation and elbow extension velocities.[138] While many studies have found that men throw at a greater velocity than women[126,127,139,145-150] the factors behind the differences are not fully understood. It has been reported that body anthropometrics such as height, weight, muscle mass, and upper extremity isometric strength[139] contribute to some of the difference in velocity but it is unknown if the kinematic contributions play a role between genders.

A study by van den Tillaar & Cabri[151], aimed to examine throwing kinematics and ball velocity differences between genders in elite team handball players to better understand throwing performance. The standing throw from 7m was analyzed in 11 male and 11 female team handball players. As hypothesized by the authors, male players had significantly higher ball release velocities (21.1 vs. 19.2 m/s) and liner velocities of the wrist (13.0 ±1.3 vs. 11.5 ±1.2 m/s) and hand (16.9 ± 1.9 vs. 15.2 ± 1.4) than females. These differences in linear velocities were in line with what has been previously observed in both male and female team handball players.[126,134,145,146,148] While these differences were observed between genders, no kinematic differences were observed. The results of this study provide solid evidence that throwing kinematics are similar between genders which may be a result of training and coaching throughout the sports. Only elite level players were examined in this study so it is still unknown whether kinematic differences between genders are present in less skilled team handball players.

Overall, advanced levels of competition have been observed to have greater throwing velocity than less experienced team handball players. While these results are largely expected when no defensive opposition is present, it is rare for an offensive player to not have defensive opposition in a game. Studies examining throwing velocity with and without opposition have consistently observed a decrease in ball velocity with an increase in defensive opposition. How ball velocity changes following fatigue has yet to be examined in the literature therefore this will be the first study to examine fatigue on ball velocity. It is hypothesized that jump shot velocity will decrease following both localized fatigue from throwing and aerobic fatigue. If ball velocity does in fact decrease once a player reaches fatigue segmental compensations may also be observed as the player attempts to produce maximal ball velocity.

Movement Variability

While it is clear throwing velocity and accuracy are important factors for a successful shot in team handball, understanding movement variability between competition levels is also important for performance. To date, movement variability between skill and competition levels in team handball has only been examined in two studies.[6,152] Wagner et al.[6] examined variability between low-skilled players, skilled players, and high-skilled players performing the standing throw, standing throw with run-up, and jump throws. Significant differences between throwing technique and skill levels were observed in this study. The highest ball release speed was observed in high-skilled players during the standing throw with run-up. Additionally, a throwing technique x skill level interaction with similar variability was observed between skill levels during the jump throw and standing throw without run-up in this study. However movement variability was increased in low-skilled players performing the standing throw with run-up. The authors postulate that increased ball release speed explains the movement variability differences observed in these players. Ilmane and LaRue[152] reported that as movement velocity increases the amount of movement variability decreases.[6] Skilled team handball players must learn to control body movement while maximizing ball release velocity in order to make a successful throw.

It is evident from the literature that the shoulder is the most frequent site to experience overuse symptoms[153] and can account for 40% of time lost injuries over a six-month period in team handball players.[88,89] While the shoulder has been identified as frequently injured in team handball players, the etiology of these overuse injuries have not been examined. In other sports that utilize repetitive overhead motions, decreased shoulder and hip range of motion profiles have been suggested to be a risk factor for injury.[60,116] Range of motion and isometric strength profiles players may be risk factors for injury in team handball players as these factors may alter kinematics during dynamic movement task such as throwing. These potentially altered kinematics during throwing may occur because the hip initiates spinal rotation[58] and any deficiency in hip motion can also affect the transfer of energy through the spine. Thus proximal instability at the hip and spine can lead to further energy transfer alterations at the distal segments of the kinetic chain. Kinetic energy transfer alterations could be altered further if range of motion at the shoulder is decreased.

CHAPTER III
METHODS

Project objectives were, first, to evaluate kinematic and kinetic changes during the performance of a team handball jump-shot following aerobic and throwing fatigue protocols. The second objective was to establish shoulder and hip range of motion patterns and isometric strength in team handball players at baseline, following aerobic and localized fatiguing protocols, and 24-hours following each fatiguing protocol. The role of this chapter was to outline and describe the methodology. Sections written to describe the methodology are the following: 1] participants, 2] setting, 3] instrumentation, 4] design and procedures, and 5] data analysis.

Participants

Male team handball players ranging from 20 to 40 years old were recruited to participate in this study. Participants were in good health and without upper or lower extremity injury or surgery in the past six months. These recruiting measures allowed for the results to be delimited across a larger population of team handball players. Participants completed a health-history questionnaire to determine eligibility in this study (Appendix A). Exclusion criteria included: 1] any current or recent injury to the upper extremity, lower extremity, pelvis, low back, or trunk, within the past six months. Prior to participation each participant signed an informed consent document approved by the Auburn University Institutional Review Board (Appendix B). The number of participants chosen was based on a power analysis. A power analysis was performed using data from previous fatigue and lower extremity biomechanics studies[26,31,37,154] and it was determined that 11 participants were needed to have a power of 0.82 and effect size of 0.70 at $\alpha = 0.05$. Eleven male team handball players (23.09 ± 3.05 years; 185.12 ± 8.33 cm; 89.65 ± 12.17 kg) volunteered to participate in the localized throwing fatigue protocol. A separate power analysis was performed for the aerobic fatigue protocol because data for only 10 players were analyzed. In order to have a power of 0.80 and effect size F of 0.50 at $\alpha = 0.05$ only 10 participants were needed.

Setting

Data collection took place in a controlled laboratory setting inside the Sports Medicine & Movement Laboratory within the School of Kinesiology at Auburn University. This location possesses the space and equipment necessary to fulfill the objectives of this study.

Instrumentation

Range of Motion

To evaluate passive glenohumeral and hip range of motion profiles in team handball players a digital inclinometer was used (Baseline® Evaluation Instruments, White Plains, NY, USA). In similar studies measuring range of motion, a goniometer[3,47,48,54,155,156] or inclinometer[116,157,158] has been used to collect data. An inclinometer was chosen due to the familiarity and ease of use for the primary investigator who collected the data for this study. Prior to data collection the inclinometer was calibrated to the manufactures recommended standards to ensure accurate measurements.

Isometric Strength

Isometric strength was measured for glenohumeral and hip internal and external rotation using a handheld dynamometer. Handheld dynamometry was reported to have a 0.2 N sensitivity and is capable of measuring 0-500 N.[119] Handheld dynamometry has been thoroughly examined in the literature and deemed a reliable and valid method for measuring strength.[75,121,123,159-161] Prior to data collection the dynamometer was calibrated to the manufactures recommended standards.

Kinematics & Kinetics

The MotionMonitor™ (Innovative Sports Training, Chicago, IL) synced with electromagnetic tracking system (Track Star, Ascension Technologies Inc., Burlington, VT) was used to collect data. The electromagnetic tracking system has been validated for tracking humeral movements, producing trial-by trial interclass correlation coefficients for axial humerus rotation in both loaded and non-loaded condition in excess of 0.96.[162] With electromagnetic tracking systems, field distortion has been shown to be the cause of error in excess of 5° at a distance of 2 m from an extended range transmitter[163], but increases in instrumental sensitivity have reduced this error to near 10° prior to system calibration and 2° following system calibration.[163-165] Thus prior to data collection, the current system was calibrated using previously established techniques.[163,165-172] Following calibration, magnitude of error in determining the position and orientation of the electromagnetic sensors within the calibrated world axes system was less than 0.01 m and 3° respectively. The collection rate for all kinematic data describing the position and orientation of electromagnetic sensors was set at 100 Hz.[80,166,168,170,173] Raw data was independently filtered along each global axis using a 4th order Butterworth filter with a cutoff frequency of 13.4 Hz.[80,166,168,170,173] Force plate data was sampled at a rate of 1000 Hz.

Design & Procedures

Range of motion and strength values were obtained at baseline (initially when they come into the lab), immediately following fatiguing protocols, and following a 24-hour period of rest. A 24-hour period of rest is the typical amount of time that players are allotted on most weeks since they train and compete year round. Participants were instructed to monitor their activity level, sleep, and diet 24 hours prior to performing each fatiguing protocol and to try replicate these variables before the second fatigue protocol. During this time participants were asked to refrain from strenuous exercise to limit any confounding effects that would hinder testing performance. Participants were also asked to eat a similar diet before each fatiguing protocol to limit the effects of nutritional intake on fatigue. Participants had a minimum rest period of one week between each fatiguing protocol. Prior to the first fatiguing protocol each participant completed a health screening questionnaire (Appendix A) and signed the Institutional Review Board approved Informed Consent document (Appendix B).

Shorts and a t-shirt were worn to allow unobstructed access to the anatomical landmarks needed for the range of motion measurements to occur. This clothing also allowed the investigator to more easily view compensations in movement that the participant may exhibit. The most common compensation observed at the shoulder when testing for range of motion is the scapula upwardly rotating causing the humerus to elevate off of the table. Compensations at the hip include hip hike (when the hip being measured elevates above the contralateral hip) or hip flexion (when the femur elevates off of the table).

Glenohumeral range of motion measures were obtained with the participant positioned supine on a table. Performing range of motion measurements in a supine position allows for the table to help stabilize the scapula. The participant's arm was then placed at 90° of abduction with their elbow flexed to 90°. A rolled towel was placed under the distal end of the participant's humerus in order to limit glenohumeral horizontal extension.[116] A digital inclinometer was then used to obtain internal and external rotation values. The inclinometer was placed along the lateral aspect of the participant's distal ulna and the investigator then passively rotated the participant's shoulder into maximum internal rotation [Figure 1]. The same procedures were performed to measure glenohumeral external rotation [Figure 2]. A visual inspection technique described by

Dwelly et al.[116] was used to control for scapulothoracic motion. This method has previously been validated as most reliable when measuring isolated glenohumeral motion.[116,174] This technique involved the investigator measuring range of motion until a firm capsular end-feel was reached or the acromion elevating off of the table.[116] Awan et al.[174] have suggested that this is the most accurate measuring technique for one investigator to perform clinically.

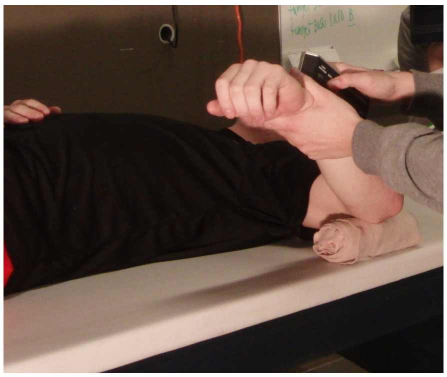


Figure 1. Shoulder internal rotation.

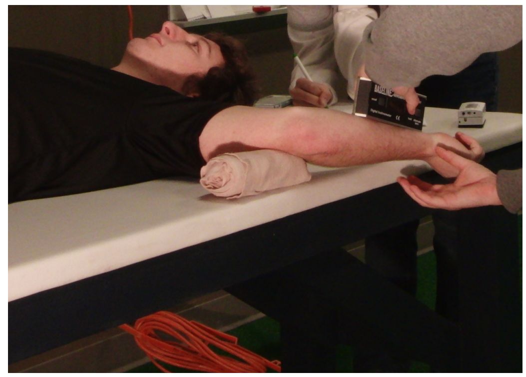


Figure 2. Shoulder external rotation.

For the purpose of this study the drive hip was defined as the throwing side hip while the stride hip was the non throwing side.[58] Hip range of motion is typically measured in either the seated or prone position. [58,59,78] For the purposes of this study, the seated position was employed. Participants were seated on the edge of a table with knees flexed to 90°.[39] A towel was placed under the femur to ensure 90° of hip flexion, if needed.[39] Participants placed their hand on the table to help stabilize their trunk during the measurements.[59] Passive range of motion was obtained for internal [Figure 3] and external rotation [Figure 4]. The end range of motion occurred at the first point of capsular resistance and no overpressure was applied by the examiner once this point was reached.[59] During the baseline testing session, glenohumeral and hip range of motion measurements were recorded twice and the average of the two measurements were calculated.[116]

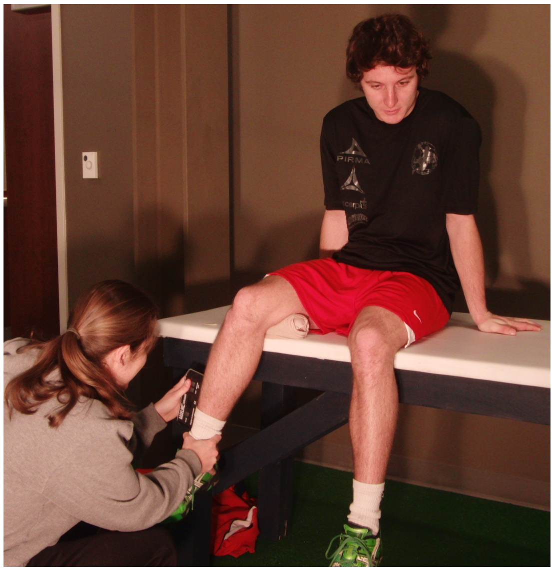


Figure 3. Hip internal rotation.

Figure 4. Hip external rotation.

Following range of motion measurements, isometric hip and shoulder internal and external rotation strength were assessed. The order of testing was as follows: shoulder external rotation, shoulder internal rotation, hip external rotation, and hip internal rotation.[119] This order of testing was completed through once and then a 20-30 second rest period was allotted to participants before the second set of measurements were recorded.[119] Two trials for each measurement were obtained prior to and following the fatiguing protocol and the mean of the two measurements was calculated.

To measure the isometric shoulder internal and external rotational strength, the participant was supine on a table and with arm positioned at 90° abduction and 0° of scapular plane rotation.[119,123] In an effort to standardize this positioning, and prevent compensations from occurring, a rolled towel was placed at 30° anterior to the frontal plane and elevated to 45° in the frontal plane beneath the distal humerus.[123] Once positioned, the dynamometer was placed on the dorsal aspect of the forearm for measurement.[119,157] To measure hip strength the dynamometer was placed on the medial aspect of the shank for external rotation and lateral aspect for internal rotation and testing was performed with the participant in a seated position. All measurements were isometric in nature and performed with the joint in mid-range position.[119] Each isometric measurement consisted of 5-6 seconds of a maximal effort contraction by the participant.[119] Participants were instructed on the importance of exerting maximal effort during all testing procedures and the examiner provided standardized encouragement for each participant.[119]

After baseline range of motion and isometric strength measures were obtained, the electromagnetic sensors needed to assess kinematics during the jump shot were attached. Participants had a series of 11 electromagnetic sensors [Track Star, Ascension Technologies Inc., Burlington, VT] attached at the following locations: [1] seventh cervical vertebra [C7] spinous process; [2] the pelvis at sacral vertebrae 1 [S1]; [3] deltoid tuberosity of the throwing arm humerus; [4] throwing arm wrist, between the radial and ulnar styloid processes; [5] throwing arm hand at the third metacarpal; [6] acromioclavicular [AC] joint of the throwing arm [7-8] bilateral shank centered between the head of the fibula and lateral malleolus; [9-10] bilateral lateral aspect of the femur and [11] third metatarsal of the foot.[80,166-170,172,175] Figure 5 illustrates the placement of each electromagnetic sensor. Sensors were affixed to the skin using PowerFlex cohesive tape (Andover Healthcare, Inc., Salisbury, MA) to ensure the sensors remain secure throughout testing. Following the application of the sensors, an additional sensor was attached to a stylus and used to digitize the position of bony landmarks described in Table 2.[80,172,175-178] Participants stood in anatomical position during digitization to guarantee accurate bony landmark identification. The medial and lateral aspect of each joint was digitized and the midpoint of the two points was calculated to determine the joint center.[80,167,170,178,179] A link segment model was developed through digitization of joint centers for the ankle, knee, hip, shoulder, thoracic vertebrae 12 [T12] to lumbar vertebrae 1 [L1], and C7 to thoracic vertebrae 1 [T1].[80,167,168,170,172]

The spinal column was defined as the digitized space between the associated spinous processes, whereas the ankle and knee were defined as the midpoints of the digitized medial and lateral malleoli, medial and lateral femoral condyles, respectively.[80,167,168,170,172] The shoulder and hip joint centers were estimated using the rotation method. This method of calculating a joint center has been reported as providing accurate positional data.[180,181] The shoulder joint center was calculated from the rotation between the humerus relative to the scapula and the hip joint center from the rotation of the femur relative to the pelvis. The rotation method was implemented with the joint stabilized and then passively moved in 10 positions in a small circular pattern.[180] The variation in the measurement of the joint center had a root mean square error less than 0.003 m in order to be accepted.

Raw data regarding sensor orientation and position were transformed to locally based coordinate systems for each of the respective body segments. Two points described the longitudinal axis of each segment and the third point defined the plane of the segment.[168] The second axis was perpendicular to the plane and the third axis was defined as perpendicular to the first and second axes. The world axis was defined as the y-axis in the vertical direction, horizontal and to the right of y was the x-axis, and posterior was the z-axis.[168,170] Euler angle decomposition sequences were used to describe both the position and orientation of the body segments.[80,167,168] International Society of Biomechanics standards and joint conventions were used to describe Euler angle sequences used to obtain kinematic data.[177,178] Specifically, ZX'Y" were used for the trunk, YX'Y" for the shoulder, YX'Z'' for the scapula, and ZX'Y" were used to define elbow rotations (Table 1).[177] Raw data was then independently filtered along each global axis using a 4^{th} order Butterworth filter with a cutoff frequency of 20.0 Hz.[80,167,168] All data were passively synchronized via a data acquisition board and time stamped through MotionMonitor^{TM}.

Table 1. Angle orientation decomposition sequences.

Segment	Axis of Rotation	Angle
Trunk		
Rotation 1	Z	Flexion [-]/Extension [+]
Rotation 2	X'	Left Lateral Tilt [-]/Right Lateral Tilt [+]
Rotation 3	Y"	Right Rotation [+]/Left Rotation [-]
Shoulder		
Rotation 1	Y	Humeral Plane of Elevation [0=Abduction; 90=Flexion]
Rotation 2	X'	Humeral Elevation
Rotation 3	Y"	Shoulder Internal Rotation [+]/Shoulder External Rotation [-]
Elbow		
Rotation 1	Z	Flexion [+]/Hyperextension [-]
Rotation 2	X'	Carrying Angle
Rotation 3	Y"	Pronation [+]/Supination [-]

* Prime ['] and double prime ["] notations represent previously rotated axes due to the rotation of the local coordinate system resulting in all axes within that system being rotated. [Rotation about X axis also results in rotation of both Y and Z axes resulting in a new system of X', Y', Z'. Subsequent rotation are then about those axes.]

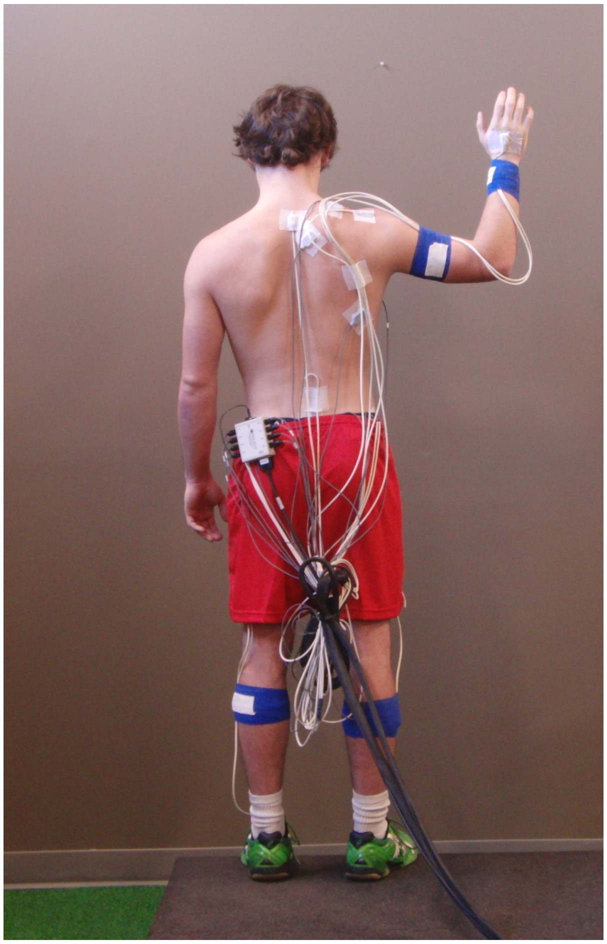


Figure 5. Electromagnetic sensor placement.

Table 2. Description of the trunk and upper extremity bony landmarks palpated and digitized to create a skeletal model of each participant.

Bony Landmarks	Digitized Bony Processes
Trunk	
Seventh Cervical Vertebra [C7]	C7 spinous process
Thoracic Vertebra 12 [T12]	T12 spinous process
Eighth Thoracic Vertebra [T8]	T8 spinous process
Suprasternal Notch	Most cranial aspect of sternum
Xiphoid Process	Most distal aspect of sternum
Humerus	
Medial Epicondyle	Medial aspect of humeral epicondyle
Lateral Epicondyle	Lateral aspect of humeral epicondyle
Forearm	
Radial Styloid Process	Lateral aspect of radial styloid
Ulnar Styloid Process	Medial aspect of ulnar styloid

Following digitization, participants were allotted an unlimited time to warm-up and become familiar with the testing protocols. Once each participant deemed himself ready, the testing protocols began. Participants performed five maximal effort jump shots, from a distance of 8 m, using an International Handball Federation (IHF) size 3 team handball.[6,136,182] The jump shot was chosen because this is the most commonly performed shot utilized during competition.[136] In order for a trial to count as a vertical jump throw the horizontal distance between takeoff and landing could not exceed 2 m.[182] Additionally, only accurate shots that hit the center of a 1 x1 m^2 target at a height of 1.75 m were saved.[6,136,182] The number of shots required to perform 5 shots accurately were recorded to determine the shot accuracy percentage.[4]

The aerobic fatiguing protocol was participant specific based on their recorded VO2max. The VO2max testing occurred a minimum of 2 weeks prior to the implementation of the aerobic fatiguing protocol. The VO_2max testing used a standard testing protocol that consisted of the following: 5 minute easy sub-maximal run (2 minute warm up, 3 minute steady state); a three minute moderate sub-maximal run (steady state); three minute fast sub-maximal run (steady state); incremental 2% increases in grade until participant volitionally quit. The three sub-maximal levels provided the oxygen cost, heart rate, and workload relationships. The incremental stages culminated in a maximal heart rate and a maximal VO_2 if the testing procedure met two of the following four criterion: 1) Volitional fatigue; 2) a VO_2 plateau despite an increase in workload; 3) and resting expiratory ratio (RER) values of 1.15 or higher; and/or 4) maximum heart rate within ±12 beats of age predicted maximum. Based on the VO_2 max testing, the workload (individually determined) that elicits a heart rate that was 80% of maximal was used for the fatigue testing protocol. The 80% work intensity was chosen based on average heart rate data (unpublished lab data) observed during team handball match play. Participants were instructed to run as long as they could (time to exhaustion) on a treadmill at a speed that corresponded with 80% of their heart rate maximum, as determined by the VO2max testing, for the aerobic fatiguing protocol.

Immediately following the performance of 5 successful jump shots one of the randomly assigned fatiguing protocols (aerobic or throwing) was implemented. The aerobic fatiguing protocol utilized the participants VO2max and the pre-selected heart rate intensity of 80%maxHR. Participants were instructed to run as long as they could (time to exhaustion) for the aerobic fatiguing protocol. During the aerobic fatiguing protocol, the Borg rating of perceived exertion (RPE) scale was used to assess the participant's perception of fatigue at each interval of the testing protocol.[183,184] Heart rate was recorded using a Polar heart rate monitor was utilized throughout testing. Immediately following the fatiguing protocol the participants performed 5 successful jump shots that met the previously established criteria.

The localized fatiguing protocol involved a repetitive throwing task to fatigue. Participants threw a 2.2 kg medicine ball into a rebounder positioned 6.10 m. Participants threw at maximum velocity every five seconds until they reached fatigue.[27-29] The participants performed each throw from a kneeling position with the contralateral hip flexed to 90° and the knee pointed towards the rebounder.[27-29] Ratings of perceived exertion were assessed after every 20 throws and the participant was considered fatigued once they reported a 15 or above.[27-29] Immediately following the fatiguing protocol the participants performed 5 successful jump shots that met the previously established criteria. In addition, range of motion and isometric strength measures were collected after each fatiguing protocol following the same protocols used during baseline testing. These measures were also repeated 24 hours following each fatiguing protocol.

Experimental Design

All five jump shot trial data were compiled and analyzed to limit variability between the trials. All statistical analyses was performed using SPSS software (version 20.0; SPSS Inc., Chicago, IL, USA), with an alpha level set *a priori* at $p \leq 0.05$, was utilized. All data were compiled in a spreadsheet in Microsoft Excel to prepare for statistical analysis. Next, a within subjects repeated measures ANOVA was employed to determine if range of motion, isometric strength, and jump shot kinematics, and kinetics were significantly different following each fatiguing protocol. The kinematic and kinetic data analysis was performed separately for each segment of the body. A within subjects 2 (time) x 4 (event) x 3 (direction) design was utilized to analyze the kinematics of the trunk segment. The variable of time included pre-fatigue and post-fatigue independent variables, the direction of movement for the trunk was flexion, lateral flexion, and rotation, and lastly the four events of the throwing motion (foot contact (FC), maximum external rotation (MER), ball release (BR), maximum internal rotation (MIR)). The design of the shoulder and scapula analysis was 2 (location) x 2 (time) x 4 (event) x 3 (direction). Location was divided into the shoulder and scapula segments, time was pre and post fatigue, event included FC, MER, BR, and MIR of the throwing motion, and direction was the movement that was being analyzed. The design for elbow kinematics was 2 (location) x 2 (time) x 4 (event) x 1 (direction). For the analysis of the kinetics about the shoulder and elbow, a 2 (location) x 4 (event) x 2 (time) x 2 (direction) within subject design was utilized for analysis.

Time (baseline, post fatigue, and 24 hours post fatigue protocol) served as the levels of the independent variable. The shoulder and hip joints also served as levels of the independent variable location. Limb dominance was also an independent variable as each limb was analyzed in this study. The dependent variables were integrated hip and shoulder internal and external rotation ranges of motion and strength. Therefore a 3 (time) x 2 (location) x 2 (direction) x 2 (limb dominance) within subjects design was implemented for all range of motion and isometric strength data. Post hoc analyses were performed for each dependent variable in which statistical significance occurred. Pairwise comparisons were used to determine at which levels the differences occurred.

The throwing motion was broken down into the events of stride foot contact (FC), maximum shoulder external rotation (MER), ball release (BR), and maximum shoulder internal rotation (MIR) (Figure 6). All kinematic and kinetic data for this study were reduced using MotionMonitor™ (Innovative Sports Training, Chicago, IL) software. Descriptive statistics were calculated for all kinematic and kinetic parameters. The kinematic variables analyzed were trunk flexion, trunk lateral flexion, trunk axial rotation, humeral elevation, humeral plane of elevation, shoulder rotation, elbow flexion, scapula protraction, scapula upward rotation, and scapula tilt. The kinetic variables analyzed included anterior/posterior shoulder force, shoulder compression/distraction force, and elbow valgus/varus force. All kinetic data were normalized by participant body weight.

Start FC MER BR MIR

Figure 6. Events of a team handball jump shot.

CHAPTER IV
RESULTS

Project objectives were, first, to evaluate kinematic and kinetic changes during the performance of a team handball jump-shot following aerobic and throwing fatigue protocols. The second objective was to establish shoulder and hip range of motion patterns and isometric strength in U.S. National team handball players at baseline, following aerobic and localized fatiguing protocols, and 24-hours following each fatiguing protocol. The role of this chapter was to outline and describe the results of each fatigue protocol. The results of the localized fatigue protocol will be presented first followed by the results for the aerobic fatigue protocol. Sections written to describe the results are the following: 1] descriptive statistics, 2] range of motion, 3] isometric strength, 4] kinematics and kinetics.

Localized Fatigue Results

The mean warm-up time for the localized throwing fatigue protocol was 5.83 ± 1.33 minutes and the time to fatigue was 38.46 ± 17.22 minutes. Mean ball speed, across the pre fatigue trials, was 19.8 m/s (44.2 mph) and decreased to 18.8 m/s (42.1 mph) following fatigue ($p = 0.12$). Accuracy percentage in the pre fatigue trials was 60.79 ± 14.13% and 52.84 ± 12.68% following fatigue ($p = 0.20$). In addition, the mean number of medicine ball throws to fatigue was 485.45 ± 290.80. All participants reached an RPE level of 20 and made a minimum of 40 medicine ball throws at this level. The mean number of throws at a 20 RPE level was 104.18 ± 96.80.

Range of Motion

Throwing and non-throwing arm internal and external rotation ranges of motion data are presented in Figures 7 and 8, respectively. Additionally, drive hip and stride hip range of motion are depicted in Figures 9 and 10, respectively. It was hypothesized that there would be decreased glenohumeral internal rotation and increased external rotation immediately following and 24 hours following localized fatigue, however this hypothesis was not supported. Baseline throwing arm external rotation (104.23 ± 8.85°) was significantly greater than the non-throwing arm (98.54 ± 11.24°) ($p < 0.01$). Statistical analysis through the use of a 3 (time) x 2 (location) x 2 (direction) x 2 (limb dominance) repeated measures ANOVA revealed no significant differences in throwing shoulder external rotation. No significant differences ($p < 0.05$) across the three time periods existed for shoulder internal rotation or hip range of motion.

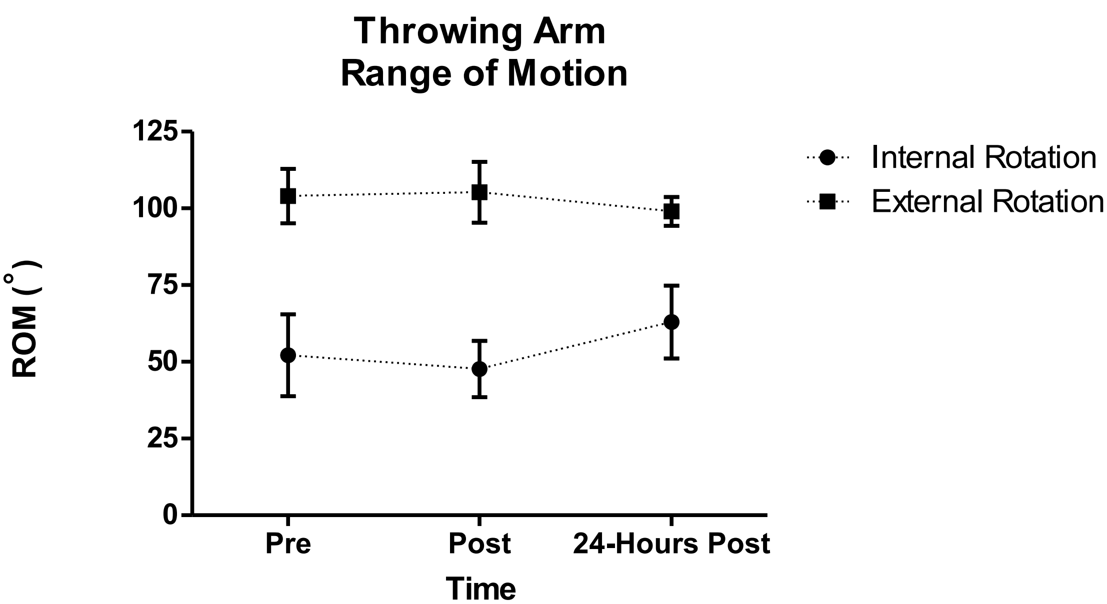


Figure 7. Throwing arm range of motion mean and standard deviations pre, post and 24-hours post localized fatigue protocol.

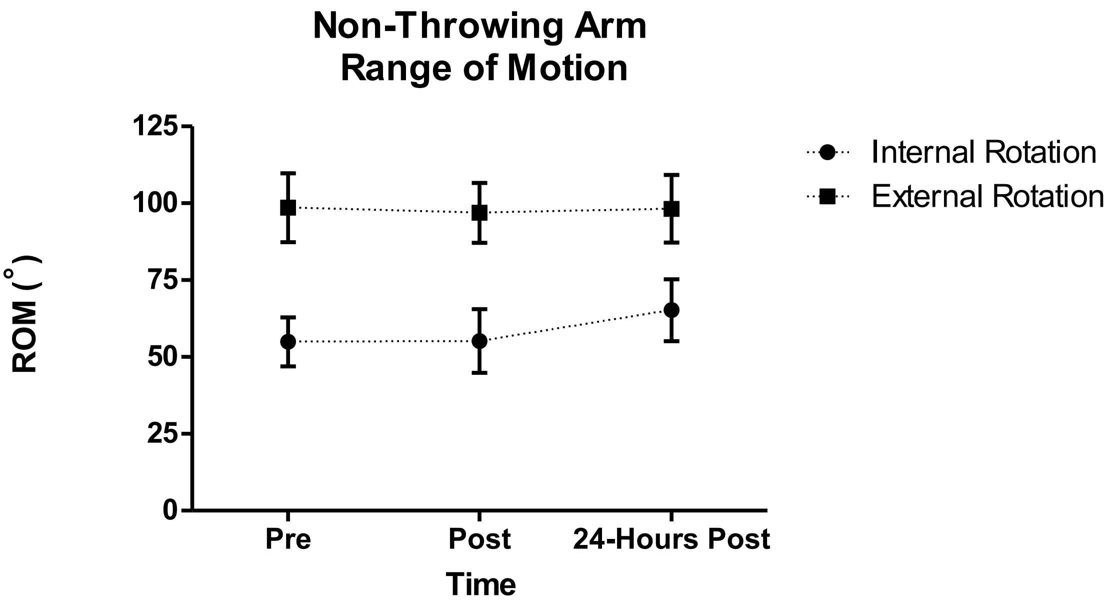


Figure 8. Non-throwing arm range of motion mean and standard deviations pre, post and 24-hours post localized fatigue protocol.

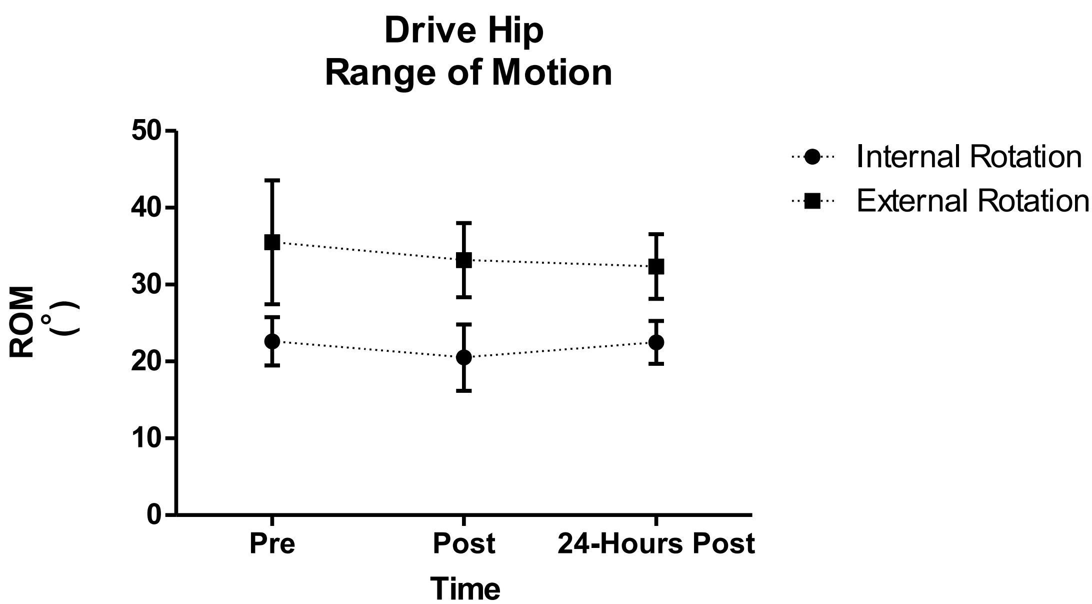


Figure 9. Drive hip range of motion mean and standard deviations pre, post and 24-hours post localized fatigue protocol.

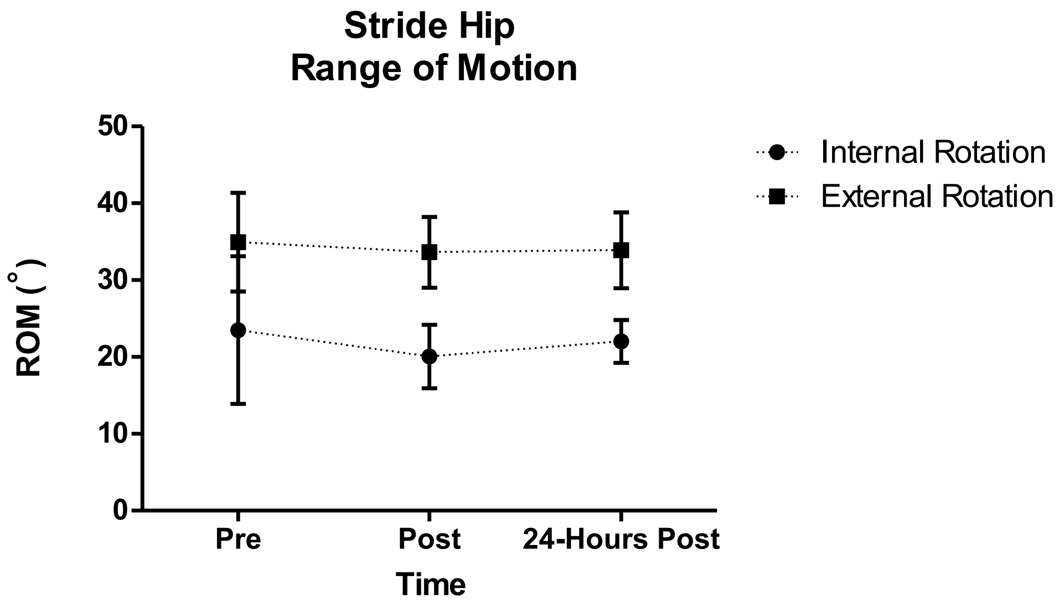


Figure 10. Stride hip range of motion mean and standard deviations pre, post and 24-hours post localized fatigue protocol.

Isometric Strength

Throwing and non-throwing arm internal and external rotation isometric strength data are presented in Figures 11 and 12, respectively. Additionally, drive and stride hip isometric strength data are depicted in Figures 13 and 14, respectively. It was hypothesized that isometric muscle strength in the shoulder and hip would decrease from baseline values immediately following localized fatigue but would return to baseline within 24 hours, however the data did not support this hypothesis. No significant isometric strength changes for the shoulder or hip were observed in this sample.

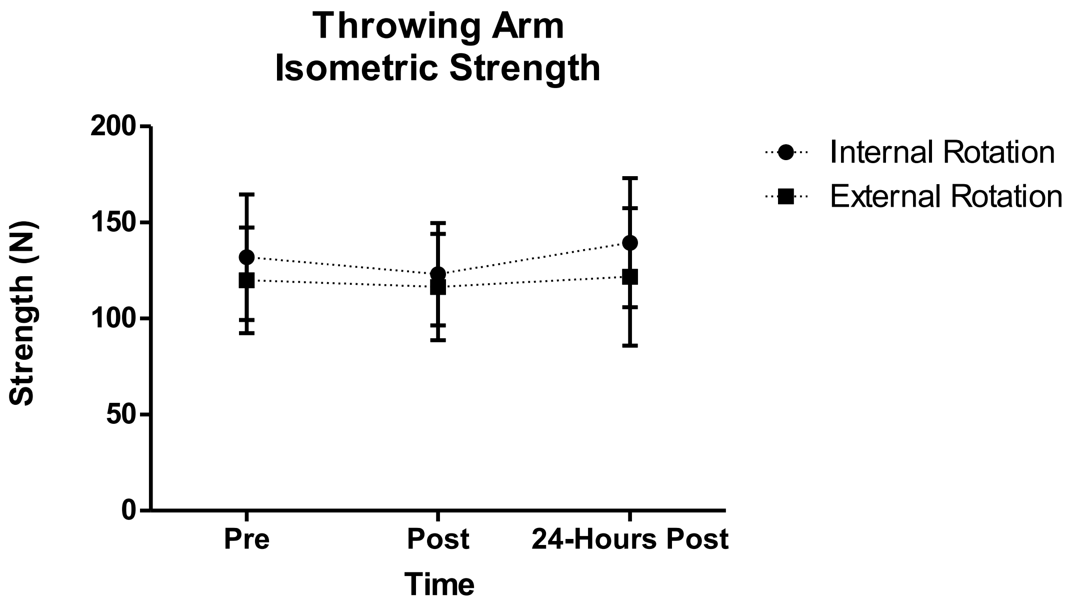


Figure 11. Throwing arm isometric strength mean and standard deviations pre, post and 24-hours post localized fatigue protocol.

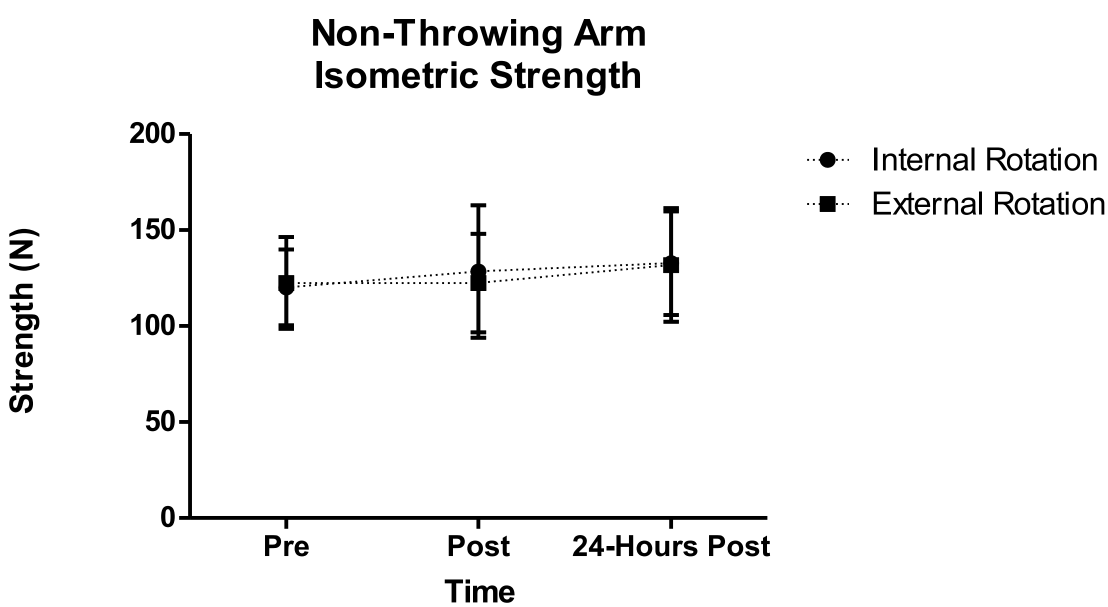


Figure 12. Non-throwing arm isometric strength mean and standard deviations pre, post and 24-hours post localized fatigue protocol.

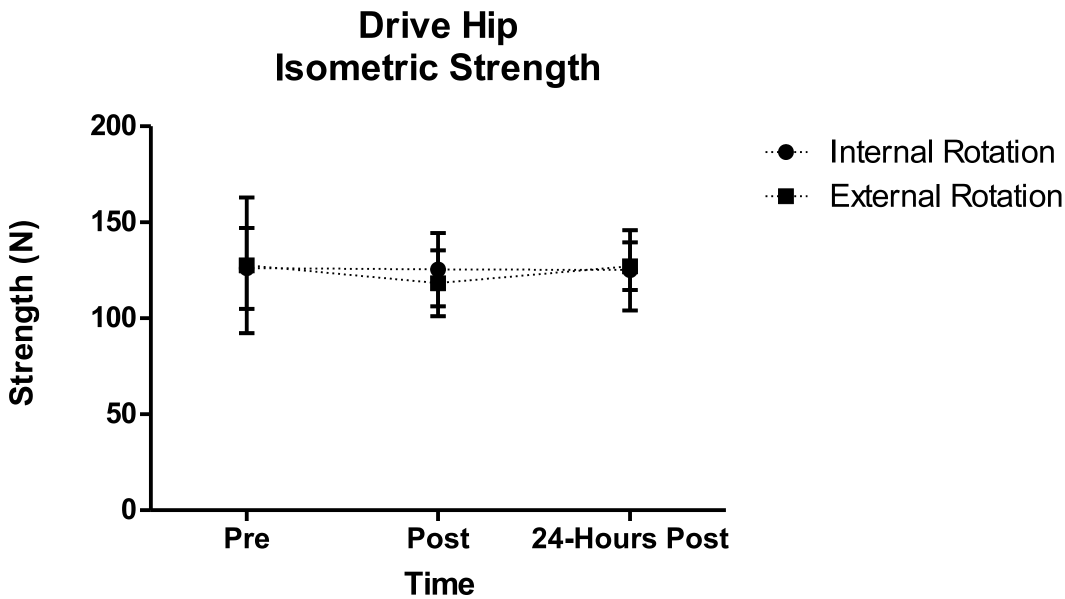


Figure 13. Drive hip isometric strength mean and standard deviations pre, post and 24-hours post localized fatigue protocol.

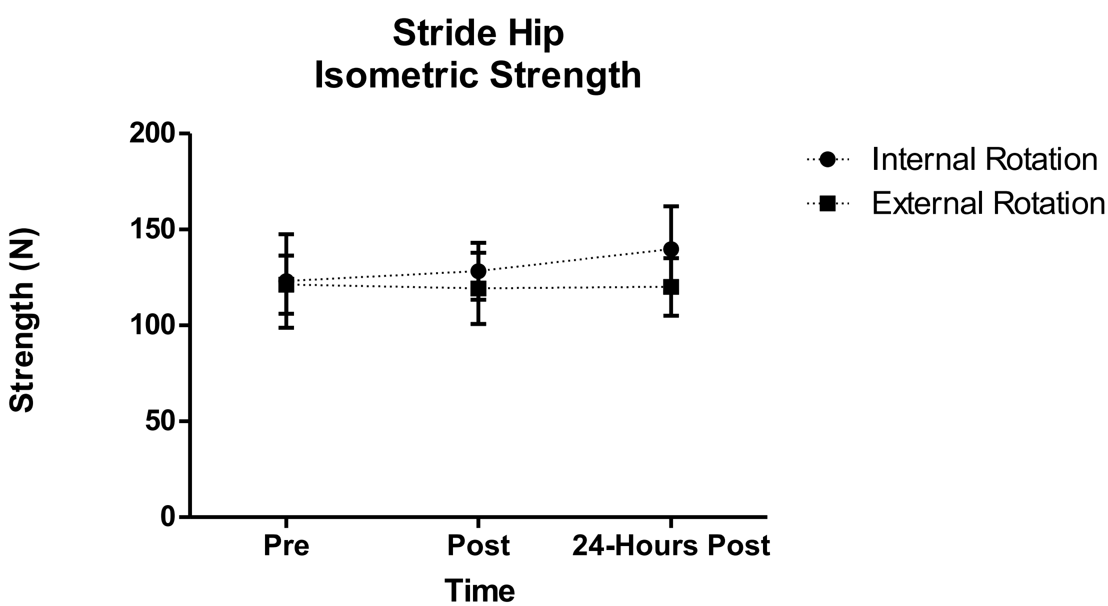


Figure 14. Stride hip isometric strength mean and standard deviations pre, post and 24-hours post localized fatigue protocol.

Kinematics and Kinetics

Kinematic and kinetic data for the jump shot are presented in Tables 3-5. Pelvis and trunk kinematics are presented in Table 3, shoulder and scapula data are in Table 4, and kinetics in Table 5. It was hypothesized that kinematic differences at the pelvis, trunk, shoulder and elbow during the jump shot would be present following both the localized fatigue protocol and this hypothesis was partially supported by the data. For the pelvis, a significant three-way interaction of event (foot contact (FC), maximum external rotation (MER), ball release (BR), maximum internal rotation (MIR)), x time (pre, post) x direction (rotation, lateral flexion) was observed ($F_{3,30}$=4.81, p = 0.008; power = 0.86). Follow-up testing revealed pelvis rotation significantly decreased at MER following fatigue from -13.08° to -2.57° ($F_{1,10}$= 5.13; p = 0.047; power= 0.53). Shoulder elevation increased at MER (108.28° to 113.05°) following localized upper extremity fatigue however this increase was not statistically significant. Scapula upward rotation increased at MER from -30.31° to -35.55° and increased as the throwing motion progressed. At ball release scapula upward rotation increased from -18.66° to -24.95° and at MIR from -5.55° to -9.96° following fatigue during the jump shot. Trunk lateral flexion decreased from a flexed position towards the non-throwing side towards neutral, from -9.57° to -5.75°, at MER. Trunk flexion increased at BR from -11.02° to -14.24°. It was hypothesized that fatigue would increase the kinetics about the shoulder and elbow during the jump shot but this did not prove to be the case as no significant differences were observed.

Table 3. Jump shot trunk kinematics pre and post localized fatigue. Mean (SD)

	Pre Fatigue				Post fatigue			
	FC	MER	BR	MIR	FC	MER	BR	MIR
Trunk Flexion (°)	-16.29 (9.97)	-2.20 (4.09)	-11.02 (4.53)	-16.59 (7.68)	-17.82 (9.77)	-2.82 (6.03)	-14.24 (5.24)	-17.90 (10.60)
Trunk Lateral Tilt (°)	-3.32 (5.46)	-9.57 (11.43)	-30.11 (7.99)	-36.15 (11.07)	-1.91 (5.00)	-5.75 (14.06)	-29.48 (9.65)	-35.75 (9.22)
Trunk Axial Rotation (°)	-47.11 (21.10)	-19.56 (10.71)	12.73 (11.46)	12.28 (14.13)	-44.99 (21.94)	-15.76 (14.28)	13.08 (9.67)	12.22 (15.15)

Flexion [-]/Extension [+]; Left Lateral Tilt [-]/Right Lateral Tilt [+]; Right Rotation [-]/Left Rotation [+].

Table 4. Jump shot upper extremity kinematics pre and post localized fatigue. Mean (SD)

	Pre Fatigue				Post Fatigue			
	FC	MER	BR	MIR	FC	MER	BR	MIR
Shoulder Plane of Elevation (°)	14.69 (17.14)	18.37 (11.16)	26.25 (17.97)	47.43 (20.46)	20.69 (21.02)	16.37 (15.31)	25.36 (16.90)	50.82 (19.98)
Shoulder Elevation (°)	33.38 (13.19)	108.28 (11.30)	95.52 (8.69)	82.63 (9.37)	34.00 (13.84)	113.05 (11.14)	98.79 (9.08)	83.98 (7.98)
Shoulder Rotation (°)	15.45 (16.41)	-74.81 (14.88)	-55.57 (16.06)	-1.81 (12.01)	6.15 (25.65)	-78.99 (14.70)	-59.12 (16.68)	-2.58 (14.47)
Scapula IR/ER Rotation (°)	6.09 (7.77)	-18.56 (12.01)	2.15 (7.02)	18.41 (11.22)	6.90 (8.90)	-19.34 (16.82)	3.16 (11.07)	20.43 (11.84)
Scapula Up/Dwn Rotation (°)	-6.31 (6.52)	-30.31 (12.56)	-18.66 (9.18)	-5.55 (9.05)	-7.78 (6.50)	-35.65 (9.78)	-24.95 (8.64)	-9.96 (5.75)
Scapula Ant/Post Tilt (°)	-1.99 (10.72)	15.68 (12.06)	1.91 (10.79)	-5.57 (10.59)	-1.91 (9.44)	18.92 (12.34)	3.83 (10.66)	-3.89 (8.70)
Elbow Flexion (°)	82.61 (33.00)	83.58 (20.82)	50.12 (18.98)	33.27 (8.06)	83.70 (31.87)	82.43 (19.98)	51.03 (18.43)	37.40 (12.80)

Humeral Plane of Elevation [0=Abduction; 90=Flexion]; Shoulder Internal Rotation [+]/Shoulder External Rotation [-]; Scapula Internal Rotation [+]/External Rotation [-]; Scapula Upward Rotation [-]/Downward Rotation [+]; Scapula Anterior Tilt [-]/Posterior Tilt [+]; Elbow Flexion [+]/Hyperextension [-].

Table 5. Jump-shot kinetics pre and post localized fatigue (%BW). Mean (SD)

	Pre Fatigue				Post Fatigue			
Variable	FC	MER	BR	MIR	FC	MER	BR	MIR
Shoulder Ant/Post Force	0.72 (4.05)	-6.09 (14.36)	-16.65 (18.57)	7.51 (23.62)	0.79 (3.16)	-6.09 (14.36)	-22.26 (70.73)	8.95 (19.54)
Shoulder Distraction Force	1.99 (2.86)	2.17 (7.90)	-21.21 (8.93)	-15.88 (0.25)	0.98 (3.23)	2.17 (7.90)	-19.34 (10.99)	-13.72 (22.20)
Elbow Valgus Force	-0.06 (2.57)	-2.14 (15.00)	-12.80 (16.66)	-7.29 (14.94)	0.67 (2.21)	-3.24 (14.52)	-16.65 (18.57)	-8.32 (13.20)
Elbow Distraction Force	0.64 (2.54)	-2.00 (7.24)	45.92 (21.31)	8.02 (14.87)	0.60 (2.68)	-0.29 (6.34)	49.76 (19.85)	9.03 (9.40)

Shoulder Anterior Force [+]/Posterior Force [-]; Shoulder Compression Force [+]/Distraction Force [-]; Elbow Varus [+]/Valgus Force [-]; Elbow Compression Force [+]/Distraction[-].

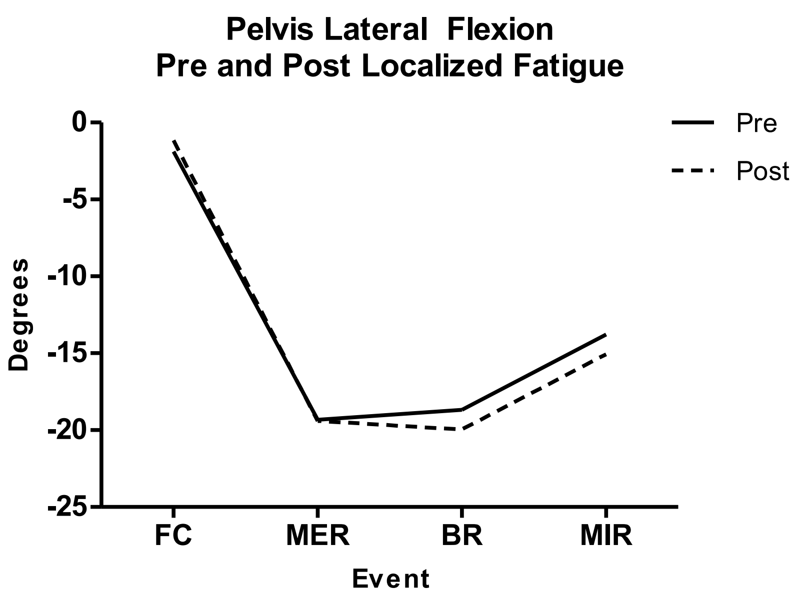
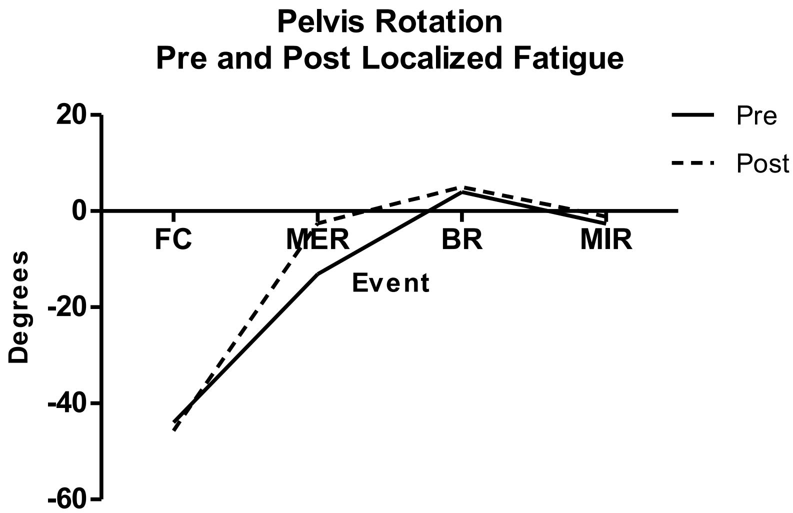


Figure 15. Pelvis lateral flexion over time pre and post localized fatigue.



*P < 0.05 at MER

Figure 16. Pelvis rotation over time pre and post localized fatigue.

Aerobic Fatigue

Ten male team handball players (23.6 ± 3.06 years; 184.67 ± 8.78 cm; 84.76 ± 9.23 kg) volunteered to participate. An additional participant volunteered however during the fatigue protocol he began experiencing knee discomfort and concluded testing prior to reaching his maximum aerobic fatigue. The mean throwing warm-up time for the aerobic fatigue protocol was 4.88 ± 1.58 minutes and each participant was allotted a three-minute running warm-up on the treadmill at 5.5 mph. The mean time to reach aerobic fatigue was 28.49 ± 13.92 minutes. Mean ball speed across the pre fatigue trials was 41.96 ± 3.02 mph and the speed was to 41.96 ± 3.04 mph ($p = 0.99$) following fatigue. Accuracy percentage in the pre fatigue trial was 54.49 ± 13.15% and post aerobic fatigue accuracy percentage was 60.75 ± 13.94% ($p = 0.31$).

Range of Motion

Throwing and non-throwing arm internal and external rotation ranges of motion data are presented in Figures 15 and 16 respectively. Additionally, drive hip and stride hip range of motion are depicted in Figures 17 and 18, respectively. It was hypothesized that there would be decreased glenohumeral internal rotation and increased external rotation immediately following and 24 hours following aerobic fatigue, however this hypothesis was not supported by the data. A three-way, location x rotation x dominance, interaction ($F_{1,7}$= 13.89; p = 0.007; power= 0.89) was observed. Baseline shoulder and hip range of motion bilaterally was not significantly different in this sample of team handball players. Statistical analysis through the use of a repeated measures ANOVA and follow-up testing reveled no significant differences in range of motion across the three examined time periods (pre, post, 24 hours post) for the shoulder and hip.

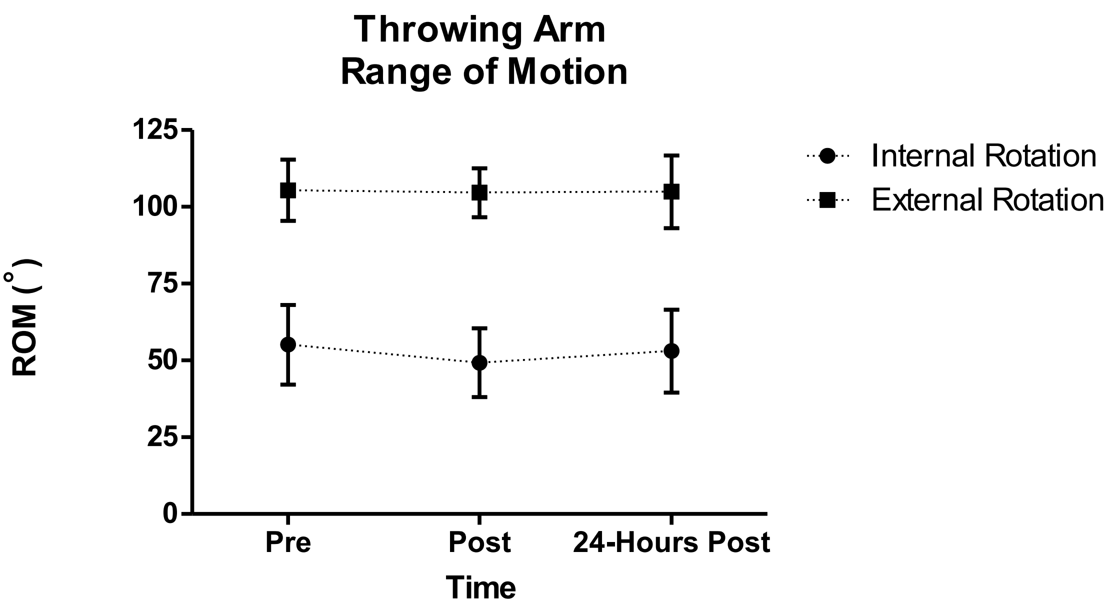


Figure 17. Throwing arm range of motion mean and standard deviations pre, post and 24-hours post aerobic fatigue protocol.

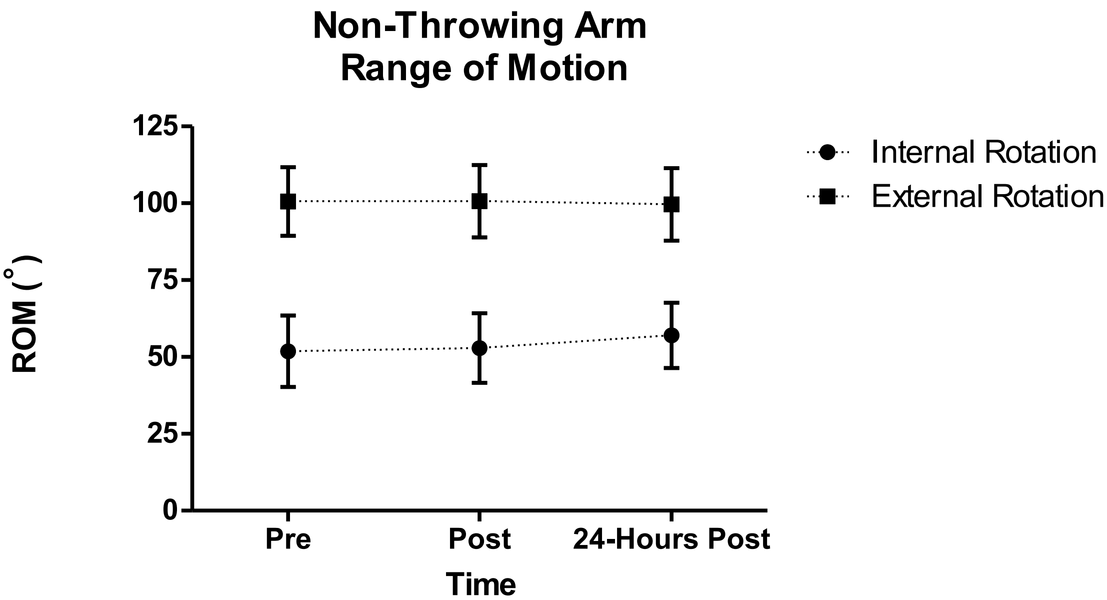


Figure 18. Non-throwing arm range of motion mean and standard deviations pre, post and 24-hours post aerobic fatigue protocol.

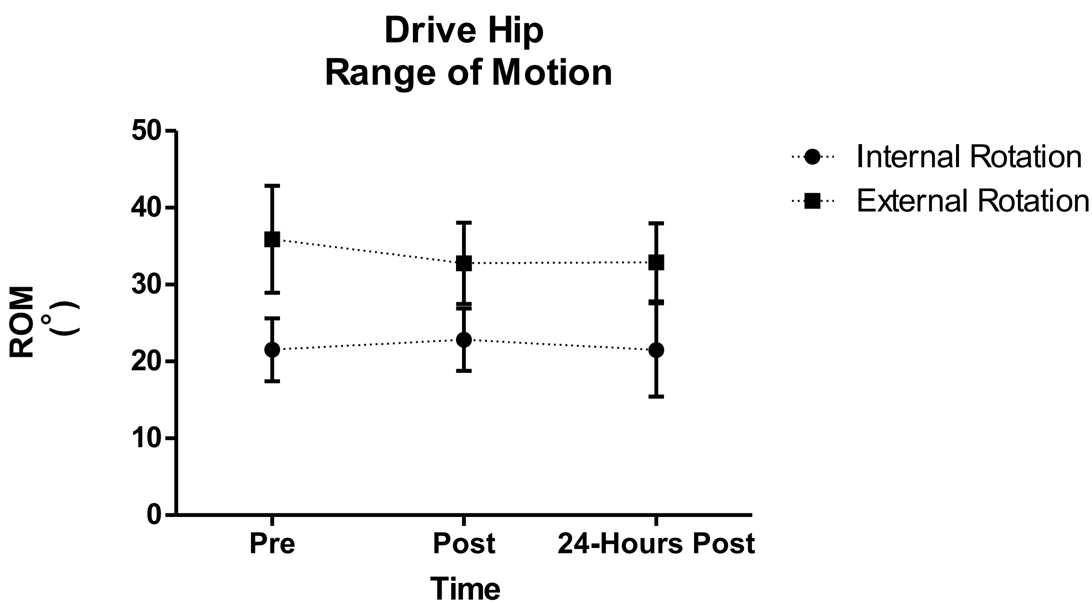


Figure 19. Drive hip range of motion mean and standard deviations pre, post and 24-hours post aerobic fatigue protocol.

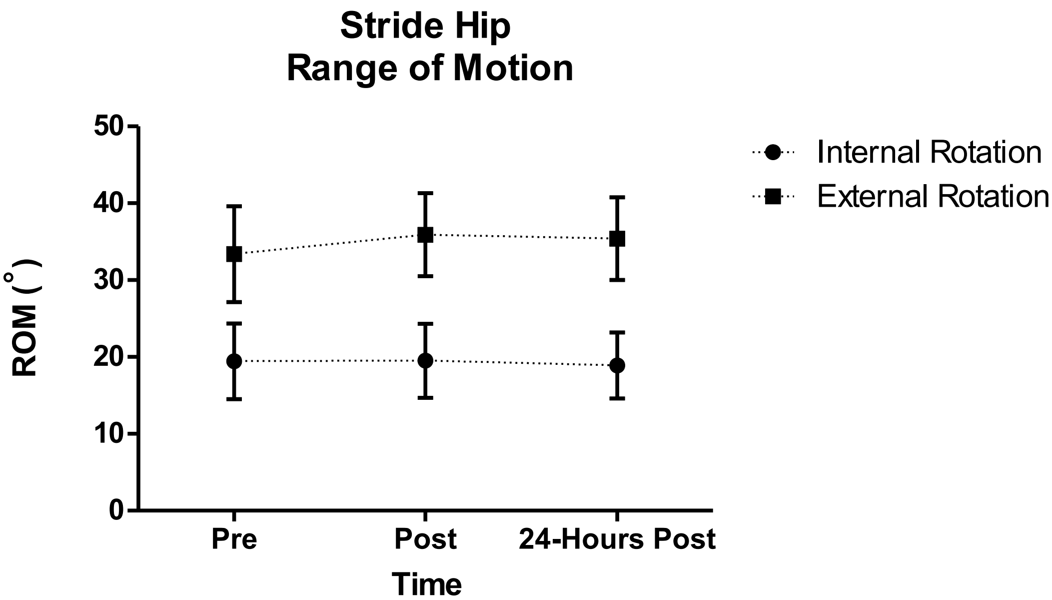


Figure 20. Stride hip range of motion mean and standard deviations pre, post and 24-hours post localized fatigue protocol.

Isometric Strength

Throwing and non-throwing arm internal and external rotation isometric strength data are presented in Figures 19 and 20, respectively. Additionally, drive hip and stride hip isometric strength data are depicted in Figures 21 and 22, respectively. It was hypothesized that isometric muscle strength in the shoulder and hip would decrease from baseline values immediately following aerobic fatigue but would return to baseline within 24 hours, however the data did not support this hypothesis. No significant isometric strength changes for the shoulder or hip were observed in this sample of team handball players.

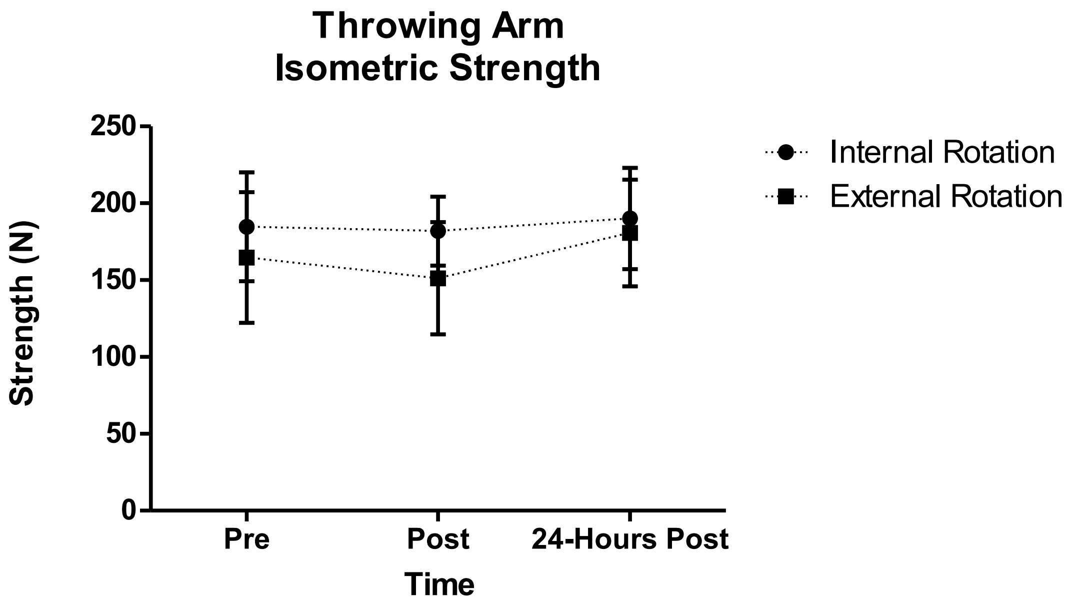


Figure 21. Throwing arm isometric strength mean and standard deviations pre, post and 24-hours post aerobic fatigue protocol.

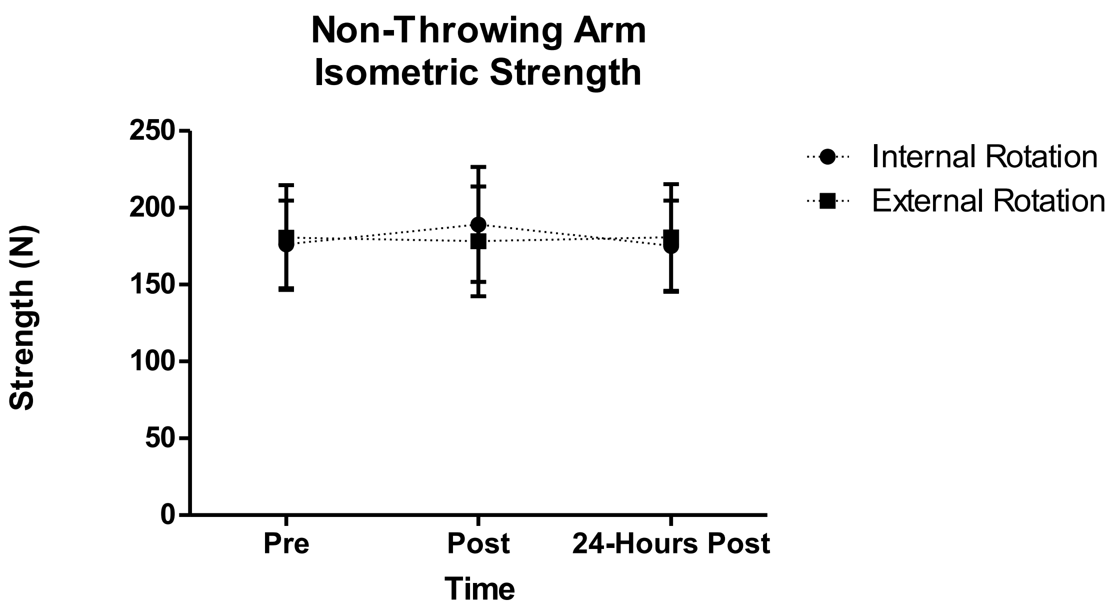


Figure 22. Non-throwing arm isometric strength mean and standard deviations pre, post and 24-hours post aerobic fatigue protocol.

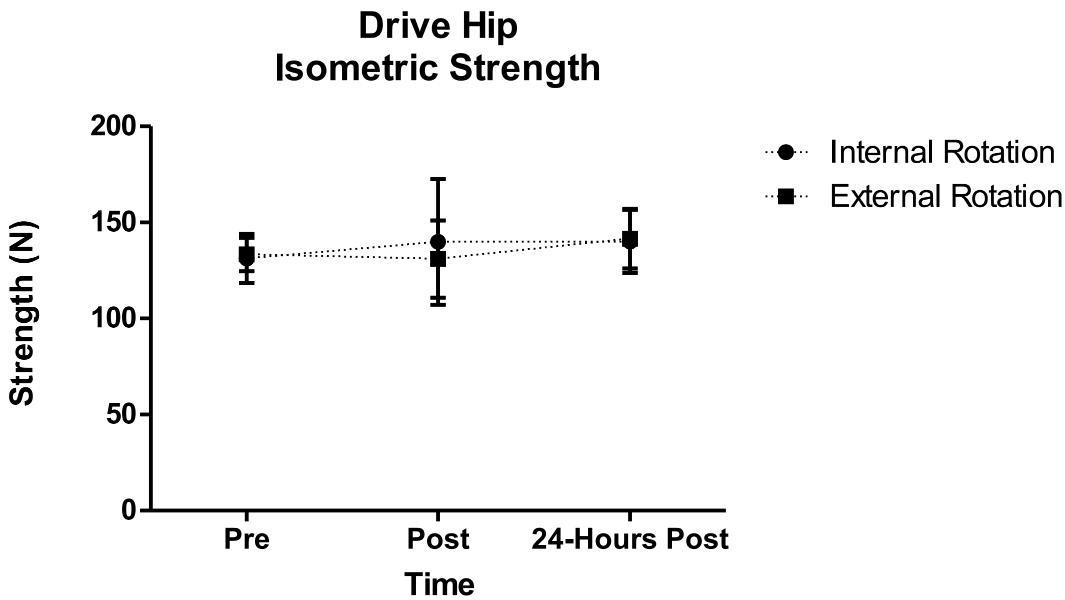


Figure 23. Drive hip isometric strength mean and standard deviations pre, post and 24-hours post drive fatigue protocol.

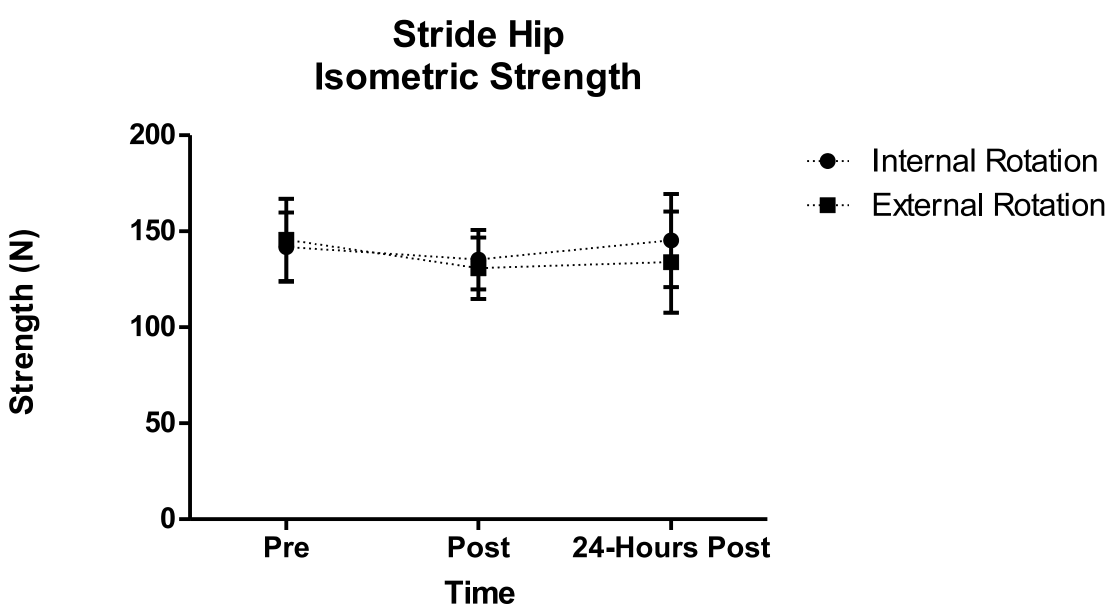


Figure 24. Stride hip isometric strength mean and standard deviations pre, post and 24-hours post aerobic fatigue protocol.

Kinematics and Kinetics

Kinematic and kinetic data for the jump shot are presented in Tables 6-8. Trunk kinematics are presented in Table 6, shoulder and scapula data are in Table 7, and kinetics in Table 8. It was hypothesized that kinematic differences at the pelvis, trunk, shoulder and elbow during the jump shot would be present following both the aerobic fatigue protocol and this hypothesis was partially supported by the data. Kinematic differences were observed using a within subjects repeated measures ANOVA. Kinematic data are presented in Figures 25-29 in effort to better illustrate the interaction main effects. Follow-up ANOVAs were then performed to identify where in the throwing motion that the significant differences were observed. No three or four-way interactions were observed for the shoulder or scapula. Shoulder external rotation decreased from -76.55 ± 13.22° to -73.15 ± 15.61°, at MER, following fatigue. Shoulder elevation and plane of elevation also decreased following aerobic fatigue. In addition to the differences observed at the shoulder, there were also significant changes for scapula internal and external rotation. Scapula external rotation increased at BR from -3.75 ± 9.75° to -8.19 ± 9.87° following fatigue. At the next event in the jump shot motion (MIR), the scapula was positioned in less internal rotation from 7.20 ± 16.35° to 3.29 ± 15.57°. Significant pelvis and trunk kinematic differences were observed following the aerobic fatigue protocol. For both the trunk ($F_{6,54}$= 5.10; p < 0.01; power= 0.99) and pelvis ($F_{3,27}$= 14.47; p < 0.01; power= 1.00) a three-way interaction of event x time x direction was observed. At FC of the jump shot, significant differences were observed for pelvis lateral flexion, pelvis rotation, and trunk flexion. The pelvis was positioned with greater lateral flexion to the contralateral side ($F_{1,9}$= 5.48; p = 0.044; power= 0.551) following aerobic fatigue (-1.25 ± 3.41° to -3.39 ± 4.14°) at FC. Increased contralateral pelvis rotation was also observed in the jump shot following fatigue ($F_{1,9}$= 14.18; p = 0.004;

power= 0.917; -43.07 ± 12.92° to -50.79 ± 12.26°) at FC. Pelvis lateral flexion towards the contralateral side was also significantly greater ($F_{1,9}$= 7.34; p = 0.024; power= 0.675) at BR following aerobic fatigue (-21.90 ± 5.99° to -25.55 ± 7.79°). Additionally the trunk had significantly greater flexion at FC ($F_{1,9}$= 7.57; p = 0.022; power= 0.688) following aerobic fatigue (-16.16 ± 8.84°) compared to when fatigue was not a factor in jump shot mechanics (-13.83 ± 8.95°). Trunk rotation significantly increased ($F_{1,9}$= 6.64; p = 0.03; power= 0.632) from -6.80 ± 10.07° to -12.55 ± 10.97° at MER following fatigue in this sample of team handball players.

It was also hypothesized that fatigue would increase the kinetics about the shoulder and elbow during the jump shot, however, this was not supported. No three or four-way interactions were observed for shoulder and elbow kinetics following aerobic fatigue. Shoulder compression force was greater at MER following aerobic fatigue. Also at the shoulder, medial force increased from 3.6 ± 11.0%BW to 7.2 ± 7.0%BW. Elbow valgus force was greater -16.02 ± 12.34%BW to -21.04 ± 14.69%BW at BR following aerobic fatigue in this sample of team handball players.

Table 6. Jump shot pelvis and trunk kinematics pre and post aerobic fatigue. Mean (SD)

	Pre Fatigue				Post fatigue			
	FC	MER	BR	MIR	FC	MER	BR	MIR
Trunk Flexion (°)	-13.83 (8.95)*	-4.97 (4.22)	-9.92 (5.64)	-17.53 (6.21)	-16.16 (8.84)*	-4.51 (3.88)	-9.47 (4.51)	-17.53 (9.44)
Trunk Lateral Tilt (°)	-1.76 (6.91)	-14.84 (4.23)	-36.61 (10.39)	-40.64 (10.44)	-0.82 (6.71)	-12.58 (7.82)	-36.65 (8.51)	-40.64 (9.44)
Trunk Axial Rotation (°)	-46.74 (18.31)	-6.80 (10.07)*	20.82 (7.90)	19.69 (10.80)	-47.20 (18.72)	-12.55 (10.97)*	21.11 (7.38)	19.69 (10.80)

Flexion [-]/Extension [+]; Left Lateral Tilt [-]/Right Lateral Tilt [+]; Right Rotation [-]/Left Rotation [+]. $P < 0.05$ significance level indicated by *.

Table 7. Jump shot upper extremity kinematics pre and post aerobic fatigue. Mean (SD)

	Pre Fatigue				Post Fatigue			
	FC	MER	BR	MIR	FC	MER	BR	MIR
Shoulder Plane of Elevation (°)	1.27 (12.77)	5.92 (13.56)	14.16 (17.30)	28.78 (27.04)	-6.23 (22.34)	1.91 (14.65)	10.39 (18.15)	25.77 (28.20)
Shoulder Elevation (°)	24.69 (9.64)	95.38 (8.68)	81.41 (9.40)	80.01 (12.19)	24.87 (9.21)	92.21 (12.84)	77.67 (11.43)	81.69 (11.31)
Shoulder Rotation (°)	25.60 (19.09)	-76.55 (13.22)	-53.92 (8.94)	-1.95 (16.42)	30.06 (28.62)	-73.15 (15.61)	-54.28 (10.56)	-0.85 (20.23)
Scapula IR/ER Rotation (°)	6.09 (7.77)	-22.66 (9.60)	-3.75 (9.75)	7.20 (16.35)	-2.75 (11.32)	-22.66 (9.60)	-8.19 (9.87)	3.28 (15.57)
Scapula Up/Dwn Rotation (°)	-2.75 (11.32)	-30.76 (5.39)	-21.63 (9.87)	-13.47 (8.57)	-7.01 (5.33)	-30.76 (5.39)	-20.29 (5.50)	-14.40 (5.13)
Scapula Ant/Post Tilt (°)	3.52 (10.06)	10.73 (10.34)	6.31 (11.48)	7.04 (11.71)	3.52 (10.06)	10.73 (10.34)	5.40 (10.30)	6.32 (11.08)
Elbow Flexion (°)	93.32 (21.20)	95.83 (20.95)	54.03 (9.44)	48.99 (12.40)	96.08 (18.47)	96.18 (9.06)	50.07 (34.33)	45.22 (12.97)

Humeral Plane of Elevation [0=Abduction; 90=Flexion]; Shoulder Internal Rotation [+]/Shoulder External Rotation [-]; Scapula Internal Rotation [+]/External Rotation [-]; Scapula Upward Rotation [-]/Downward Rotation [+]; Scapula Anterior Tilt [-]/Posterior Tilt [+]; Elbow Flexion [+]/Hyperextension [-]. $P < 0.05$ significance level indicated by *.

Table 8. Jump shot kinetics pre and post aerobic fatigue (%BW). Mean (SD)

	Pre Fatigue				Post Fatigue			
Variable	FC	MER	BR	MIR	FC	MER	BR	MIR
Shoulder Ant/Post Force	1.16 (2.03)	-10.40 (14.38)	-35.83 (41.28)	3.55 (11.42)	1.39 (2.12)	-10.06 (14.71)	-41.41 (37.57)	7.23 (13.99)
Shoulder Distraction Force	2.39 (3.18)	0.94 (5.60)	-11.46 (12.51)	-16.67 (8.50)	0.73 (2.87)	2.95 (4.64)	-16.71 (18.20)	-14.94 (15.29)
Elbow Valgus Force	0.62 (1.19)	-5.82 (10.00)	-16.02 (12.34)	-7.48 (7.52)	0.81 (1.49)	-6.94 (8.70)	-21.04 (14.69)	-8.12 (9.12)
Elbow Distraction Force	0.43 (2.58)	2.55 (6.03)	40.00 (10.75)	5.96 (11.12)	-0.44 (2.19)	3.55 (2.34)	38.22 (7.39)	6.53 (9.30)

Shoulder Anterior Force [+]/Posterior Force [-]; Shoulder Compression Force [+]/Distraction Force [-]; Elbow Varus [+]/Valgus Force [-]; Elbow Compression Force [+]/Distraction[-].

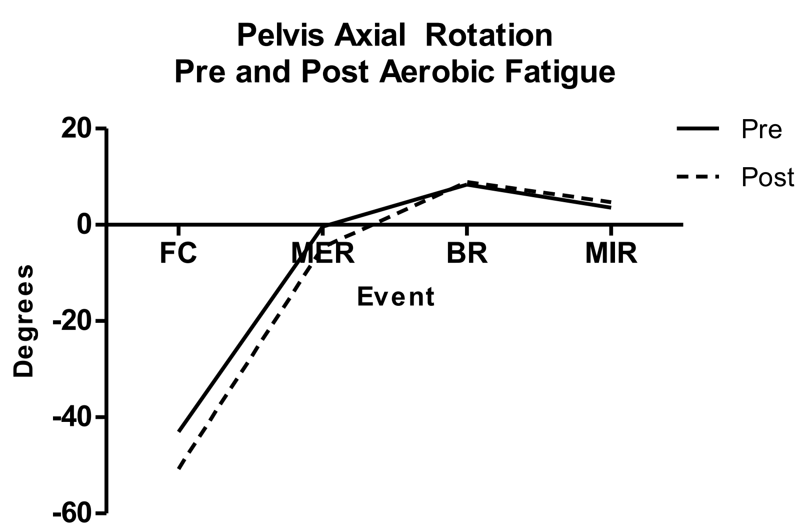
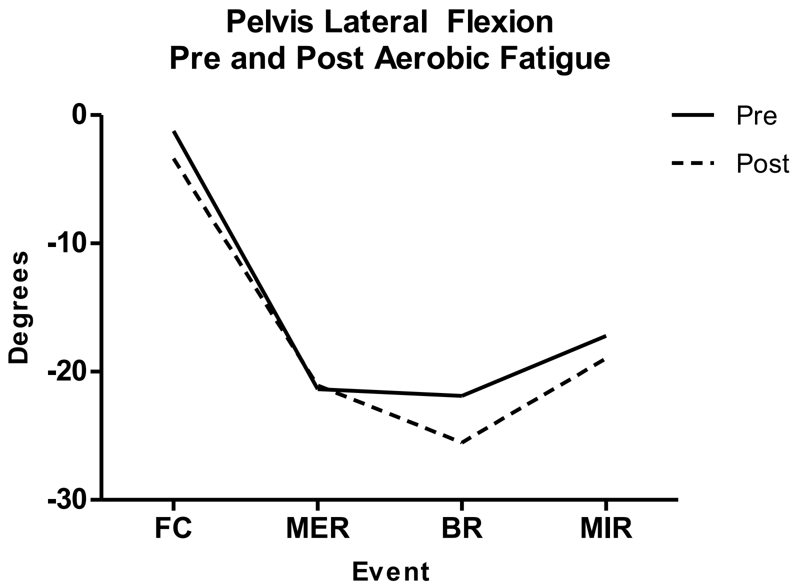


Figure 25. Pelvis axial rotation over time pre and post aerobic fatigue.



*P < 0.05 at BR

Figure 26. Pelvis lateral flexion over time pre and post aerobic fatigue.

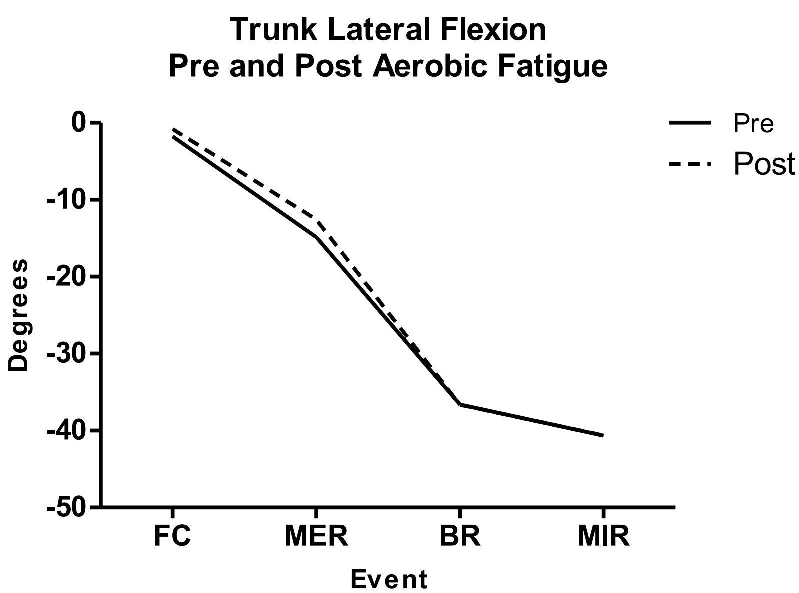
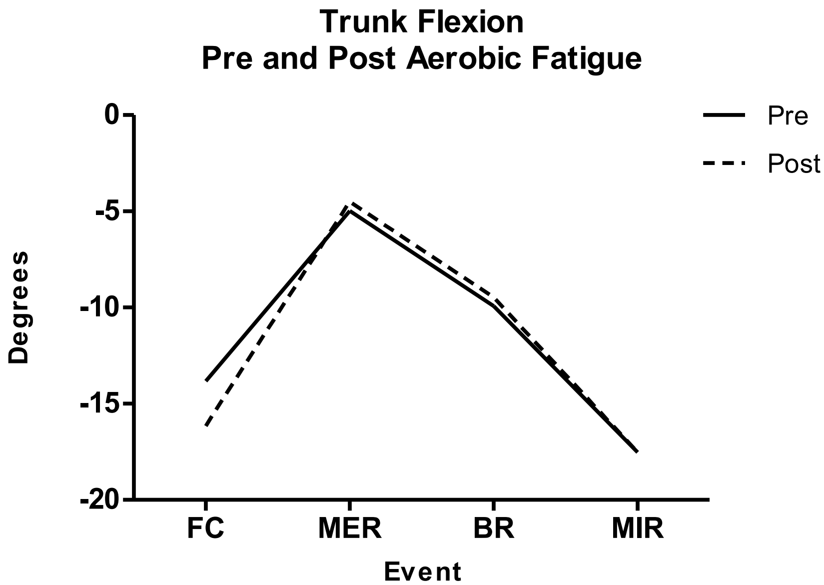
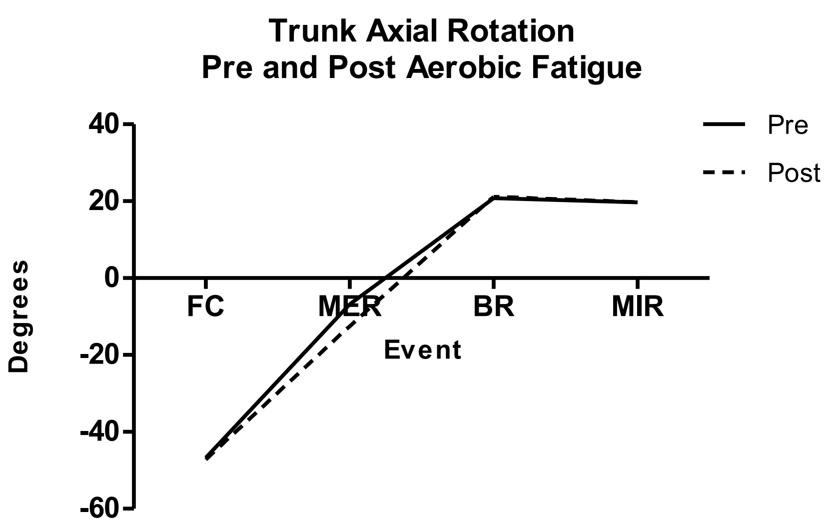


Figure 27. Trunk lateral flexion over time pre and post aerobic fatigue.



*P < 0.05 at FC

Figure 28. Trunk flexion over time pre and post aerobic fatigue.



*P < 0.05 at MER

Figure 29. Trunk axial rotation over time pre and post aerobic fatigue.

CHAPTER V
Discussion

Project objectives were, first, to evaluate kinematic and kinetic changes during the performance of a U.S. national player for the team handball jump-shot following aerobic and throwing fatigue protocols. The second objective was to establish shoulder and hip range of motion patterns and isometric strength in team handball players at baseline, following aerobic and localized fatiguing protocols, and 24-hours following each fatiguing protocol. The role of this chapter was to discuss the results of this study. This section will combine the results of the localized and aerobic fatigue protocols and discuss the following: 1] range of motion, 2] isometric strength, 3] kinematics and kinetics.

The results of this study provide valuable insight into the range of motion patterns in team handball players prior to and following localized and aerobic fatiguing protocols. To the authors knowledge this is the first study to examine the effects of localized and aerobic fatigue on range of motion of the shoulder and hip as well as establish range of motion data in team handball players in the United States. Few studies examining shoulder range of motion in team handball players, in which the current data can be compared, have been reported.[3,88] In both of the previous studies, significant differences between internal and external rotation between the throwing and non-throwing shoulder were present.[3,88] While range of motion differences between shoulders existed in the previous samples, the current data were not significantly different. As the current study revealed, baseline throwing shoulder external rotation was 104.03 ± 8.85° whereas the non-throwing arm was 98.54 ± 11.23°. Lastly, baseline internal rotation of the throwing shoulder was 51.13 ± 13.38° and the non-throwing shoulder was 54.93 ± 7.98°. Similar to the localized fatigue protocol no significant differences in range of motion occurred in this sample of participants prior to, immediately following, and 24 hours post aerobic fatiguing protocol. The lack of significant change in isometric strength and hip range of motion following this fatiguing protocol was surprising because the protocol was designed to mimic the heart rate intensity of running during competition. The results of this study indicate that running to fatigue, at a pre-determined speed, does not have a significant impact on range of motion and isometric strength in male team handball players. It is possible that a more sport-specific aerobic fatiguing protocol that utilizes a combination of sprinting, change-of direction, lateral movements, and jogging may have a different effect on range of motion and isometric strength than the current protocol.

In addition to establishing range of motion between shoulders in the current sample, it is also pertinent to compare the observed baseline range of motion data to the data presented in the literature. Almeida et al.[3] examined team handball players with and without shoulder pain in effort to determine if range of motion may be a contributing factor to shoulder pain. The non-pain group had significantly greater internal rotation of the throwing arm (39.4 ± 11.1°) compared to the pain group (33.3 ± 9.2°).[3] Significantly greater throwing arm external rotation, $p = 0.042$, was recorded in the pain group compared to the non-pain group (108.0 ± 9.8° vs. 102.4 ± 10.6°).[3] Similar range of motion values were observed for throwing arm internal rotation was 44.5 ± 8.5° in the group with no pain (n = 74), 45.0 ± 8.2° for the group with previous pain (n = 40), and 43.6 ± 7.1° (n = 65) in those team handball players currently experiencing pain in the study by Myklebust et al.[88] Similarly, external rotation in the dominant arm for the group with no pain was 106.1 ± 9.5°, 105.0 ± 8.1° for the group with previous pain, and 103.6 ± 8.9° for the players with current pain.[88] Whereas in the current study observed external and internal rotation values were similar to the no pain group.

Athletes in overhead throwing sports often present with an altered range of motion pattern of increased external rotation and decreased internal rotation in their throwing shoulder compared to their non-throwing shoulder.[3,42-44,54,63,104,117,185] Repetitive microtrauma to the anterior capsule has been attributed to the increased external rotation observed in the throwing arm compared to the non-throwing arm.[49] This reduced internal rotation in the throwing shoulder has been termed glenohumeral internal rotation disorder (GIRD).[3,54,65-69] The cause of GIRD is believed to be the result of a contracture of the posterior capsule and the inferior glenohumeral ligaments [3,64,70-72] and torsion to the humeral head.[3,54,65-69] When comparing the results of the current study to the data from the previous studies it is evident that external rotation range of motion values are similar. On the other hand, internal rotation in the current study is quite larger than those data reported in the literature.[3,88] These internal rotation differences, along with the lack of significant difference in range of motion between shoulders, are likely due to the sample of participants that were studied. Team handball is not a popular sport in the United States and the participants in this study only had 2.72 ± 2.17 years of experience playing the sport. These participants all grew up playing other sports and some of which never played a sport that involved repetitive throwing. The physiological adaptations that cause GIRD are likely exacerbated prior to an athlete reaching skeletal maturity are not present in this sample. It is also possible that the difference in internal rotation across studies is due to training differences. The number of weekly practice sessions/games, the amount of throwing during practice/game sessions, and the amount of time for recovery between practice/games may affect range of motion in participants across studies. Additionally, internal rotation may have been greater in the current sample due to the structured strength and conditioning program that the participants perform.

Range of motion of the shoulder in team handball players is beginning to receive attention in the literature, however range of motion at the hip has yet to be reported. As this is the first study to examine hip internal and external range of motion in team handball players, comparisons to other throwing sports will be discussed. The hip range of motion data in the current study are similar to previous data reported by Ellenbecker et al.[78] for elite tennis players and professional baseball pitchers. Baseline hip range of motion was not significantly different between the stride leg and drive leg in team handball players which is consistent with the data of baseball[59] and tennis[78] players. Furthermore, the observation of greater external rotation compared to internal rotation is similar to normative hip rotational profiles.[78,186] Having appropriate amounts of range of motion at the hip is imperative for throwing as it can aid in energy transfer from the lower extremity to the upper extremity.[59,73,187] In particular, proper alignment of the pelvis results in decreased force on the throwing arm and increased ball velocity.[59,188,189] It has been reported that optimal hip rotational values are 45° for both internal and external rotation.[190] The observed range of motion in team handball players was significantly less than the recommended 45° particularly for internal rotation. Similar values of less than 45° have been observed in baseball and tennis players, thus warranting further exploration into the physiological adaptations of dynamic upper extremity movements such as throwing and serving. In baseball pitching, insufficient internal rotation of the drive leg is speculated to lead to throwing across the body, thus limiting the transfer of energy from the lower extremity to the upper extremity and increasing the forces about the shoulder.[59,73,187] Because of this, it has been reported that decreased hip internal rotation of the drive leg may increase a player's susceptibility for upper extremity injury and declined performance.[59,73,187]

Decreased shoulder range of motion and muscle strength is believed to be contributing factors to shoulder injury in overhead athletes.[119-121] Specifically in male team handball players a significant association between external rotation weakness and shoulder injuries throughout the course of a season has been observed.[191] The current study revealed that at baseline, no significant differences between isometric strength in the throwing arm and non-throwing arm were observed. Similarly, no significant changes in isometric strength were observed over the three time periods that were analyzed (pre, post, 24 hours post). The current results differ from Clarsen et al.[191] who reported that external rotation strength was significantly weaker in the throwing arm compared to the non-throwing arm in team handball players. During the acceleration phase of the throwing motion the shoulder must rapidly rotate from a position of maximum external rotation into internal rotation. As this occurs the internal rotators go from eccentrically contracting, at maximum external rotation, to concentrically contracting as the arm moves into internal rotation. As rapid internal rotation is occurring the external rotators act to negatively accelerate the arm by eccentrically contracting. The repeated eccentric contractions of the shoulder external rotators are believed to cause repetitive microtrauma to the posterior capsule and the posterior band of the inferior glenohumeral ligament.[3,64,70,76] It can be speculated that the repetitive microtrauma likely has a negative effect on external rotation strength in addition to the adaptations that occur in joint range of motion. External rotation weakness in team handball players has been associated with shoulder injury over the course of a season.[191] Though the current study did not observe this type of weakness, examining shoulder isometric strength in team handball players may help sports medicine professionals identify players who are at risk for injury. Thus there is a need for established normative strength measures in this population of athletes in order to better understand the isometric strength results in this study.

It was hypothesized that isometric strength and range of motion at the hip and shoulder joint would be altered following the localized fatiguing protocol. Specifically that isometric muscle strength in the shoulder and hip would be decreased from baseline values immediately following the fatiguing protocol but would return to baseline within 24 hours. However this hypothesis was not supported and no significant differences in isometric strength occurred in this sample of participants prior to, immediately following, and 24 hours post localized and aerobic fatiguing protocols. The lack of significant change in isometric strength and hip range of motion following this localized fatiguing protocol is not surprising because the protocol was designed to fatigue the upper extremity through repeated throwing. The lack of significant change in isometric strength and hip range of motion following the aerobic fatiguing protocol was surprising because the protocol was designed to mimic the heart rate intensity of running during competition. The results of this study indicate that running to fatigue, at a pre-determined speed, does not have a significant impact on range of motion and isometric strength. It is possible that a more sport-specific aerobic fatiguing protocol that utilizes a combination of sprinting, change-of direction, lateral movements, and jogging may have a different effect on range of motion and isometric strength than the current protocol.

Regardless of the lack of significant changes observed in this study, it is important to monitor isometric strength data to better understand the role of hip and shoulder strength in team handball players. Shoulder isometric strength has currently only been reported in one sample of male team handball players and these data are useful for comparison purposes.[192] Fieseler et al.[192] examined shoulder internal and external rotation isometric strength in 31 professional team handball players over the course of a season. Prior to the beginning of the season throwing shoulder internal rotation strength was 157 ± 40 N and external rotation was 141 ± 32 N. It was reported that shoulder external rotation strength significantly increased ($p = 0.003$) from week 6 (133 ± 26 N) to week 22 (143 ± 25 N). The aerobic fatigue baseline isometric strength data, in the current study, were greater for both internal (184.78 ± 35.41 N) and external rotation (164.69 ± 42.46 N) compared to the results reported by Fieseler et al.[192] The isometric strength data for the localized fatigue protocol was however less than both the aerobic fatigue protocol data (IR: 131.91 ± 32.73 N; ER: 119.93 ± 27.56 N) and the data reported by Fieseler et al.[192] It is possible that the decreased isometric strength prior to the localized fatigue protocol was related to the players training schedule when the testing occurred. This protocol was performed near the end of a training cycle whereas the isometric strength data for the aerobic fatigue protocol was collected immediately following a break in the training schedule.

While very few significant differences were observed in the range of motion and isometric strength data it was hypothesized that kinematic and kinetic data following fatigue would be altered. Surprisingly, the results revealed very few kinematic and kinetic differences following the localized fatiguing protocol. While studies in baseball pitchers throwing a simulated game[125,193,194] have reported few kinematic changes between the first and last innings that were pitched it was believed that the current protocol would be physically taxing enough to induce changes in jump shot mechanics especially at the upper extremity. Although not significant, shoulder elevation increased between the pre and post localized fatigue trials from 108.28° to 113.05°. These values were not significant from a statistical perspective however there may be clinical implications to the increase in shoulder elevation. In baseball pitching, the recommended position of the humerus, for reducing joint torques and maximizing shoulder stability, has been reported as 90°.[195-197] Computer simulations analyzing the pitching motion suggest that a narrow range of shoulder abduction centering around 90° with slight lateral trunk tilt maximizes wrist and ball velocity.[196] Deviating by as few as 10° of lateral trunk tilt and to 100° of shoulder abduction led to increased elbow varus torque.[196] While there are inherent differences in baseball and team handball, optimal mechanics of the team handball jump shot have yet to be reported thus making it difficult to extrapolate results between the two sports. It is important to note that no kinetic differences at the shoulder or elbow were observed with the increase in shoulder elevation in this sample of team handball players.

To the authors knowledge only two studies examining throwing in team handball have reported shoulder elevation[151,198] van den Tillaar et al.[198] examined the kinematic differences between throwing a handball with a circular versus a whip-like wind up in experienced team handball players. The circular pattern was described as showing similarities to the baseball pitching wind-up motion whereas the whip-like technique was described as moving the ball upwards and then backwards when the throwing motion is initiated.[198] The limitation of this comparison, as with the few other handball studies, was that data were only presented at the event of ball release. Shoulder abduction (elevation) at ball release for the circular technique was 97.0 ± 6.7° which was similar to what was observed in the current study at ball release. Pre-localized fatiguing protocol shoulder elevation was 95.5 ± 8.7° and post shoulder elevation was 98.79 ± 9.08°. However, the participants in the current study were much less experienced compared to those in the van den Tillaar et al.[198] study. These values of shoulder elevation at BR are less than those reported in the localized fatigue protocol and by van den Tillaar et al.[198] van den Tillaar & Cabri[151] observed slightly greater shoulder abduction of 103.0 ± 15.4° in a sample of elite male team handball players,[151] similarly to what was observed at maximum shoulder external rotation in the current study [108.3 ± 11.3°].

The scapula plays a vital role in optimal shoulder function during overhead activities such as throwing. It is necessary to understand the roles of the scapula when examining shoulder motion as there are five major roles of the scapula in facilitating normal shoulder motion.[199] The roles include being a stable base for the articulation of the glenohumeral joint, retraction and protraction, elevation of the acromion, a base for muscle attachment, and the link in sequencing of energy from the lower extremity to the upper extremity.[199] The scapula provides a stable base for the articulation of the glenohumeral joint by maintaining a coordinated moving pattern with the humerus and keeping the glenoid of the scapula and the humeral head aligned.[199] Retraction of the scapula is needed during throwing to provide tension to the anterior musculature for the type of muscle contraction to move from eccentric to concentric as the acceleration phase of throwing begins.[199] The third role of the scapula is elevation of the acromion to increase the subacromial space in which the rotator cuff tendons can pass and avoid impingement.[199] The scapula also serves as a base of attachment for both extrinsic and intrinsic muscles of the shoulder and proper positioning of the scapula is needed to maximize the length tension ratio of each muscle.[199] Lastly, the scapula serves as the link in the kinetic chain that connects the lower extremity to the upper extremity and allows kinetic energy to be funneled to the shoulder. It is clear, based upon the notion that the scapula plays a key role in normal shoulder function during throwing that small changes in the positioning of the scapula may have large effects on the shoulder.

Proper scapula kinematics are paramount to the function of the shoulder during overhead movements.[200] Segmental sequencing and energy transfer, from the lower extremity to the upper extremity, is linked through the scapula and the transfer of energy is dependent on stability of the scapula.[201] Decreased scapula stability may contribute to altered energy transfer from the lower extremity to the shoulder, elbow, wrist and hand. If energy transfer is altered then the distal segments may have to compensate to make up for the decreased energy possibly contributing to upper extremity injury over time.

Previous research has examined changes in scapula kinematics during a fastball pitch in youth baseball pitchers during the first and last innings of a simulated game.[201] The pitchers in this study were limited to pitching up to their age restricted pitch count of 75 pitches and level of fatigue was not quantified at the end of the simulated game. Scapula kinematics did not significantly change following a simulated game however this study provides valuable data on the movement of the scapula during throwing. Upward rotation was -35.6 ± 12.6° at maximum external rotation in the first inning in this sample of baseball pitchers and -35.6 ± 13.7° in the last inning. These values are similar to the amount of scapula upward rotation in the current study of -30.3 ± 12.56° and -35.65 ± 9.78° pre and post fatigue, respectively. When comparing the results between the two studies it can be speculated that the greater upward rotation in the youth baseball pitchers and the similar post fatigue rotation in team handball players may be the result of decreased scapular stability. The lack of significant change in the youth baseball pitchers between the first and last innings may indicate that they do not have adequate upper trapezius, lower trapezius, and serratus anterior strength to control upward rotation of the scapula during pitching. Likewise once a team handball player accumulates localized fatigue of the upper extremity these muscles may have a decreased ability to control the rate of scapula upward rotation. Laudner et al.[200] have hypothesized that upward rotation discrepancies may result in lost center of rotation, decreased kinetic chain function between the lower and upper extremity, and decreased muscular function. If these factors do indeed occur with changes in upward rotation of the scapula then there may also be an increased risk of shoulder injury.[200]

As it is clear that the scapula is paramount in normal shoulder function during throwing, it is also important to understand the other motions that occur at the scapula. Scapular internal and external rotation, as well as anterior and posterior tilt, also contributes to efficient shoulder function. External rotation of the scapula is important during the cocking phase of throwing because it enables a stable base for the shoulder as energy begins to be transferred through the scapula to the shoulder.[199] Once the acceleration phase of the throw begins the scapula quickly moves from external rotation to internal rotation. Inadequate internal rotation of the scapula as the throw progresses into the follow-through phase of throwing increases the forces about the shoulder whereas too much internal rotation can lead to impingement as the scapula rotates down and forward.[199] Furthermore, anterior and posterior tilt of the scapula also contributes to impingement as this motion directly affects the amount of subacromial space. During the cocking phase of throwing the scapula should be positioned in external rotation, posterior tilt, and downward rotation in order to maximize shoulder function and subacromial space. As the throwing motion progresses from here the scapula moves into internal rotation, anterior tilt, and upward rotation. These movements should all occur in a coordinated fashion and controlled by the musculature attached to the scapula.

Oliver et al.[201] also examined internal and external rotation and anterior and posterior tilt of the scapula in their study of youth baseball pitchers. At maximum external rotation of the shoulder the scapula was positioned at -22.7 ± 15.7° of external rotation during the first inning of the simulated baseball game and -20.2 ± 13.3° in the last inning. These values of scapula external rotation are slightly greater than the -18.6 ± 12.0° and -19.3 ± 16.8° of external rotation observed pre and post localized fatigue, respectively in team handball players. Following the aerobic fatigue protocol, the scapula was positioned with more external rotation compared to the pre-fatigue trials. Then as the shot progressed, to shoulder internal rotation, the scapula also had less internal rotation following aerobic fatigue. Anterior and posterior tilt of the scapula during overhead throwing is also critical to normal shoulder mechanics. At maximum external rotation of the shoulder in youth baseball pitchers the scapula was posteriorly tilted 13.2 ± 16.1° in the first inning and 8.2 ± 21.8° in the last inning. When compared to the results following localized fatigue the scapula had slightly greater posterior tilt both pre (15.7 ± 12.1°) and post fatigue (18.9 ± 12.3°) in the team handball jump shot. The slight differences in scapula motion between the baseball pitch and team handball jump shot may be related to the throwing mechanics as well as the size of the ball. It can be speculated that because the jump shot is performed in the air that a player may abbreviate their upper extremity mechanics in effort to quickly release the ball. Another possible explanation for the differences observed between the sports is the size and weight of the two balls. A standard men's team handball weighs 0.46 kg whereas a baseball only weighs 0.14 kg. The additional weight of the team handball may limit some of the motion that occurs at the scapula and shoulder because additional weight must be accelerated by these structures.[202]

While stability of the scapula is paramount to normal shoulder function it is also necessary to have stability proximally at the trunk and pelvis. Stability of these segment is provided by the musculature of the lumbopelvic-hip complex.[203] A stable lumbopelvic-hip complex is needed to generate and transfer energy up the kinetic chain as it has been reported that 51% of total kinetic energy is created by the legs, hip, and trunk.[199] Because a large amount of energy is generated by these structures, kinematic changes to the trunk following fatigue may have implications at the proximal segments of the kinetic chain. In the current study there was a trunk flexion changed from -11.02° to -14.24° at ball release following localized fatigue.

Following the aerobic fatigue protocol trunk flexion significantly increased ($p = 0.022$) at foot contact to -16.16 ± 8.84° compared to -13.83 ± 8.95°. The increase in trunk flexion differs from what has been observed in baseball pitchers as they approach fatigue in a simulated game. Escamilla et al.[193] observed a decrease in trunk flexion at ball release 34 ± 12° to 29 ± 11° in collegiate baseball pitchers who threw between 105 and 135 pitches. It has previously been reported in baseball pitching that as trunk flexion increases, ball velocity also increases and as trunk flexion decreases, ball velocity also tends to decrease.[204] This trend does not seem to be the case in the team handball jump shot because ball velocity decreased even though there was an increase in trunk flexion. Increased trunk flexion has been proposed to help dissipate upper extremity forces during the follow-through phase of throwing.[193] Overall no kinetic differences were observed following localized fatigue and it is difficult to relate the lack of changes to the kinematics of the throw because ball velocity also decreased in this sample. In addition to the increase is trunk flexion; the trunk had less lateral flexion at maximum external rotation following localized fatigue. These results indicate that the trunk was in a more neutral, upright position during the throw following fatigue. This decrease in trunk lateral flexion may have occurred as the participants attempted to maintain their center of gravity between the base of support.

Following the completion of the aerobic fatigue protocol trunk rotation significantly increased ($p = 0.03$) from -6.80 ± 10.07° to -12.55 ± 10.97° at maximum external rotation indicating that the participants were rotated more to the non throwing side, towards the target, once they were fatigued. Similar results were observed at the pelvis where increased rotation was also observed (-43.07 ± 12.92° to -50.79 ± 12.26°). The pelvis was positioned with greater lateral flexion to the non-throwing side following aerobic fatigue (-1.25 ± 3.41° to -3.39 ± 4.14°; p =

0.044) at foot contact. Pelvis lateral flexion towards the non-throwing side was also significantly greater ($p = 0.024$) at ball release following aerobic fatigue (-21.90 ± 5.99° to -25.55 ± 7.79°). These alterations in trunk and pelvis kinematics may lead to decreased proximal stability and energy transfer to the upper extremity. If decreased energy is transferred to the upper extremity it is possible that the upper extremity will compensate by trying to increase segmental contributions to the outcome of the shot. Kibler[199] reports that a 20% decrease in energy transfer from the hip and trunk, to the arm, necessitates an 80% increase in mass or a 34% increase in rotational velocity at the shoulder to create an equivalent resultant force at the hand. The muscles of the shoulder function mainly to provide stability and there is less reliance on force generation. Increased shoulder rotational velocity over time due to an unstable trunk and pelvis may contribute to the incidence of injury.

It is evident that the body relies on both scapula and lumbo-pelvic stability during throwing however if stability at either of these segments are altered than implications exist for increased kinetics about the shoulder and elbow. No significant differences in shoulder and elbow kinetics were observed following the localized or aerobic fatigue protocols. Following aerobic fatigue, shoulder compression force at maximum external rotation increased from 0.94 ± 5.60%BW to 2.95 ± 4.60%BW. The rotator cuff functions primarily to stabilize the humeral head in the glenoid.[205] In effort to stabilize the humeral head in the glenoid the rotator cuff must provide a compressive force to the shoulder during dynamic overhead movements such as throwing. This shoulder compressive force supplied by the rotator cuff musculature is necessary to resist the concurrent glenohumeral distraction that is present during throwing. Shoulder compressive force during the deceleration phase of pitching has been reported to reach 1090 N.[206] Elbow valgus force was changed from -16.02 ± 12.34%BW to -21.04 ± 14.69%BW at ball release following aerobic fatigue. The literature reports that kinetics about the shoulder and elbow are greatest during the deceleration or follow through phase of pitching[206-208] and similarly at maximum shoulder internal rotation when catchers throw to second base from the stance position.[167] Similar to the reported throwing literature elbow kinetics were greatest at ball release and shoulder compression force was greatest at maximum internal rotation. It is interesting to note that kinetic differences were not observed following localized fatigue even though there was a decrease in ball speed and following aerobic fatigue while ball speed stayed consistent. This could be an indication that kinematic compensations are occurring in the kinetic chain but further research is needed to determine the underlying cause of the increased kinetics. It is likely that the proximal segments of kinetic chain became fatigued during the aerobic protocol and in effort to maintain a similar ball speed compensations occurred at the more distal segments.

It can be argued that changing the amount of shoulder elevation during the jump shot during a game can be advantageous for a player. From a performance standpoint, altering the release point of the shot allows a player to shoot either high or low on the goal making it more difficult for the goalie to defend. Implementing different arm angles and subsequent release points during a game is highly dependent on the positioning of the defensive players as well as the angle that a player wishes to shoot. For example, if a defender is blocking a clear shot to the goal then a player may elect to use a sidearm shot around the defender or try to go over the player with an overhead shot by increasing the elevation of their arm. Changing the plane at which the shot travels, vertically or horizontally, adds another variable that the goalie must account for when defending a jump shot.

While examining changes in jump shot kinematics during competition is likely not practical in most situations, two variables that can easily be tracked during competition for signs of fatigue in a player is ball velocity and shot accuracy. Following the localized fatigue protocol ball velocity decreased from 19.8 m/s (44.2 mph) to 18.8 m/s (42.1 mph). Similarly, small decreases in ball velocity have been reported across baseball simulated game studies.[193] Escamilla et al.[193] observed a significant decrease (34.7 m/s to 33.7 m/s) in ball velocity of collegiate baseball pitchers in the last two innings of a simulated game compared to the first two innings. In addition to a decrease in ball velocity following fatigue, there was also a decrease in shot accuracy in this sample of team handball players. Shot accuracy pre fatigue was 60% and following the fatigue protocol accuracy decreased to 52%. To the authors knowledge this is the first study to report throwing accuracy prior to and following a fatigue protocol. The decreases in ball velocity and shot accuracy help to validate that the participants in this study did reach a fatigued state. It is possible that once the participants were fatigued they sacrificed jump shot ball velocity in order to have better accuracy and hit the target. If sacrificing ball velocity was a factor in shot accuracy then there may be a greater decrease in accuracy during competition when other external factors (defense and goalie) are present.

Limitations

This study provides valuable data on the effects of localized fatigue on team handball jump-shot mechanics however limitations do exist. This study was performed in a controlled laboratory setting rather than a competition setting. Performing this study in a laboratory environment makes it difficult to determine if the results are indicative of a competitive setting. The participants did not have to take into account the actions of the defense and the goalie in the laboratory and these external factors could have significant influence on jump shot mechanics. A benefit of being in a controlled laboratory setting is that kinematic and kinetic measures could easily be obtained and more accurate data could be collected compared to a competitive setting.

In addition to the testing setting being a limitation, the fatigue protocol that was chosen involved throwing a medicine ball instead of a team handball. Ideally if a team handball could have been used it would have been more revealing of the fatigue that may be sustained in live competition. Pilot testing was performed with both a team handball and a medicine ball within the confined laboratory space proved difficult to keep a consistent pace of throwing into a rebounder because the ball would travel fast in unknown directions when it hit the rebounder. In effort to fatigue the participants in the most time efficient manner the medicine ball protocol was selected. When performing the fatiguing protocol there was no standard pace for each throw to be made and this may have contributed to the difference in the number of throws that it took to reach fatigue between participants. Some participants threw at a much faster pace than others even though all participants were instructed to throw the ball as soon as they caught it off of the rebounder. There were times that a researcher had to catch the ball off of the rebounder because the rebound angle was directed towards them and not the participant thus delaying the timing of the participants following throw.

Muscular fatigue is individualized and subjective for each participant and is dependent on many factors such as genetics, motivation, overall conditioning, specificity of training, and cumulative stress from training.[193] This study did not control for practice, strength training workouts or individual stretching programs that participants may have completed prior to and following testing. By not accounting for these variables there may have been changes in range of motion that were not observed in this sample. Unfortunately, it was not possible to have participants avoid practice and training for a period of three days while testing was being performed. This sample was on the same team and therefore had similar training programs throughout the two weeks that testing occurred. A final limitation of this study was that the number of throws was capped to avoid having participants make over 1,000 throws during the fatigue protocol. This was done as a safety precaution to try and prevent upper extremity injury during testing as participants were extremely motivated to try and beat the number of throws that previous participants made during testing. All participants were required to reach a level of 20 on the RPE scale and they had to maintain this level of fatigue for 40 throws once this level was reached.

The aerobic fatiguing protocol was performed a minimum of one week following the localized fatiguing protocol and the timing was designed to test the participants following a two-week break in training in effort to limit any confounding factors of fatigue from training. Nevertheless, the end result of reaching an RPE level of 20 and running for as long as each participant could was met and this was the overall goal of the fatigue protocol. Another limitation of this study was the variability in playing experience (1-8 years) of the participants that volunteered. Because of the variability in team handball playing experience it is possible that the observed differences following fatigue cannot be generalized to more experienced players.

Future Research

Regardless of the limitations that exist in this study, valuable data are provided but there is still a great need for understanding the role of fatigue on throwing mechanics in team handball players. Fatiguing protocols that are more closely related to the competitive demands of team handball should be developed to better determine kinematic changes that may occur as a result of fatigue. Future research should aim to examine injury prevalence and kinematics in a large sample of experienced team handball players in an effort to establish if relationships between throwing kinematics and injury exist. If relationships between these variables do in fact exist then further examining the effects of fatigue can have important implications on the development and implementation of injury prevention protocols in team handball players. The current study did not examine the contributions of muscle activation on the kinematics and kinetics of the jump shot prior to or following aerobic fatigue. Future research should also include the examination of muscle activation and firing patterns during the jump shot to better understand the role of fatigue.

This study is novel because it is the first attempt to examine the role of fatigue on jump shot mechanics in team handball players. Furthermore, this study aimed to examine two possible sources of fatigue that may be sustained by team handball players in competition. It was hypothesized that range of motion, isometric strength, and kinematics and kinetics during the jump shot would change following each fatiguing protocol though remarkably few differences were observed. It is likely, that while few changes were observed in this study, cumulative fatigue would have a greater effect on range of motion, isometric strength, and the kinematics and kinetics of throwing in team handball players than what was observed after a single bout of fatigue. If these fatiguing protocols were performed on consecutive days then more significant differences in jump shot kinematics would likely have been observed. During team handball tournaments the schedule requires that teams play a game a day for 3-5 consecutive days with the additional practice session that typically occur. This scheduling may not allow for adequate recovery time from the physical demands of the sport. During a team handball game certain position players may make approximately 175 throws (unpublished data) and it is likely that this number is exceeded in most practice sessions. Repetitive throwing, with insufficient recovery time and altered mechanics, may be a contributing factor to the prevalence of shoulder injuries in team handball. Seil et al.[153] identified the shoulder as the most frequent site to experience overuse symptoms over the course of a year. Additionally, shoulder pain in elite German team handball players accounted for 40% of time lost injuries over a six-month period.[88,89] Analysis of the effects of cumulative fatigue on mechanics and injury are needed to establish how these factors are related so that injury prevention and enhance strength and conditioning programs can be created.

Summary

H01: Kinematic differences at the pelvis, trunk, shoulder and elbow during the jump shot will be present following both the aerobic and localized fatigue protocols.

Of the analyses performed, there was only one significant interaction present in this sample. A significant three-way interaction, for the pelvis, at event (MER) x time (pre, post) x direction (rotation, lateral flexion) was observed ($F_{3,30} = 4.81$, $p = 0.008$; power = 0.86) for the localized fatigue protocol. At MER, pelvis rotation significantly increased following localized fatigue going from -13.08° to -2.57°. These alterations in pelvis kinematics may lead to decreased proximal stability and energy transfer to the upper extremity. For the aerobic fatigue protocol, the pattern of pelvis rotation was similar to the localized fatigue protocol. However following aerobic fatigue, increased pelvis rotation, to the right, was observed (-43.07 ± 12.92° to -50.79 ± 12.26°) at FC.

When examining pelvis lateral flexion/tilt during the throwing motion at FC the pelvis is almost in a neutral position which is indicated by 0 degrees. As the throwing motion progresses the pelvis begins to laterally flex toward the stride leg. Pelvis lateral flexion towards the contralateral (stride leg) side was also significantly greater ($F_{1,9}$= 7.34; $p = 0.024$; power= 0.675) at BR following aerobic fatigue (-21.90 ± 5.99° to -25.55 ± 7.79°).

H02: Fatigue will increase the kinetics about the shoulder and elbow during throwing.

This hypothesis did not prove to be true for either the localized or aerobic fatigue protocols. However this study does provide valuable baseline kinetic data in which future research can build upon for the jump shot.

H03: There will be decreased glenohumeral internal rotation and increased external rotation immediately following and 24 hours following each fatiguing protocol.

This hypothesis did not prove to be true for either the localized or aerobic fatigue protocols. Athletes in overhead throwing sports often present with an altered range of motion pattern of increased external rotation and decreased internal rotation following a throwing performance and therefore this study sought to determine if similar range of motion patterns exist in team handball players. Range of motion did not significantly change immediately following or in the 24 hours following each fatiguing protocol. When comparing the results of the current study to data from the previous studies, it is evident that throwing arm external rotation range of motion values are similar however internal rotational values quite larger than those previously reported.[3,88]

H04: Isometric muscle strength in the shoulder and hip will be decreased from baseline values immediately following each fatiguing protocol but will return to baseline within 24 hours.

This hypothesis did not prove to be true for either the localized or aerobic fatigue protocols. Similar to the data for range of motion, no significant isometric strength differences were observed over time in this sample of team handball players. This study does however provide valuable data on isometric strength patterns in team handball players that can be used for comparison purposes in future studies.

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Appendix A

TEAM HANDBALL

HEALTH and SPORT HISTORY QUESTIONNAIRE

Part 1. Participant Information

[Please print]

ID #: ______________________________

Age: _______ State: __________________ Phone: __________________Email: ____________________

Height: _____ft _____in   Weight: ________lbs

Part 2. Athletic Participation

(Circle or fill in your responses)

1. Are you currently cleared to participate in team handball?   **YES**   **NO**

2. What arm do you shoot with most frequently?   **RIGHT**   **LEFT**

3. What position is your primary position?

4. At what competition level are you currently playing?

5. For how many years have you been participating at this level?   ________

6. List all leagues you played in within the past year

____
____

7. Do you play in every game?   **YES**   **NO**

8. Is team handball your primary sport?   **YES**   **NO**
   List all sports you play competitively

   ____

9. How many years have you played competitive team handball? __________

10. During the season, how many hours per week do you spend with the following?
a. Playing team handball: _____**hrs/week**
b. Upper extremity training/conditioning: _____ **hrs/week**
c. What is the average number of games you play per week ________?
d. What is the average number of days in between games ______?

11. During the off-season, how many hours per week do you spend on the following?
a. Playing team handball: _____**hrs/week**
b. Upper extremity training/conditioning: _____**hrs/week**

12. Estimate the typical amount of throws (warm-up through cool-down) during a typical:
a. In-season practice: _______**throws**
b. Game day: _______**throws**

13. Estimate the number of throws you make at an effort level greater than 90% of your maximal effort during
a. In-season practice: _____ **throws**
b. Game day: _____ **throws**

Part 3. Medical History

14. Are you allergic to adhesive tape or other adhesive products? **YES NO**
If **YES, explain**:
____

15. Have you ever had surgery on your throwing arm before? **YES NO**
If **YES, explain**:
____
____

If YES, on what part(s)? **SHOULDER ELBOW WRIST HAND/FINGER**

If YES, how long ago? ______ **Years**

16. In the past year, have you had any injury to your upper-extremity that has caused you to miss a practice or game? **YES NO**
If **YES, explain**:
____
____

If YES, on what part(s)? **SHOULDER ELBOW WRIST HAND/FINGER**

17. Do you currently experience pain/stiffness in your shoulder or elbow before, during or after throwing?
YES NO

If **YES, please explain** and continue onto question 20:

____

____

If **NO, please sign on page 3**.

IF you answered YES to question 19:

18. For how long have you been experiencing pain? (Indicate a number next to 1 category)
 _____**Years** _____**Months** _____ **Days**

19. When you do experience pain, how would you describe the onset of pain? (Circle one)
 SUDDEN GRADUAL

20. When you do experience pain, how is it related to activity? (Circle one)
 ASSOCIATED WITH USE INTERMITTENT ALL THE TIME

21. Have you changed your training/competition habits because of upper extremity pain? **YES NO**

If **YES, explain**:

____

____

22. Have your activities of daily living been effected by your pain? **YES NO**

If **YES, explain**:

____

____

23. Has your pain disrupted your sleep? **YES NO**

If **YES, explain**: ____

____

24. Have you sought medical consultation because of your pain? **YES NO**

If **YES, explain**:

____

____

25. Have you been given treatment for your pain? **YES NO**

If **YES, explain**:

____

____

26. When you do experience pain, what is the intensity of the pain (1= NO pain; 10= unbearable pain)?

NO PAIN **UNBEARABLE PAIN**

1 2 3 4 5 6 7 8 9 10

I hereby state, to the best of my knowledge, my answers to the above questions are complete and correct.

Signature of Participant: ____

Appendix B Informed Consents

AUBURN UNIVERSITY

COLLEGE OF EDUCATION

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMED CONSENT for a Research Study entitled

Role of Aerobic Fatigue on Throwing Mechanics in Team Handball

Auburn University

CONSENT TO PARTICIPATE IN RESEARCH

Explanation and Purpose of the Research

You are being asked to participate in a research study for the Sports Medicine & Movement Group in the Department of Kinesiology by Dr. Gretchen Oliver. Before agreeing to participate in this study, it is vital that you understand certain aspects of what might occur. This statement describes the purpose, methodology, benefits, risks, discomforts, and precautions of this research. This statement describes your right to confidentiality and your right to discontinue your participation at any time during the course of this research without penalty or prejudice. No assurances or guarantees can be made concerning the results of this study.

This study is designed to examine the differences in the throwing mechanics across different throws of team handball players' pre and post fatigue. To investigate this, joint kinematic, kinetic, temporal, and range of motion data will be collected during jump throws before and after you exceed fatigue.

Research Procedures

To be considered for this study, you must have participated in team handball at least four days a week at a competitive level and be between the ages of 20-40 years old. You must also be deemed free of injury, surgery, and pain for the last 6 months. You must also not have an allergy to adhesive tape. Throwing arm dominance will not be a selection factor for this study.

Testing in this research will require the evaluation of height, body mass, age, and range of motion. Body mass and height will be measured with Motion Monitor motion capture system and will be recorded to the nearest tenth of a kilogram and centimeter. Age will be determined from this consent form and will be recorded to the nearest month. Range of motion will be measured with a goniometer and will be recorded to the nearest degree.

Testing will occur over the course of three separate days. Once all preliminary paperwork has been completed, you will need to be dressed loose fitting athletic attire for testing. Session 1 will consists of VO2max testing. VO2 max testing will use a standard testing protocol that consists of the following: 5 minute easy sub max run (2 minute warm up, 3 minute steady state); a three minute moderate sub max run (steady state); three minute fast sub max run (steady state); incremental 2% increases in grade until you quit running. This testing session will last approximately 30 minutes.

During session 2 you will perform the aerobic fatiguing protocol. Range of motion of the shoulder and hip will be first be measured and recorded. To measure shoulder range of motion, you will lay supine on the table with your arm hanging off the side at the shoulder. An investigator will hold the your arm parallel to the frontal plane with your elbow flexed to ninety degrees. The investigator will then passively rotate your arm in the sagittal plane until maximal internal rotation is reached. This will then be repeated for maximal external rotation. For hip range of motion, you will sit on a table with their lower leg hanging off the side. An investigator will passively rotate your lower leg in the frontal plane until maximal internal rotation is reached. This will then be repeated for maximal external rotation.

Similar procedures will be performed to measure strength. To measure shoulder strength you will be positioned lying on a table with their shoulder abducted and the elbow flexed. You will then externally/internally rotate against a hand held dynamometer that will be located proximal to the ulnar styloid. Supraspinatus strength will be measured with you seated and your arm internally rotated and flexed in the scapular plane. For the latissimus dorsi muscle you will be prone (on stomach) on a table with your arm rotated in a neutral position and extended by your side. You will then adduct (move towards your body) your arm against a hand held dynamometer while performing an isometric contraction. An isometric contraction will be required to last 5-6 seconds at maximal effort. In order to reduce the effects of fatigue a rest period of 20-30 seconds will be allotted between each of the three testing trials

Next, electromagnetic sensors will be placed on your legs, arms, torso, and neck. Placement of the markers at these locations will allow the movement of the joint centers to be properly monitored during testing.

Once these measurements have been collected and following the placement of the markers, you will perform your own specified pre-competition warm-up routine. During the warm-up period, we ask that you contribute five minutes to throwing jump shots. After completing the warm-up, maximal effort will be made into a standard size handball goal. Once 5 accurate jump shots have been performed you will begin the fatiguing protocol. You will be asked to run as long as they can (time to exhaustion) on a treadmill at 80% work intensity (as determined by your VO2max results). Following fatigue, 5 accurate jump shots will be performed. This testing session will last approximately 1 hour 30 minutes.

Subsequent 24-hours follow-up testing to reassess range of motion and strength will be approximately 5 minutes.

Potential Risks

As with any movement research, certain risks and discomforts may arise. The possible risks and discomforts associated with this study are no greater than those involved in competitive handball and may include: death, muscle strain, muscle soreness, ligament and tendon damage, and general overuse injury to the throwing arm. Every effort will be made to minimize these risks and discomforts by selecting participants who are currently playing competitively. It is your responsibility, as a participant, to inform the investigators if you notice any indications of injury or fatigue, or feel symptoms of any other possible complications that might occur during testing. You can stop testing at any time you desire and testing will end when you reach your maximum estimated heart rate (220-age).

To reduce the risk of injury, certain precautions will be taken. During the fatiguing protocol, two board certified athletic trainers will be present to monitor you as you throw. Ample warm-up and cool-down periods will be required of you, water will be provided to you as needed, and ice will be made available after testing.

Confidentiality
All information gathered in completing this study will remain confidential. Your individual performance will not be made available for public use, and will not be disclosed to any person(s) outside of the research team. The results of this study may be published as scientific research. Your name or identity shall not be revealed should such publication occur.

The researcher will try to prevent any problem that could happen because of this research. If at any time there is a problem you should let the researcher know and she will help you. Should an emergency arise, we will call 911 and follow our Emergency Action Plan. You are responsible for any cost associated with medical assistance.

Participation and Benefits

Participation in this research is strictly voluntary and refusal to participate will result in no penalty. You will be allowed to withdraw consent and discontinue your participation in this research at any time; without bias or prejudice from the Auburn University or the research team.

By participating in this study, you will receive information regarding throwing mechanics that may help prevent injury. This will allow you the opportunity to alter your training programs in an effort to minimize injury resulting from fatigue. By receiving this information, you may be able to better determine when fatigue begins to alter your throwing mechanics.

Questions Regarding the Study

If you have questions about this study, please ask them now. If you have questions later you may contact Dr. Gretchen Oliver, 844-1497 or goliver@auburn.edu.

If you have any questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or email at irbadmin@auburn.edu or IRBChair@auburn.edu.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

_______________________________________ ______yr.______mo.
Printed Name of Participant Age of Participant

_______________________________________ _______________
Signature of Participant Date

The above consent form was read, discussed, and signed in my presence. In my opinion, the person signing said consent form did so freely and with full knowledge of its contents.

_______________________________________ _______________
Signature of Investigator, Dr. Gretchen Oliver Date

AUBURN UNIVERSITY

COLLEGE OF EDUCATION

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMED CONSENT for a Research Study entitled

Change in Team Handball Throwing Mechanics Following A Fatiguing Protocol

Auburn University
CONSENT TO PARTICIPATE IN RESEARCH

Explanation and Purpose of the Research

You are being asked to participate in a research study for the Sports Medicine & Movement Group in the Department of Kinesiology by Dr. Gretchen Oliver. Before agreeing to participate in this study, it is vital that you understand certain aspects of what might occur. This statement describes the purpose, methodology, benefits, risks, discomforts, and precautions of this research. This statement describes your right to anonymity and your right to discontinue your participation at any time during the course of this research without penalty or prejudice. No assurances or guarantees can be made concerning the results of this study.

This study is designed to examine the differences in the throwing mechanics across different throws of team handball players' pre and post fatigue. To investigate this, joint kinematic, kinetic, temporal, and range of motion data will be collected during standing throw, throw with a run-up, and jump throw with a defensive opposition player before and after you exceed fatigue.

Research Procedures

To be considered for this study, you must have participated in team handball at least twice a week at a competitive level. You must also be deemed free of injury, surgery, and pain for the last 6 months. You must also not have an allergy to adhesive tape. Throwing arm dominance will not be a selection factor for this study.

Testing in this research will require the evaluation of height, body mass, age, and range of motion. Body mass and height will be measured with Motion Monitor motion capture system and will be recorded to the nearest tenth of a kilogram and centimeter. Age will be determined from this consent form and will be recorded to the nearest month. Range of motion will be measured with a goniometer and will be recorded to the nearest degree.

Once all preliminary paperwork has been completed, you will need to be dressed loose fitting athletic attire for testing. Range of motion of the shoulder and hip will be first be measured and recorded. Next, electromagnetic sensors will be placed on your legs, arms, torso, and neck. Placement of the markers at these locations will allow the movement of the joint centers to be properly monitored during testing.

Once these measurements have been collected and following the placement of the markers, you will perform your own specified pre-competition warm-up routine. During the warm-up period, we ask that you contribute five minutes to throwing the 3 types of throws being examined in this study. After completing the warm-up, maximal effort will be made into a standard size handball goal.

You will be directed to make standing throws, throws with a run-up, and jump in a randomized manner provided by the research team. A fatigue scale of 0-3 will be used to assess your muscular fatigue during the protocol. Once you have reached a level of 3, you will complete 3 trials each for the standing throw, throw with a run-up, and jump throw. Once testing is complete, range of motion will be measured again. After 24 hours, 48 hours, and 72 hours, you will return to have range of motion measured again. We estimate that the initial data collection session will require 1.5 hours of time, and each subsequent visit will require 10 minutes.

Potential Risks

As with any movement research, certain risks and discomforts may arise. The possible risks and discomforts associated with this study are no greater than those involved in competitive handball and may include: muscle strain, muscle soreness, ligament and tendon damage, and general overuse injury to the throwing arm. Every effort will be made to minimize these risks and discomforts by selecting participants who are currently playing competitively. It is your responsibility, as a participant, to inform the investigators if you notice any indications of injury or fatigue, or feel symptoms of any other possible complications that might occur during testing.

To reduce the risk of injury, certain precautions will be taken. During the fatiguing protocol, two board certified athletic trainers will be present to monitor you as you throw. Ample warm-up and cool-down periods will be required of you, water will be provided to you as needed, and ice will be made available after testing.

Confidentiality
All information gathered in completing this study will remain confidential. Your individual performance will not be made available for public use, and will not be disclosed to any person(s) outside of the research team. The results of this study may be published as scientific research. Your name or identity shall not be revealed should such publication occur.
The researcher will try to prevent any problem that could happen because of this research. If at any time there is a problem you should let the researcher know and she will help you. Should an emergency arise, we will call 911 and follow our Emergency Action Plan. You are responsible for any cost associated with medical assistance.

Participation and Benefits

Participation in this research is strictly voluntary and refusal to participate will result in no penalty. You will be allowed to withdraw consent and discontinue your participation in this research at any time; without bias or prejudice from the Auburn University or the research team.

By participating in this study, you will receive information regarding throwing mechanics that may help prevent injury. This will allow you the opportunity to alter your training programs in an effort to minimize injury resulting from fatigue. By receiving this information, you may be able to better determine when fatigue begins to alter your throwing mechanics.

Questions Regarding the Study

If you have questions about this study, please ask them now. If you have questions later you may contact Dr. Gretchen Oliver, 844-1497 or goliver@auburn.edu.

If you have any questions about your rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or email at irbadmin@auburn.edu or IRBChair@auburn.edu or the primary investigator at goliver@auburn.edu or (334)-844-1497.

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

____ ______yr.______mo.

Printed Name of Participant Age of Participant

____ __________________

Signature of Participant Date

The above consent form was read, discussed, and signed in my presence. In my opinion, the person signing said consent form did so freely and with full knowledge of its contents.

____ __________________

Signature of Investigator, Dr. Gretchen Oliver

Appendix C Statistical Outputs

Localized Fatigue Protocol

Tests of Within-Subjects Effects

Localized Fatigue Range of Motion Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	2	3.972	.035	.284	.643
Error(time)	20				
location	1	849.394	.000	.988	1.000
Error(location)	10				
rotation	1	623.679	.000	.984	1.000
Error(rotation)	10				
dom	1	.001	.977	.000	.050
Error(dom)	10				
time * location	2	6.340	.007	.388	.848
Error(time*location)	20				
time * rotation	2	17.953	.000	.642	.999
Error(time*rotation)	20				
location * rotation	1	181.773	.000	.948	1.000
Error(location*rotation)	10				
time * location * rotation	2	9.320	.001	.482	.956
Error(time*location*rotation)	20				
time * dom	2	.281	.758	.027	.088
Error(time*dom)	20				
location * dom	1	.039	.848	.004	.054
Error(location*dom)	10				
time * location * dom	2	.092	.913	.009	.062
Error(time*location*dom)	20				
rotation * dom	1	6.974	.025	.411	.664
Error(rotation*dom)	10				
time * rotation * dom	2	4.380	.026	.305	.689
Error(time*rotation*dom)	20				
location * rotation * dom	1	5.059	.048	.336	.529
Error(location*rotation*dom)	10				
time * location * rotation * dom	2	1.690	.210	.145	.313
Error(time*location*rotation*dom)	20				

Tests of Within-Subjects Effects

Localized Fatigue Isometric Strength Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	2	1.768	.196	.150	.326
Error(time)	20				
location	1	.024	.881	.002	.052
Error(location)	10				
rotation	1	5.981	.035	.374	.598
Error(rotation)	10				
dom	1	.135	.721	.013	.063
Error(dom)	10				
time * location	2	.354	.706	.034	.099
Error(time*location)	20				
time * rotation	2	1.037	.373	.094	.205
Error(time*rotation)	20				
location * rotation	1	.062	.808	.006	.056
Error(location*rotation)	10				
time * location * rotation	2	.410	.669	.039	.107
Error(time*location*rotation)	20				
time * dom	2	1.667	.214	.143	.309
Error(time*dom)	20				
location * dom	1	.008	.929	.001	.051
Error(location*dom)	10				
time * location * dom	2	.178	.838	.017	.074
Error(time*location*dom)	20				
rotation * dom	1	.030	.866	.003	.053
Error(rotation*dom)	10				
time * rotation * dom	2	.304	.741	.030	.092
Error(time*rotation*dom)	20				
location * rotation * dom	1	.986	.344	.090	.147
Error(location*rotation*dom)	10				
time * location * rotation * dom	2	1.136	.341	.102	.222
Error(time*location*rotation*dom)	20				

Tests of Within-Subjects Effects

Localized Fatigue Kinetic Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	3	.129	.942	.013	.071
Error(time)	30				
prepost	1	.040	.846	.004	.054
Error(prepost)	10				
location	1	30.201	.000	.751	.998
Error(location)	10				
direction	1	5.250	.045	.344	.544

Error(direction)	10				
time * prepost	3	.195	.899	.019	.082
Error(time*prepost)	30				
time * location	3	9.432	.000	.485	.993
Error(time*location)	30				
prepost * location	1	.011	.918	.001	.051
Error(prepost*location)	10				
time * prepost * location	3	.551	.652	.052	.149
Error(time*prepost*location)	30				
time * direction	3	4.945	.007	.331	.871
Error(time*direction)	30				
prepost * direction	1	2.466	.147	.198	.295
Error(prepost*direction)	10				
time * prepost * direction	3	2.373	.090	.192	.537
Error(time*prepost*direction)	30				
location * direction	1	69.357	.000	.874	1.000
Error(location*direction)	10				
time * location * direction	3	6.487	.002	.393	.948
Error(time*location*direction)	30				
prepost * location * direction	1	.114	.742	.011	.061
Error(prepost*location*direction)	10				
time * prepost * location * direction	3	.008	.999	.001	.051
Error(time*prepost*location*direction)	30				

Tests of Within-Subjects Effects

Localized Fatigue Elbow Kinematic Data:

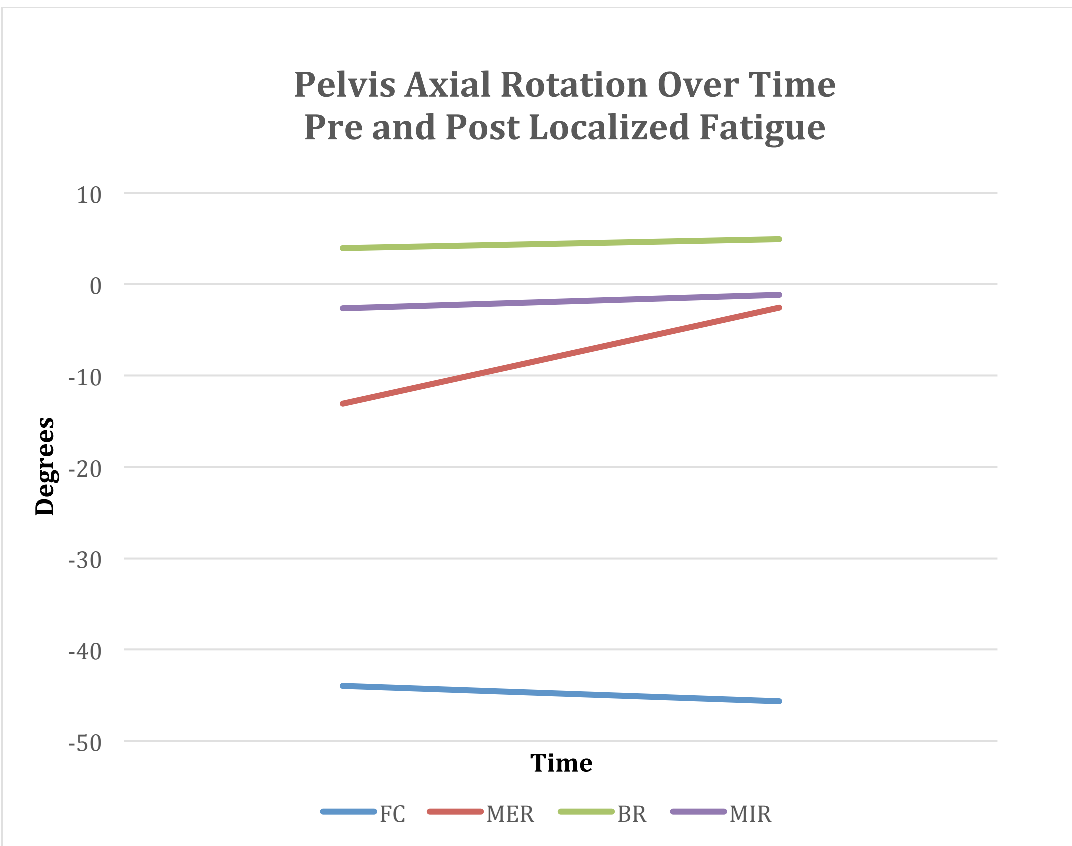
Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	3	13.582	.000	.629	1.000
Error(time)	24				
prepost	1	.319	.587	.038	.079
Error(prepost)	8				
time * prepost	3	.249	.861	.030	.090
Error(time*prepost)	24				

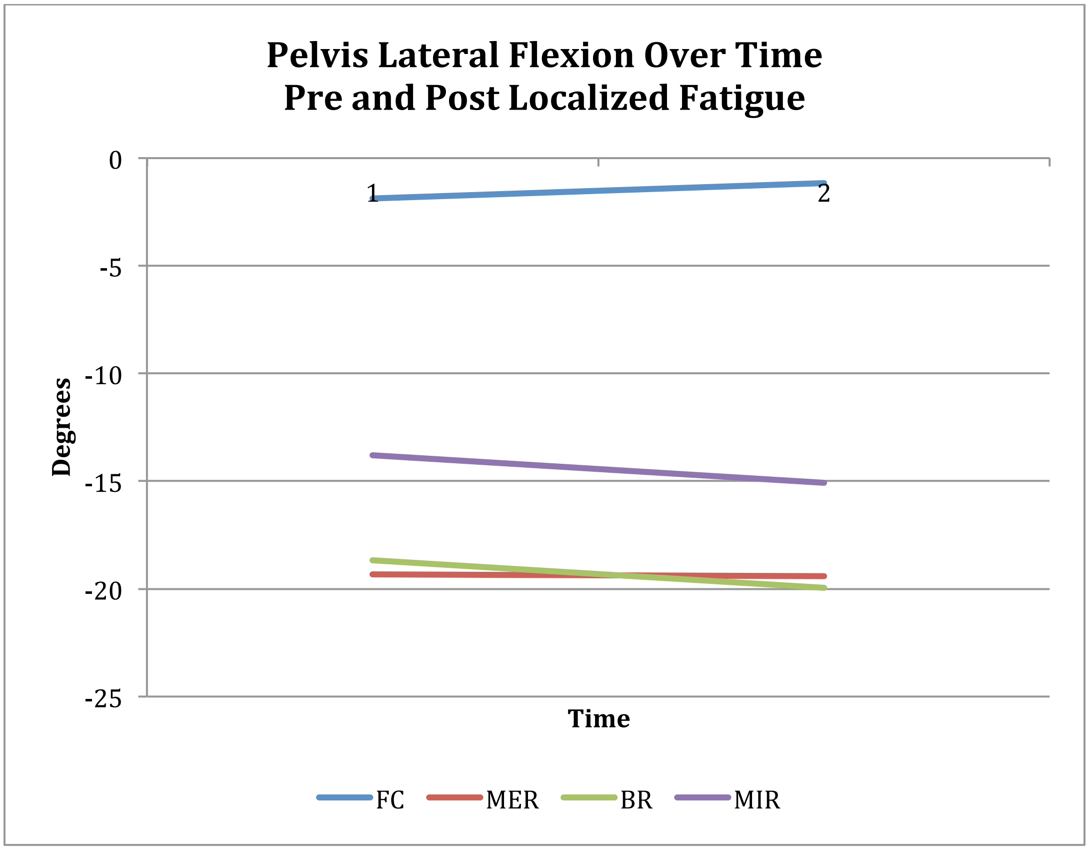
Tests of Within-Subjects Effects

Localized Fatigue Pelvis Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	3	22.852	.000	.696	1.000

Error(time)	30				
prepost	1	1.004	.340	.091	.149
Error(prepost)	10				
direction	1	.156	.702	.015	.065
Error(direction)	10				
time * prepost	3	7.573	.001	.431	.974
Error(time*prepost)	30				
time * direction	3	108.258	.000	.915	1.000
Error(time*direction)	30				
prepost * direction	1	1.551	.241	.134	.204
Error(prepost*direction)	10				
time * prepost * direction	3	4.805	.008	.325	.860
Error(time*prepost*direction)	30				





Tests of Within-Subjects Effects

Localized Fatigue Shoulder and Scapula Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	3	182.105	.000	.953	1.000
Error(time)	27				
location	1	227.083	.000	.962	1.000
Error(location)	9				
prepost	1	3.347	.101	.271	.373
Error(prepost)	9				
direction	2	171.235	.000	.950	1.000
Error(direction)	18				
time * location	3	139.495	.000	.939	1.000
Error(time*location)	27				
time * prepost	3	1.326	.286	.128	.313
Error(time*prepost)	27				
location * prepost	1	1.418	.264	.136	.187
Error(location*prepost)	9				
time * location * prepost	3	.991	.412	.099	.240
Error(time*location*prepost)	27				
time * direction	6	23.971	.000	.727	1.000
Error(time*direction)	54				
location * direction	2	117.567	.000	.929	1.000
Error(location*direction)	18				

time * location * direction	6	66.026	.000	.880	1.000
Error(time*location*direction)	54				
prepost * direction	2	2.793	.088	.237	.480
Error(prepost*direction)	18				
time * prepost * direction	6	1.772	.122	.164	.617
Error(time*prepost*direction)	54				
location * prepost * direction	2	3.192	.065	.262	.536
Error(location*prepost*direction)	18				
time * location * prepost * direction	6	.886	.512	.090	.319
Error(time*location*prepost*direction)	54				

Tests of Within-Subjects Effects

Localized Fatigue Trunk Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	3	18.655	.000	.651	1.000
Error(time)	30				
prepost	1	.362	.561	.035	.085
Error(prepost)	10				
direction	2	4.437	.025	.307	.695
Error(direction)	20				
time * prepost	3	2.945	.049	.227	.639
Error(time*prepost)	30				
time * direction	6	67.907	.000	.872	1.000
Error(time*direction)	60				
prepost * direction	2	1.900	.176	.160	.347
Error(prepost*direction)	20				
time * prepost * direction	6	.312	.928	.030	.129
Error(time*prepost*direction)	60				

Tests of Within-Subjects Effects

Localized Fatigue Segmental Velocities:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	3	95.181	.000	.905	1.000
Error(time)	30				
prepost	1	1.049	.330	.095	.153
Error(prepost)	10				

location	4	276.011	.000	.965	1.000
Error(location)	40				
time * prepost	3	.222	.881	.022	.087
Error(time*prepost)	30				
time * location	12	31.805	.000	.761	1.000
Error(time*location)	120				
prepost * location	4	.983	.428	.090	.282
Error(prepost*location)	40				
time * prepost * location	12	.228	.997	.022	.133
Error(time*prepost*location)	120				

Aerobic Fatigue Protocol

Tests of Within-Subjects Effects

Aerobic Fatigue Isometric Strength Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	2	.310	.738	.042	.090
Error(time)	14				
location	1	27.803	.001	.799	.994
Error(location)	7				
rotation	1	3.126	.120	.309	.333
Error(rotation)	7				
dominance	1	1.288	.294	.155	.166
Error(dominance)	7				
time * location	2	.306	.741	.042	.089
Error(time*location)	14				
time * rotation	2	1.621	.233	.188	.285
Error(time*rotation)	14				
location * rotation	1	1.164	.316	.143	.155
Error(location*rotation)	7				
time * location * rotation	2	.410	.671	.055	.104
Error(time*location*rotation)	14				
time * dominance	2	1.595	.238	.186	.281
Error(time*dominance)	14				
location * dominance	1	.203	.666	.028	.068
Error(location*dominance)	7				
time * location * dominance	2	4.524	.031	.393	.673
Error(time*location*dominance)	14				
rotation * dominance	1	2.106	.190	.231	.242
Error(rotation*dominance)	7				
time * rotation * dominance	2	.075	.928	.011	.059
Error(time*rotation*dominance)	14				
location * rotation * dominance	1	5.466	.052	.438	.522

Error(location*rotation*dominance)	7				
time * location * rotation * dominance	2	1.496	.258	.176	.266
Error(time*location*rotation*dominance)	14				

a. Computed using alpha = .05

Tests of Within-Subjects Effects

Aerobic Fatigue Range of Motion Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	2	.386	.687	.052	.100
Error(time)	14				
location	1	523.108	.000	.987	1.000
Error(location)	7				
rotation	1	367.564	.000	.981	1.000
Error(rotation)	7				
dominance	1	1.525	.257	.179	.188
Error(dominance)	7				
time * location	2	.596	.565	.078	.130
Error(time*location)	14				
time * rotation	2	.718	.505	.093	.147
Error(time*rotation)	14				
location * rotation	1	56.768	.000	.890	1.000
Error(location*rotation)	7				
time * location * rotation	2	1.375	.285	.164	.247
Error(time*location*rotation)	14				
time * dominance	2	3.699	.051	.346	.580
Error(time*dominance)	14				
location * dominance	1	.133	.726	.019	.062
Error(location*dominance)	7				
time * location * dominance	2	.215	.809	.030	.077
Error(time*location*dominance)	14				
rotation * dominance	1	.347	.575	.047	.081
Error(rotation*dominance)	7				
time * rotation * dominance	2	.190	.829	.026	.074
Error(time*rotation*dominance)	14				
location * rotation * dominance	1	13.888	.007	.665	.890
Error(location*rotation*dominance)	7				
time * location * rotation * dominance	2	5.348	.019	.433	.749
Error(time*location*rotation*dominance)	14				

a. Computed using alpha = .05

Aerobic Fatigue Shoulder and Scapula Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	3	132.983	.000	.937	1.000
Error(time)	27				
location	1	135.092	.000	.938	1.000
Error(location)	9				
prepost	1	.708	.422	.073	.117
Error(prepost)	9				
direction	2	67.147	.000	.882	1.000
Error(direction)	18				
time * location	3	89.061	.000	.908	1.000
Error(time*location)	27				
time * prepost	3	1.268	.305	.123	.300
Error(time*prepost)	27				
location * prepost	1	.203	.663	.022	.069
Error(location*prepost)	9				
time * location * prepost	3	.862	.473	.087	.212
Error(time*location*prepost)	27				
time * direction	6	30.729	.000	.773	1.000
Error(time*direction)	54				
location * direction	2	64.883	.000	.878	1.000
Error(location*direction)	18				
time * location * direction	6	68.648	.000	.884	1.000
Error(time*location*direction)	54				
prepost * direction	2	4.604	.024	.338	.704
Error(prepost*direction)	18				
time * prepost * direction	6	1.285	.280	.125	.461
Error(time*prepost*direction)	54				
location * prepost * direction	2	1.122	.347	.111	.216
Error(location*prepost*direction)	18				
time * location * prepost * direction	6	1.049	.405	.104	.378
Error(time*location*prepost*direction)	54				

Tests of Within-Subjects Effects

Aerobic Fatigue Elbow Data:

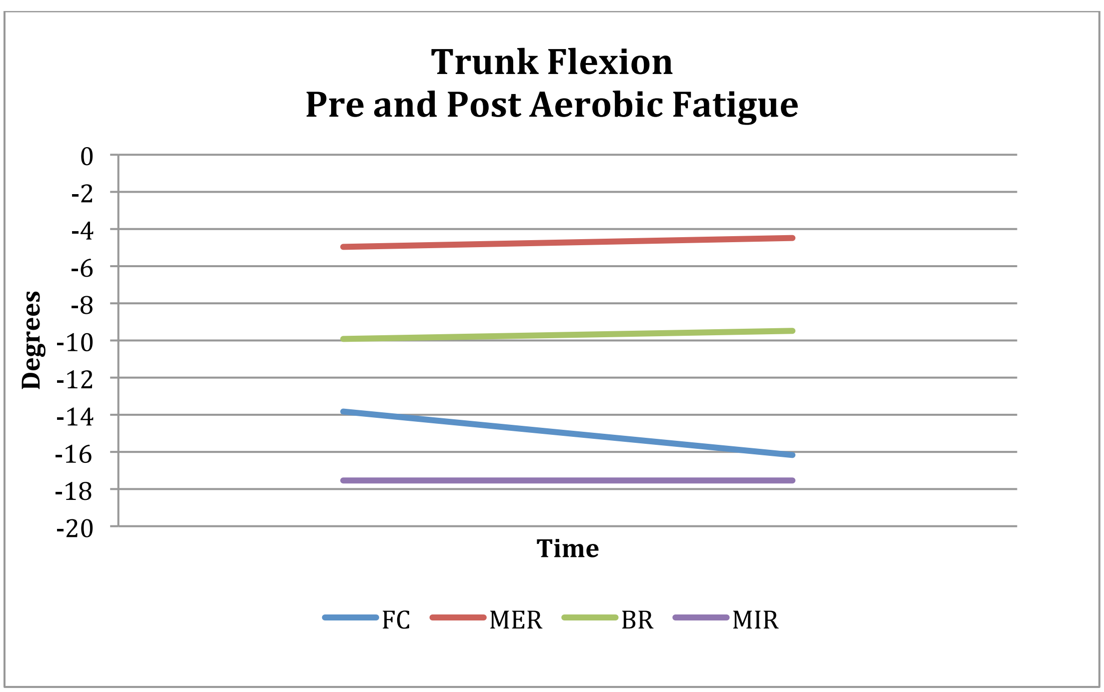
Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	3	27.36 7	.000	.753	1.000

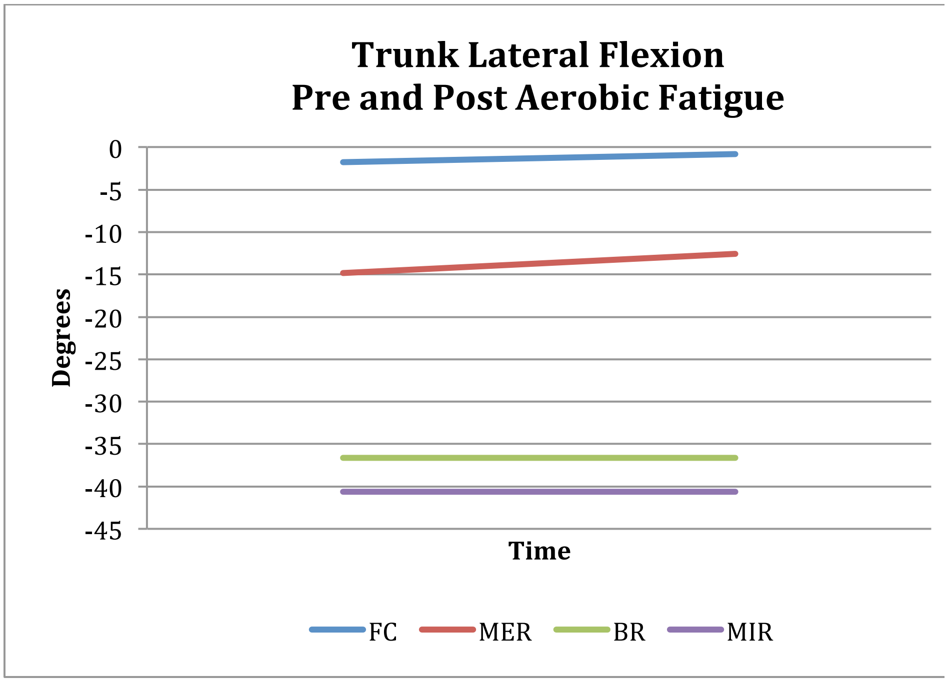
Error(time)	27				
prepost	1	.112	.746	.012	.060
Error(prepost)	9				
time * prepost	3	.359	.783	.038	.111
Error(time*prepost)	27				

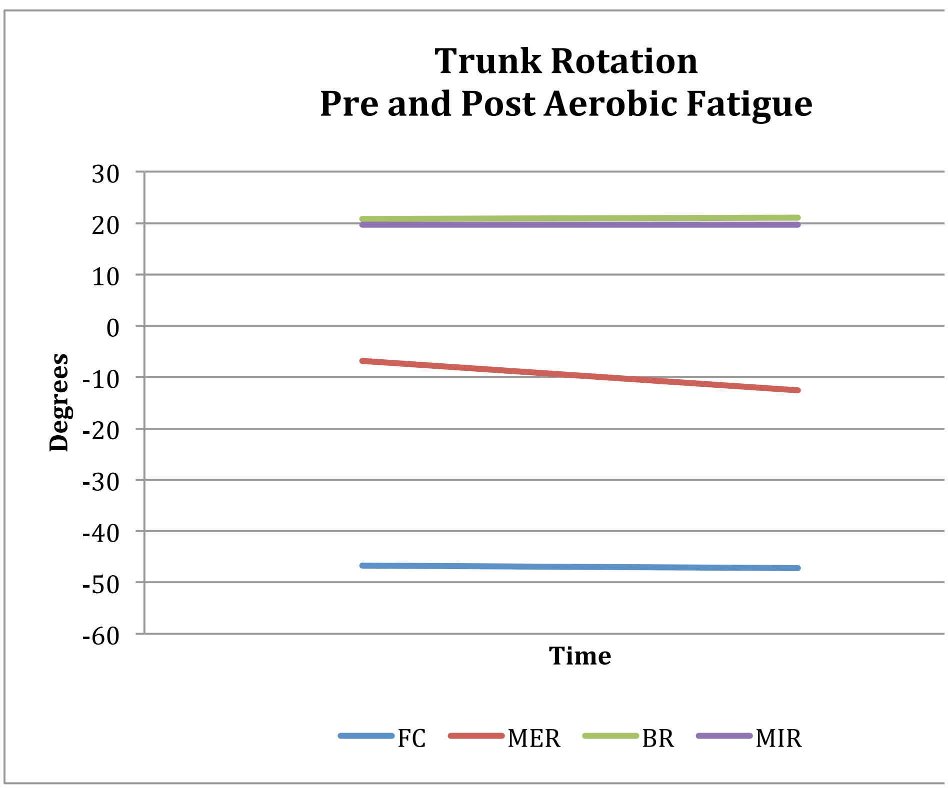
Tests of Within-Subjects Effects

Aerobic Fatigue Trunk Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	3	24.586	.000	.732	1.000
Error(time)	27				
prepost	1	.002	.966	.000	.050
Error(prepost)	9				
direction		17.994	.000	.667	.999
Error(direction)	18				
time * prepost	3	1.915	.151	.175	.439
Error(time*prepost)	27				
time * direction	6	86.430	.000	.906	1.000
Error(time*direction)	54				
prepost * direction	2	.533	.596	.056	.124
Error(prepost*direction)	18				
time * prepost * direction	6	5.096	.000	.362	.988
Error(time*prepost*direction)	54				

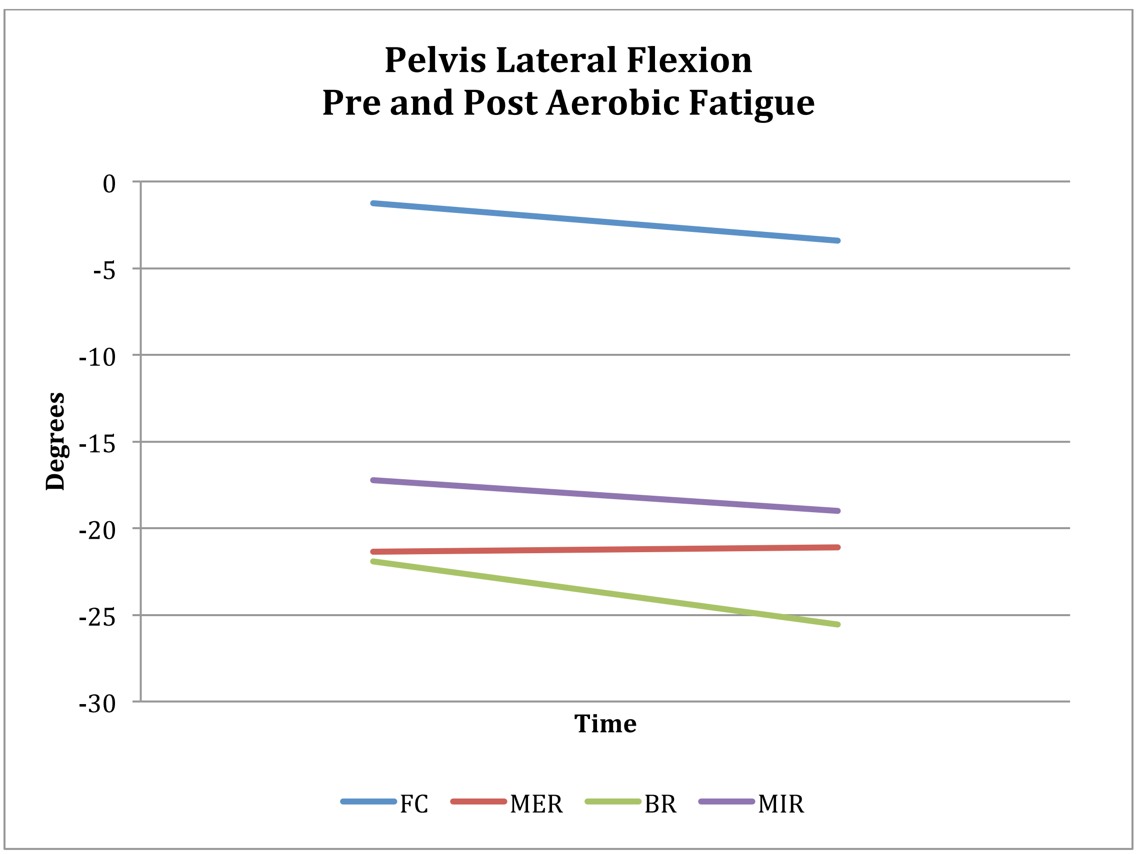


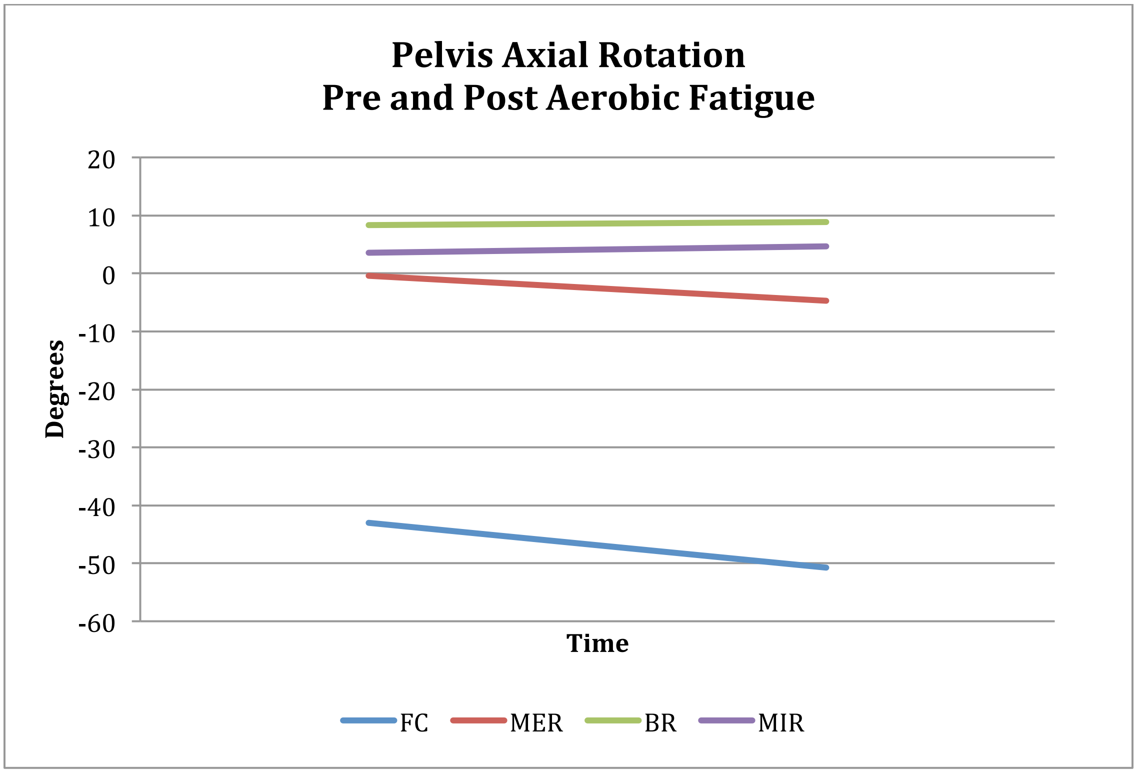

Trunk Lateral Flexion
Pre and Post Aerobic Fatigue
Degrees
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
Time
FC
MER
BR
MIR


Trunk Rotation
Pre and Post Aerobic Fatigue
Degrees
30
20
10
0
-10
-20
-30
-40
-50
-60
Time
FC
MER
BR
MIR

Aerobic Fatigue Pelvis Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	3	46.132	.000	.837	1.000
Error(time)	27				
prepost	1	6.670	.030	.426	.634
Error(prepost)	9				
direction	1	7.242	.025	.446	.669
Error(direction)	9				
time * prepost	3	6.307	.002	.412	.939
Error(time*prepost)	27				
time * direction	3	120.789	.000	.931	1.000
Error(time*direction)	27				
prepost * direction	1	.085	.777	.009	.058
Error(prepost*direction)	9				
time * prepost * direction	3	14.467	.000	.616	1.000
Error(time*prepost*direction)	27				





Tests of Within-Subjects Effects

Aerobic Fatigue Kinetic Data:

Source	df	F	Sig.	Partial Eta Squared	Observed Power[a]
time	3	2.250	.105	.200	.507
Error(time)	27				
prepost	1	7.052	.026	.439	.658
Error(prepost)	9				
location	1	32.284	.000	.782	.999
Error(location)	9				
direction	1	15.378	.004	.631	.936
Error(direction)	9				
time * prepost	3	5.830	.003	.393	.919
Error(time*prepost)	27				
time * location	3	30.943	.000	.775	1.000
Error(time*location)	27				
prepost * location	1	1.533	.247	.146	.199
Error(prepost*location)	9				
time * prepost * location	3	1.677	.195	.157	.389
Error(time*prepost*location)	27				
time * direction	3	19.692	.000	.686	1.000
Error(time*direction)	27				
prepost * direction	1	1.996	.191	.181	.244
Error(prepost*direction)	9				

time * prepost * direction	3	.939	.436	.094	.228
Error(time*prepost*direction)	27				
location * direction	1	68.346	.000	.884	1.000
Error(location*direction)	9				
time * location * direction	3	7.508	.001	.455	.971
Error(time*location*direction)	27				
prepost * location * direction	1	1.757	.218	.163	.221
Error(prepost*location*direction)	9				
time * prepost * location * direction	3	.188	.904	.020	.081
Error(time*prepost*location*direction)	27				