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Effects of a Functional Fatigue Protocol on Maximal Softball Hitting

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Thesis Summary

Effects of a Functional Fatigue Protocol on Maximal Softball Hitting

Fatigue can affect athletic performance in many ways, including a decrease in sport specific accuracy, impairments in joint angles, and a decrease in overall muscle performance. In regards to fatigue, little research has been conducted examining the effects of fatigue on baseball and softball performance.

The majority of the research stems from examining the effects of fatigue on the overhead throwing motion among collegiate baseball players. Research suggested that as a result of a functional fatigue protocol, baseball pitchers experienced impairments in joint angles in the overhead throwing motion. Among this same population, throwing velocities decreased significantly from the first to last inning pitched, resulting in a great deal of in-game fatigue. Researchers attested that such changes in angles and velocities as a result of fatigue, would negatively affect performance. The purpose of this study was to examine the effects of a functional fatigue protocol on softball hitting form.

Additional research, examined the effects of fatigue on performance among skilled tennis athletes. A functional fatigue protocol was implemented, which directly simulated tennis matchplay. Results revealed decreases in tennis hitting accuracy, and just as with the baseball players, fatigue resulted in a decrease in performance. A secondary objective was to identify the relationship between hitting variables, muscular power, and body composition.

Participants (n = 6) were NCAA Division II softball players with a mean age of 19.5 ± 1.4 years who completed a functional fatigue protocol (FFP). The FFP was filmed using a digital video camera, and results were analyzed using Dartfish motion analysis software. To address the secondary objectives, participants completed the Wingate Anaerobic Power test to assess muscular power and a dual-energy x-ray absorptiometry (DXA) scan to discover body composition values.

To detect differences in swing angles pre- and post-fatigue, an ANOVA was conducted revealing significant ($p < .05$) decreases in linear bat-end velocity (LBEV; F = 12.479, p = .017) and batted-ball velocity (BBV; F = 11.856, p = .018) as a result of fatigue. A Pearson's product moment correlation coefficient performed to examine relationships between hitting variables, muscular power, and body composition. Results revealed no significant relationships ($p > .05$) between muscular power and LBEV or BBV, in addition to no significant relationships between percent fatigue as measured by WAnT or the FFP. Meaningful relationships were discovered between peak power and LBEV and BBV. A strong, negative correlation was present between peak power and BBV (r = -.73, p = .097) and a moderate, negative correlation between peak power and LBEV (r = -.68, p = .138). Additionally, percent body fat was negatively related to percent fatigue in LBEV(r = -.76, p = .082).

Results indicated that fatigue did in fact have a negative effect on softball hitting form, with significant decreases in LBEV and BBV, and that peak power and hitting velocities were inversely related. Although no differences were found in swing angles at ball contact, changes in LBEV and BBV could be detrimental to swing timing and performance. Results of this study will be utilized to further understand the effects of fatigue on softball hitting form and the role of muscular power and body composition on hitting performance.

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Chapter One

Introduction

Fatigue can affect athletic performance in many ways including a decrease in sport specific accuracy, impairments in joint angles, and a decrease in overall muscle performance (Davey, Thorpe, & Williams, 2002; Morris, Dawes, Howells, Scott, & Cramp, 2008; Mullaney, McHugh, Donofrio, & Nicholas, 2005; Tripp, Yochem, & Uhu, 2007). Each of the aforementioned aspects are vital in sport performance, specifically in baseball and fastpitch softball hitting. When analyzing the hitting swing, the majority of the research conducted examined the positive impacts resistance training has on baseball hitting performance. Due to limited research specifically involving the softball swing, supplemental studies examining similar sport movements such as golf and tennis will be utilized to better understand the swinging motion. In regards to fatigue, no known research has been conducted examining the effects of functional fatigue on baseball and softball hitting performance, although the effects are well documented when looking at the overhand throw among baseball players. The purpose of this study was to examine the effects of a functional fatigue protocol on softball hitting form among National Collegiate Athletic Association (NCAA) Division II softball players. In addition to the purpose, four objectives were formulated and were addressed throughout this project.

Objectives.

1) To develop a functional fatigue protocol

2) To determine the relationship between muscular power and linear bat-end velocity (LBEV) and batted-ball velocity (BBV)

3) To determine the relationship between power fatigue and hitting fatigue

4) To determine the relationship between body composition and fatigue

The primary objective for this project was to develop a functional fatigue protocol that directly simulated a softball hitting practice environment. This protocol, which will be explained in detail, was modeled after the Loughborough Intermittent Tennis Test (LITT), and altered to be relevant for fastpitch softball application. The functional fatigue protocol (FFP) for this project involved intermittent bouts of maximal hitting performed to volitional fatigue just as in the LITT. The secondary objective for this project was to identify the relationship between measured muscular power and hitting performance variables (bat and batted ball velocity). The researcher hypothesized that those with greater muscular power would have greater bat and batted ball velocity. Anaerobic muscular fatigue was calculated using the Wingate Anaerobic Power Test (WAnT). Objective number three addressed a relationship between each player's anaerobic fatigue and hitting fatigue as measured with the functional fatigue protocol. Anaerobic fatigue was determined by calculating the percent of power lost throughout the WAnT. The researcher hypothesized that players with greater anaerobic fatigue would hit fewer balls prior to reaching fatigue. The final objective examined if a relationship was present between body composition and fatigue. The researcher hypothesized that those with a less lean tissue mass would fatigue more quickly in regards to anaerobic fatigue and the functional fatigue protocol.

Delimitations

The specific population of NCAA Division II was selected due to the limited research on NCAA Division II athletes in addition to the access to a Division II softball team. The researcher also recruited collegiate athletes to ensure a higher skill level in fastpitch softball. The use of an intact group was utilized to recruit subjects, which was a threat to external validity. While a threat to validity, it was necessary due to access to athletes and target of a specific population. A delimitation of performing testing in the off-season for the athletes was also necessary due to timing and scheduling for the participants.

Variables

The independent variable for this research project was fatigue, while dependent variables were swing angles and hitting velocities. Specific angles were measured at the point of ball contact at the front and back elbows, wrists, back knee, and bat to examine differences in hitting form. Batted-ball velocity (BBV) as well as linear bat-end velocity (LBEV) were measured as performance variables. The importance of BBV was emphasized in a study conducted examining fastpitch softball fielders and anticipation skills. These players showed excellent reaction time to batted balls (Gabbett, Rubinoff, Thorburn, & Farrow, 2007). With the fielder's ability to anticipate and react to hit balls, bat and ball velocity are vital aspects to successful softball hitting. Decreases in bat and/or ball velocity could be the difference between a ground ball getting through the infield and a routine ground out to the short stop, or between a long fly ball and a game winning homerun. This research focused on female NCAA Division II college softball players at the University of Central Oklahoma (UCO). The null hypothesis was that there would be no difference in swing angles, BBV, or LBEV as a result of a functional fatigue protocol. In regards to the objectives, the researcher hypothesized that those with greater muscular power would have greater hitting velocities, those who experienced less fatigue on the WAnT would fatigue less in the FFP, and those with more lean tissue mass would have greater hitting velocities.

Definition of Terms

Anaerobic fatigue – Percentage of power lost during the WAnT

Anaerobic fatigue = [(peak power – minimum power) / peak power) * 100

Ball Contact – Point at which the bat and ball made contact. Ball contact was detected using Dartfish video analysis software. If the exact point of ball contact was not captured, ball contact was defined as the frame immediately prior to ball contact.

BBV – Batted-ball velocity, measured using the displacement of the ball from ball contact to the frame immediately following ball contact using Dartfish (meters/second).

Dartfish – Dartfish video analysis software, used to assess swing angles and velocities for the functional fatigue protocol.

DXA – Dual-energy x-ray absorptiometry, body composition measurement assessing percent body fat and lean tissue and fat mass.

FFP – Functional Fatigue Protocol, consisted of six phases involving maximal softball hitting and was designed to enduce fatigue in a softball hitting practice environment.

LBEV – Linear bat-end velocity, measured using the displacement of the distal end of the bat head traveled in the frame immediately before ball contact to ball contact (meters/second).

NCAA – National Collegiate Athletic Association, a governing body for collegiate athletics.

RPE – Ratings of Perceived Exertion, assessed using the Borg scale (6-20).

WAnT – Wingate Anaerobic Power Test, a 30-second muscular power test performed on a cycle ergometer.

Significance

The National Collegiate Athletic Association (NCAA), a governing body for collegiate sports programs across the United States, puts many rules and restrictions on athletes and teams, specifically regarding practices both in- and outside of the regular playing season. For NCAA Division II fastpitch softball, the regular playing season, or championship season, occurs during the spring semester, which begins in January. The championship season is over when teams are eliminated from post-season play or when a National Champion is crowned in early June. During the championship season, players are allowed to participate in no more than 20 hours of countable athletic related activities each week, with no more than four hours spent daily. Teams are outside of the regular playing season for the majority of the fall semester. When teams are outside of the regular playing season, players may not take part in team practices and are limited to eight hours of countable athletic related activities each week. Of the eight total hours, no more than two hours may be spent in individual skill instruction (NCAA, 2008). These practice times are vital to coaches and players, as this is the time where skills are perfected to increase game performance. Practices are comprised of a combination of hitting, fielding, base running, pitching, and catching drills, as well as game-like situations, with additional time spent focusing on strength and conditioning. With such daily and weekly practice restrictions, it is often difficult for players to get adequate rest for maximal performance between practice drills, specifically hitting. Practices with a high number of hitting repetitions or swings often give players minimal time for recovery between bouts of hitting, potentially resulting in fatigue. The primary goal for this research project was to establish at what point collegiate softball players experience fatigue in a simulated hitting practice environment. The researcher hypothesizes that as a result of the functional fatigue protocol swing angles will suffer, and both bat speed and ball velocity will decrease, resulting in a potential decrease in overall performance. Changes in practice hitting form as a result of fatigue potentially turn into bad habits, which could then translate into games. By changing bat angles, the point of contact between the bat and ball could be altered, causing the hitter to miss-hit a pitch, resulting in a pop-up, ground out, or strike out in a game at bat.

Chapter Two

Literature Review

The purpose of this study was to examine the effects of a functional fatigue protocol on maximal softball hitting. Although no known research has been performed involving hitting and fatigue, multiple studies have examined fatigue in the overhand throwing motion among baseball players, the benefits of resistance-training in swing velocity and hitting performance (baseball, softball, and golf), as well the effects of fatigue on tennis hitting accuracy and performance (Davey, Thorpe, & Williams, 2002; Morris, Dawes, Howells, Scott, & Cramp, 2008; Hughes, Lyons, & Mayo, 2004; Mullaney, McHugh, Donofrio, & Nicholas, 2005; Murray, Cook, Werner, Schlegel, & Hawkins, 2001; Tripp, Yochem, & Uhu, 2007; Szymanski, McIntyre, Szymanski, Molloy, Madsen, et al., 2006). Additional research involving fatigue has been conducted examining differences in soccer performance as well as exercise capacity based on body composition (lean tissue mass), which addressed the fourth objective in this research proposal (Kellis, Katis, & Vrabas, 2005).

Fatigue and resistance-training.

Mullaney and colleagues (2005) examined muscular fatigue in collegiate and independent league starting baseball pitchers (n = 13) after a pitching performance. Upper and lower body strength was assessed immediately prior to a spring training baseball game and immediately after the pitchers were removed from the game (99 ± 29 pitches; 7 ± 2 innings). Results showed the supraspinatus of the pitching arm to be 12% weaker (p = .02) in strength than the contralateral side at baseline. Additional findings showed an 18% decrease (p = .03) in shoulder internal rotation strength, a 15% decrease

($p = .02$) in shoulder flexion strength, and an 11% decrease ($p = .01$) in shoulder adduction strength in the pitching arm after a pitching performance. Researchers attributed the decreases in strength to fatigue experienced as the result of pitching in a game. Murray et al. (2001) also addressed fatigue following a baseball pitching performance among seven professional starting pitchers. Two fastballs thrown, one in the first and one in the last inning pitched, were analyzed using motion analysis software. Results showed a significant decrease ($p < .05$) in ball velocity from the first to last inning, with pitch velocity dropping from 90 to 85 mph. Researchers also noted significant decreases ($p < .05$) in maximal external rotation of the shoulder and knee flexion upon ball release. A combination of decreases in each variable resulted in an overall decrease in pitching performance late in the game (Murray et al., 2001). Tripp et al. (2007b) observed recovery of the upper extremity sensorimotor system among collegiate baseball players following a functional fatigue protocol. The primary role of the sensorimotor system in the overhand throwing motion is to maintain throwing form as well as dynamic stability. Participants ($n = 16$) completed a pre-test followed by the fatigue protocol and multiple post-tests, all of which were conducted with the players throwing while on one knee in order to isolate the upper body. For the functional fatigue protocol, participants were instructed to throw a baseball every five seconds at maximal velocity to fatigue. Fatigue was defined as an RPE of 15 on the Borg scale or after 160 throws, and participants were not informed of the fatigue threshold prior to testing. For testing, participants were asked to reproduce the arm cock and ball release phases of the overhand throwing motion. Testing took place immediately prior to the fatigue protocol, immediately following, as well as four, seven, and 10 minutes after completing the fatigue protocol to determine the recovery of the sensorimotor system. Players reached fatigue at a mean of 62 ± 28 balls thrown and reported a mean RPE of 15.6 ± 0.9 on the Borg scale. Results showed a significant difference ($p < .05$) in joint position reproduction following the fatigue protocol in both arm positions for various swing angles. For the arm-cocked phase significant differences ($p < .05$) were found when compared to pre-test values in the scapulothoracic, glenohumeral, and elbow joints immediately post-fatigue. These differences were still present at four minutes post fatigue in the scapulothoracic and glenohumeral joints. Researchers continued to find differences in the glenohumeral joint at seven and 10 minutes post-fatigue while not in the scapulothoracic, glenohumeral, or elbow joints. In regards to the ball release phase significant differences ($p < .05$) were found in the scapulothoracic, glenohumeral, elbow, and wrist joints immediately post-fatigue. Other than in the glenohumeral joint, no significant differences ($p > .05$) were noted in joint position at seven and 10 minutes post-fatigue during the ball release phase. Based on these results, researchers concluded that while fatigue had a significant impact on players' ability to reproduce joint angles as a result of fatigue, most sensorimotor skills were restored after 10 minutes of recovery. However, the researchers did not discover the amount of time necessary for athletes to reach full recovery in regards to the overhand throwing motion. The practical application for these results implies that changes may occur in form (joint angles) in the overhand throw throughout practices or games as a result of fatigue, but players may recover within 10 minutes to regain consistent throwing form. Tripp, Boswell, Gansneder, and Shultz (2004) conducted a study similar to the aforementioned project where researchers examined NCAA Division I baseball players' ability to reproduce the arm-cocked and ball release points of the overhand throwing motion pre- and post-fatigue. Similarly, participants were instructed to throw a baseball maximally every five seconds to fatigue. For this project, researchers defined fatigue as reaching 15 on the Borg scale. Participants reached a fatigued state with after throwing a mean of 61.5 ± 15.1 balls. Results showed significantly greater ($p < .05$) error in joint position reproduction as a result of functional fatigue in both phases of the overhand throw. These results were confirmed in a later study conducted by Tripp, Yochem, and Uhi (2007b) where results showed joint position reproduction decreased following functional fatigue. In each of the three studies conducted by Tripp and colleagues, the functional fatigue protocol involved players kneeling on one knee and throwing maximally to subjective fatigue, resulting in a decrease in the participants' ability to reproduce joint positions throughout the throwing motion in each study. In conclusion, the studies conducted examining the various aspects of overhand throwing and fatigue, showed that fatigue had a negative impact on performance. While a certain level of fatigue is inevitable throughout practice and game situations, the use of resistance and/or sport specific training could combat these negative effects.

Additional research has been conducted involving various resistance training programs among high school and college baseball players and the impacts on variables such as bat velocity and time to ball contact. Results showed consistent findings with previous studies, revealing increases in overall bat velocity following a resistance-training program. Hughes and colleagues (2004) examined differences in bat velocity between a traditional resistance-training program and a resistance-training program plus grip strength exercises. Participants were 23 NCAA Division II baseball players who were randomly assigned to either the control ($n = 12$) or experimental ($n = 11$) groups. Bat velocity was tested prior to and after completion of the six-week program. The resistance-training program consisted of the bench press, squat, lat pull, deadlift, hamstring curls, biceps curls, triceps extensions, and crunches. Each of these exercises were performed three times each week with a total of three sets consisting of 10 repetitions each (intensity was not reported). Both the control and experimental groups performed those basic exercises, with the experimental group participating in additional exercises focusing on forearm and grip strength. Those exercises were wrist curls, wrist extensions, wrist rolls, supination-pronation, one-hand chops, and wrist grips. Researchers noted no significant differences ($p > .05$) between groups in regards to bat velocity in pre- and post-testing with the control group increasing from 81.0 ± 6.2 to 82.7 ± 4.4 mph and the experimental group from 77.7 ± 6.0 to 81.3 ± 6.1 mph. Although no between group differences were found, both training groups increased bat velocity as a result of the six weeks of resistance training from 79.0 ± 6.5 to 82.0 ± 5.1 mph ($p = .05$). Similarly, Szymanski and colleagues (2006) examined differences between two training groups in bat velocity and hand velocity among high school baseball players ($n = 43$). Both groups completed a periodized full-body resistance-training program three days a week for a total of 12 weeks. The control group ($n = 23$) completed the traditional resistance-training program, while the treatment group ($n = 20$) participated in addition wrist and forearm strengthening exercises. Just as previously discussed, researchers found an overall increase ($p \leq .01$) in bat velocity with a decrease in time to ball contact as a result of training, although no differences ($p > .01$) were found between the two training groups. Both groups saw increases in bat velocity with the control and treatment groups increasing 3.5% and 3.2% respectively. In regards to hand velocity, results were similar with the control group showing a 4.9% increase and the treatment group improving hand velocity by 6.3%. Researchers concluded that such improvements in bat velocity and hand velocity increased overall hitting performance (Hughes et al., 2004; Szymanski et al., 2006 Szymanski, Szymanski, Bradford, Schade, and Pascoe (2007) also examined differences between medicine ball resistance-training and a program including additional baseball swings. Participants were high school baseball players (n = 49) who were randomly assigned to the medicine ball training group or additional baseball swings. In the medicine ball group (n = 24), players completed exercises with torso rotation, which directly mimicked the baseball hitting motion, while the other group (n = 25) completed 100 additional swings with their own bat. Each treatment was performed three times per week for a total of 12 weeks. Results showed significant increases ($p \leq .05$) in torso rotational strength in both groups with the swing group increasing by10.2 % and the medicine ball group 18.3%. While both groups experienced significant increases, the medicine ball group saw significantly greater increases ($p \leq .05$) than the swing group in torso rotational strength. Although researchers did not measure hitting variables, they concluded that greater torso rotational strength would increase bat swing velocity, ultimately increasing performance (Szymanski et al., 2007). In regards to training and improved hitting performance, other studies were conducted examining the effects of golf specific exercise programs on swing mechanics and overall performance. Fletcher and Hartwell (2004) randomly assigned participants to either the control (n = 5) or treatment group (n = 6). The control group was instructed to continue with their normal routine. Participants reported their normal routine to include light resistance-training using weight machines, although no specifics on frequency or intensity were given. The treatment group performed plyometric training in addition to a weight-training program. Traditional resistance exercises such as bench press, squat, and rows were performed with plyometric medicine ball exercises. The plyometric medicine ball exercises included seated and standing horizontal twists, standing back extensions, and medicine ball golf swings. Participants completed the exercises twice each week for eight weeks, performing three sets of each exercise with six to eight repetitions per set. Results of the training program showed significant increases ($p \leq .05$) in driving distance (4.3%) and club head speed (1.5%) among the treatment group, while the control group saw no significant differences ($p > .05$) in driving distance (- 0.7%) and club head speed (+ .5%) (Fletcher et al., 2004). Similarly, the benefits of golf-specific training were observed among a group or recreational golfers (Lephart, Smoliga, Myers, Sell, & Tsai, 2007). Participants ($n = 15$) completed eight weeks of flexibility, balance, and resistance-training specific to the golf swing. Strengthening exercises were completed using elastic tubing and included exercises such as scapular retraction, resisted golf back swings, and hip abduction and adduction, which were performed while standing on one leg to increase balance. Stretching exercises included seated torso rotation with the golf club, hip flexion and rotation as well as torso flexion. As a result of the program, researchers noted significant increases in strength with an 8.9% increase in left torso ($p = .008$), 7.5% in right torso, 8.6% in left hip abduction, and 9.9% in right hip abduction. In regards to flexibility, significant increases were found in each variable measured with improvements ranging from 3.7% in left shoulder flexion ($p = .007$) to 46.9% in right knee extension ($p = .002$). When examining golf variables, results showed a 6.8%

increase in total driving distance (p = .001), a 5% increase in ball velocity (p = .001), and a 5.2% increase in club velocity (p = .001). These increases each translate into a potential increase in golf performance as a result of a golf specific exercise program (Lephart et al., 2007). These findings paralleled the results of the aforementioned baseball studies, with overall increases in bat (swing) velocity, which translated into greater batted ball speed or distance (Fletcher & Hartwell, 2004). Additional research was conducted focusing on bat speed prior to ball contact. This study examined peak bat speed in regards to ball contact when using three different ball weights. Participants (n = 8) were collegiate baseball players who hit three different balls, which were suspended by a string. Each swing was recorded and analyzed using motion analysis software. When the players hit a ball that was lighter than regulation, peak bat speed was not reached until after ball contact was made, potentially inhibiting performance. Results indicated that hitters reached peak bat speed immediately prior to impact on the normally weighted baseball, and that the impact of the bat and ball was what caused the deceleration phase of the hitting swing (Tabuchi, Matsuo, & Hashizume, 2007). In regards to bat kinematics, Nicholls et al. (2003) examined ball exit velocity and player safety with various baseball bats. Participants (n = 17) hit pitched balls, with each swing filmed and then analyzed using motion analysis software. Ball exit velocity and swing time was measured using wooden and aluminum bats. Ball exit velocity was significantly greater (p = .001) when the hitters utilized the aluminum bat (99.1 ± 6.1 mph) compared with the wooden bat (93.9 ± 4.9 mph). Similar results were noted when examining hitter swing time, with hitters swinging the metal bats significantly faster (p = .01) than the wooden bats, at .14 ± .02 and .15 ± .01 seconds, respectively. Researchers noted that with an increase in ball velocity off of the bat and a decrease in swing time, players (specifically infielders and pitchers) have less time to react to a batted ball, which gave the hitter an increased chance to get a base hit (Nicholls, Elliot, Miller, & Koh, 2003). A combination of hitters reaching peak bat velocity immediately prior to ball contact to optimize ball velocity and an increase in bat speed as a result of training optimized performance. Based on the literature, researchers concluded that as a result of resistance training, hitters could increase performance through increased bat and ball velocity, and that decreases in the aforementioned variables as a result of fatigue could inhibit such performance.

Although the majority of the literature addresses male athletes, specifically golfers and baseball players, one study was conducted examining anticipation skills among elite softball players (Gabbett et al., 2007). Participants were randomly selected to one of three groups, a video-based perceptual training group (*n* = 9), a placebo group (*n* = 8), or a control group (*n* = 8). Anticipation skills were assessed using a video-based batter, that simulated a hit to an infielder. This test was conducted once prior to the initiation of the program and again following four weeks of training. Results of the training program showed a significant difference (*p* = .01) in decision accuracy with the video-based training program making the correct decision 100% of the time when compared with the placebo and control groups. While significant differences were found between groups following video-based training, researchers concluded that elite softball players at the national, state, and club levels had superior anticipation skills in regards to infield play, which made getting a base hit through the infield a difficult task in fastpitch softball (Gabbett et al., 2007). Due to the excellent anticipation skills of collegiate fielders, high levels of bat speed and batted-ball velocity are vital to the game of fastpitch softball. If those variables are decreased (possibly as a result of fatigue), fielders have more time to react to batted balls, decreasing the hitter's ability to get a base hit.

In regards to tennis match play, Davey et al. (2002) examined the effects of fatigue on tennis performance through maximal tennis hitting. Participants were skilled senior county tennis players (9 males and 9 females) with a mean age of 20.7 ± .9 years. They completed the Loughborogh Intermittent Tennis Test (LITT), which included bouts of maximal tennis hitting, performed to volitional fatigue. The protocol was developed to simulate a tennis match. Participants began with a five-minute warm-up followed by a five-minute rest period. Prior to beginning the fatigue protocol participants completed a skills test for hitting accuracy. Accuracy was measured by having the participants hit two targets located on each side at the back of the opposite court. The fatigue protocol included four-minute bouts of maximal hitting with a cadence of one ball every two seconds, followed by 40-second rest periods. After completion of the fatigue protocol another skills test was performed. Throughout the LITT hitting accuracy was measured. Results showed no significant changes in accuracy until participants reached 75% completion of the fatigue protocol. At that time, a significant decrease ($p \leq .05$) in percent accuracy was noted from the start of the LITT protocol. A significant decrease ($p \leq .05$) in hitting accuracy of 69% was also noted at volitional fatigue. Such decreases in accuracy from fatigue could be detrimental to performance, specifically at the end of a match. Ratings of Perceived Exertion (RPE) was also taken throughout the course of the test in order to quantify fatigue. Participants reached fatigue when they reported an RPE of 20 on the Borg scale. Davey and colleagues (2003) performed another study observing differences in hitting accuracy in skilled tennis players (*n* = 10). Results of the LITT showed an 81% decrease ($p \leq .05$) in hitting accuracy in comparison with the 69% found in a previous study (Davey et al., 2002; Davey et al., 2003). Overall, both studies had a significant decrease in sport specific performance as a result of fatigue.

The use of functional fatigue to address sport performance has been used in a variety of sports from baseball and tennis to soccer. Kellis, Katis, and Vrabas (2006) conducted a study examining the effects of fatigue on biomechanical characteristics of the instep soccer kick. Participants (*n* = 10) were experienced male amateur soccer players with a mean age of 22.6 ± 2.0 years. Each player completed a 90-minute intermittent exercise protocol that directly mimicked soccer matchplay. Prior to the fatigue protocol, at 45 minutes, and immediately after completing the protocol, participants performed three instep kicks that were recorded and analyzed using video analysis software. Results showed a significant decrease in maximal ball velocity ($p < .01$) from pre- to mid- and pre- to post-fatigue (pre- 25 m/s; mid- 23 m/s; post- 20 m/s). This decrease in kicked ball velocity could be detrimental to soccer performance at the end of a match (Kellis et al., 2006).

When measuring fatigue, the majority of the research utilized RPE as a subjective assessment (Davey et al. 2002; Davey et al., 2003; Tripp et al., 2004; Tripp et al., 2007a; Tripp et al., 2007b). While subjective fatigue is frequently utilized in the literature, Egret et al. (2004) used electromyography (EMG) as an objective measure of fatigue. Researchers conducted a biomechanical analysis of the golf swing with and without an EMG attached while swinging. Participants (*n* = 6) were experienced golfers who completed six swings with and without the EMG. All swings were filmed and analyzed using motion analysis software. Results showed significant differences ($p \leq .05$) in shoulder joint rotation at maximal backswing, right elbow flexion at the top of the backswing, and in clubhead speed with and without the EMG. Researchers attributed such differences to the cumbersome EMG equipment, which inhibited the golf swing. Based on these results and the widely accepted use of RPE as a measure of fatigue, researchers concluded that RPE was the most appropriate measure of fatigue for the proposed study as previously mentioned (Egret et al., 2004).

The lack of research among fastpitch softball players makes the results of the aforementioned studies difficult to predict the effects of fatigue on fastpitch softball players. It is important to understand the effects of fatigue on hitting form and performance, specifically in a practice situation. While increases in performance variables were noted as a result of resistance training, opposite results were found following fatigue protocols or general game fatigue (Davey et al., 2002; Davey et al., 2003; Fletcher et al., 2004; Hughes et al., 2004; Lephart et al., 2007; Kellis et al., 2006; Mullaney et al., 2005; Murray et al., 2001; Szymanski et al., 2006; Szymanski et al., 2007; Tripp et al., 2004; Trip et al., 2007a; Tripp et al., 2007b)

Body composition and fatigue.

In regards to objective number four, limited research was available examining the relationship between body composition and fatigue. Basile, Otto, and Wygand (2007) examined body composition measures and baseball performance variables among collegiate baseball players. Participants were 14 position players on an NCAA Division I baseball team. Lean body mass, bat velocity, and batted-ball velocity were measured. Performance variables were obtained at the conclusion of the team's 59-game season.

Results showed moderate correlations between lean body mass and batted-ball velocity ($r = .56$, $p < .01$) and lean body mass and bat speed ($r = .64$, $p < .05$). Such results suggest that the absolute amount lean tissue mass a player has does play an important role in baseball hitting performance (Basile et al., 2007).

Buford, Smith, O'Brien, Warren, & Rossi (2008) observed changes in body composition of NCAA Division I male wrestlers. Their body composition and muscular performance were assessed in pre-season, during their regular season, pre-nationals, and post-season. Body composition was measured using skinfolds and muscular performance of the quardriceps was assessed using an isokinetic dynamometer. Results showed wrestlers to be at their highest in regards to percent body fat post-season with decreased muscular performance at that time. Differences in body composition and muscular performance were noted from pre-nationals to post-season values. This decrease in muscle performance was simultaneous with the increase in percent body fat (Buford et al., 2008). Hulens, Vansant, Lysens, Claessens, and Muls (2001) examined differences in exercise capacity between lean ($n = 81$) and obese ($n = 225$) women. Participants completed a variety of tests including a submaximal (70 watts) and maximal VO_2 test. Results revealed at a submaximal load on a cycle ergometer that obese women were at 78% of their VO_2 peak while the lean women were only at 69%. Researchers also found that lean women recovered more quickly than their obese counterparts. At two minutes after maximal effort in a VO_2 maximum test (cycle ergometer) obese women had recovered to 47% of their VO_2 peak while lean women were down to 35%. Based on the literature, the researcher hypothesized that an inverse relationship would occur between body composition and fatigue, in that the greater percent body fat the less time it would take for players to fatigue.

In regards to body composition assessment, air displacement plethysmography (ADP) and dual-energy x-ray absorptiometry (DXA) methods among female collegiate athletes were compared. Participants were 47 NCAA Division II female athletes from various sports (basketball, soccer, volleyball, swimming, fastpitch softball and track). Height and weight measurements were obtained, and then participants completed a DXA scan followed by ADP measured by the Bod Pod. Results showed a strong prediction for the measures with fat free mass (FFM) (R^2 = .94, *SEE* =1.228) as well as percent body fat (R^2 = .94, *SEE* =2.1). Based on these results researchers concluded that both DXA and ADP are valid methods for assessing body composition among female college athletes (Ballard, Farfara, & Vukovich, 2004).

Research suggests that body composition and lean tissue mass have effects on exercise and athletic performance (Basile et al., 2007; Buford et al., 2008; and Hulens et al., 2001). While relationships were found between body composition and baseball performance variables, further investigation is necessary among fastpitch softball players (Basile et al., 2007). Based on the literature, the researcher hypothesizes that lower percent body fat or fat mass and greater amounts of lean tissue mass will have positive effects on fatigue in maximal softball hitting and muscular power.

Chapter Three

Methodology

As stated in the literature review, fatigue has been shown to inhibit performance in sports such as baseball, tennis, and soccer (Davey et al., 2002; Davey et al., 2003; Kellis et al., 2006; Tripp et al., 2004; Trip et al., 2007a; Tripp et al., 2007b). The purpose of this study was to examine the effects of a functional fatigue protocol on softball hitting form. The purpose was addressed through the development and implementation of a functional fatigue protocol for maximal softball hitting. In addition to the purpose of the project, objectives were formulated involving muscular power and body composition. Research suggested that muscular power was a vital component in regards to baseball and softball performance, with a combination of speed and strength necessary for sport specific movements such as hitting (Szymanski, DeRennee, & Spaniol, 2009). To better understand the role of muscular power in softball hitting performance, muscular power was assessed. With the previously mentioned research involving the importance of lean tissue mass on baseball performance variables, body composition was measured as well.

Objectives.

1) To develop a functional fatigue protocol

2) To determine the relationship between muscular power and LBEV and BBV

3) To determine the relationship between power fatigue and hitting fatigue

4) To determine the relationship between body composition and fatigue

Participants

Participants (n = 6) were NCAA Division II softball players with a mean age of 19.5 ± 1.4 years. Prior to recruiting subjects, the researcher obtained permission from the head softball coach at the University of Central Oklahoma to recruit research subjects from the 2009-2010 UCO softball team. While initial consent was obtained from 16 participants, 10 participants did not complete all of the tests. Scheduling conflicts prevented five players from completing testing, two participants left the team, two players were not hitters, and an error in data collection prevented use of data for one participant. First, the athletes completed an athlete information survey, which involved questions about playing experience, hand dominance (throwing and hitting), bat size and weight, age, and athletic classification. This survey was administered to better understand certain characteristics of the athletes. Participants then completed a battery of tests including the functional fatigue protocol (FFP), Wingate Anaerobic Power Test (WAnT), total body DXA scan (dual-energy x-ray absorptiometry), with height and weight measurements obtained as well.

Testing.

Testing took place in the off-season during the fall semester. The researcher made individual appointments with each athlete to complete the laboratory measures (WAnT and body composition) and the FFP. Participants reported the Kinesiology Laboratory where they completed all body composition measures followed by the WAnT. Two to three weeks following completion of the laboratory measures, participants reported to a local batting cage where they completed the FFP.

The Loughborough Intermittent Tennis Test (LITT), which was discussed previously, directly simulated a tennis match play environment and was created to analyze elite tennis athletes' response to fatigue (Davey et al., 2003). The functional fatigue protocol (Table 1) for this research project was modeled after the LITT and was altered for softball application. Pilot testing was done using former collegiate softball players to determine the rate of balls for each phase.

Functional fatigue protocol.

The functional fatigue protocol (FFP) consisted of six phases, which were illustrated in Table 1. The FFP was conducted in a controlled environment at an indoor hitting facility. Participants used their own bat to ensure that they were swinging the size and type of bat that they were accustomed to swinging in practices and games. This was done to make the results more applicable to game and practice situations. Pre- and post-tests will be conducted on a batting tee, with the remaining phases being completed using a Jugs™ pitching machine. A Jugs™ 5-point batting tee was used for the pre- and post-tests, with the ball placed in the middle of the plate below the player's waist. The pitching machine speed was set at a 52 miles per hour, which was a typical speed for the players to use in regular practices. Pitch height was set approximately at the player's waist, over the middle of the plate. Before each FFP, the speed was calibrated using a Jugs™ radar gun. The first phase in the FFP was the familiarization phase. This phase consisted of 10 balls in which the participants bunted or simply watched. No full swings were taken in this phase. The purpose of both the familiarization and warm-up phases was to get the participants used to the fatigue protocol (ball speed, rate of balls, location of pitch). After a three minute rest period following the warm-up phase, participants hit six balls off of a tee for the pre-test. The purpose of both the pre- and post-testing phases was to create a slightly more controlled and stationary environment for testing and video analysis. Although pitching machines are relatively consistent, by utilizing a tee the researcher has a greater amount of control of the location of the ball. Following completion of the pre-test, participants immediately began the fatigue phase. For the fatigue phase participants hit one ball every three seconds off of the pitching machine and were instructed to swing maximally to volitional fatigue. Fatigue was defined through meeting test termination criteria. Test termination criteria were 1) if the participant asked to stop, 2) could no longer maintain pace, 3) if they swing and miss or foul tip three consecutive balls, or 4) if the participant reached 100 balls. In this phase participants were instructed to swing maximally at every pitch regardless if they perceive it to be out of the strike zone. Immediately following the fatigue phase participants completed the post-test, which was conducted in the same manner as the pre-test.

Each of the six phases were recorded using a digital video camera, and results were analyzed using the Dartfish Teampro version 5.0 motion analyzing software. The camera was placed on a tripod located directly across from the hitters in an adjacent batting cage. Markers were placed on the ground to ensure that the tripod and home plate were in the same place for each participant. The camera was set at a height where the player's entire body and home plate were both included in the camera frame. The side of home plate in the plane perpendicular to the video camera was utilized for a reference distance in order to calculate velocities. This distance was 0.35m. For video analysis, the researcher examined swing angles at the point of ball contact pre- and post-fatigue. Specific swing angles that were measured at the front and back elbows as well as at the wrists, bat, and back knee to determine changes in hitting form as a result of fatigue. The front and back elbows were measured with the vertex of the angles at the respective elbow joint, with the rays located on the acromion process and styloid processes. Reflective markers were placed on participants to ensure that the same locations are used for swing angle analysis. Markers were placed on the acromion process (right and left), lateral aspect of the elbow joint (right and left), styloid process of the wrist (right and left), anterior superior iliac spine (ASIS, right and left), lateral epicondyle of the knee joint (back leg), and lateral malleolus (back leg). Wrist angle was defined with the vertex of the angle located at the point at which the bat is gripped with the hands between the right and left wrists with angle rays extending to the medial aspect of each elbow. Bat angle was measured with the vertex of the angle located at the lateral aspect of the wrist with the rays of the angle extending to the distal end of the bat head and the acromion process of the back arm. Finally, back knee angle was measured with the vertex of the angle located at the lateral epicondyle of the back knee, with rays extending to the lateral malleolus and to the point at which the hip joint hinges. Bat and batted-ball velocity (BBV) were calculated using Dartfish software as well. Linear bat-end velocity (LBEV) was calculated using the frame immediately prior to ball contact and the point of ball contact. Linear displacement of the bat head was calculated using Dartfish, then divided by time (sec) between frames. Similarly, BBV was calculated by finding the linear displacement of the softball from the point of contact to the first frame following ball contact. Displacement was then divided by time to find BBV.

Throughout the duration of the functional fatigue protocol, participants were asked their Rating of Perceived Exertion (RPE) using the Borg scale (6-20). This method was used throughout the literature in both baseball and tennis fatigue protocols (Davey et al., 2002; Tripp et al., 2007). Another study examined the effects of the use of electromyographic (EMG) equipment on golf swing kinematics, and researchers found that the use of an EMG, although it directly measures electrical activity through the muscles, actually inhibited portions of the swing (Egret, Weber, Dujardin, & Chollet, 2004). Based on the results of the aforementioned studies and the widely accepted use of RPE scales, the researcher chose to utilize a subjective fatigue scale. Initially, the researcher defined fatigue as reporting an RPE of 18. This was chosen based on the assumption that most participants would not physically be able to complete the fatigue phase of the FFP. The researcher also anticipated that the participants would not report a 20 on the RPE scale even if they could no longer maintain the cadence of the FFP due to the competitive nature of collegiate athletes. While the Borg RPE scale was frequently utilized, values defining fatigue varied from 15 (Tripp et al., 2004; Tripp et al., 2007a; Tripp et al., 2007b) to 20 (Davey et al., 2002; Davey et al., 2003). During the FFP, the researcher observed the participants during the fatigue phase and chose to eliminate reporting an RPE of 18 as a fatigued state due to their ability to complete the phase, despite their reported RPE. Ratings of perceived exertion were reported to better understand the effort being expended during the FFP.

Wingate anaerobic power test.

The Wingate Anaerobic Power Test (WAnT), a 30 second test that measured anaerobic power was conducted in the Kinesiology Laboratory using a Monark Cycle Ergometer (828E). Participants completed a 5-minute warm up with 5-second sprints performed each minute with increased intensity. Following the 5-minute warm-up, the resistance on the cycle ergometer was set at 8.6% of the participant's body weight in kilograms (kg). Participants were instructed to pedal as fast as possible for a total of 30 seconds. Revolutions were counted and recorded every 5 seconds. After the 30 seconds, the participant remained on the cycle ergometer for a cool down to ensure that their heart rate returned to approximately 110 bpm (ACSM, 2006; Nieman, 2007). Peak power, average power, and percent fatigue were calculated following testing. One potential limitation to the WAnT was the use of the Monark Cycle Ergometer. If the participant weighed more than 95 kg, sufficient resistance would not be applied for the test. For the present investigation, no participant weighed more than 95 kg.

Body composition.

The researcher obtained height and weight measurements in addition to a DXA scan. After completing initial measurements, a DXA scan was conducted using a GE Lunar iDXA total body scan. Participants were positioned on the DXA machine and were asked to lie supine without moving for the duration of the scan (7-10 minutes). Lean tissue mass, fat mass, and region percent body fat were examined using results from the total body DXA scan.

Statistical Design and Analysis

To detect differences in swing angles (front and back elbows, wrist, bat, and back knee) and velocities (BBV and LBEV) from pre- to post-testing, an analysis of variance (ANOVA) with repeated measures was utilized. A Pearson's product moment correlation coefficient was conducted to address each of the other three objectives. The alpha level for this research project was set at $\alpha = .05$. Multiple statistical tests were conducted, therefore the researcher had an increased chance of making a type I error. The alpha level was not adjusted due to the exploratory nature of this study and the robust nature of the *F* statistic. In regards to detecting differences and statistical power, an effect size of .59 was calculated based on mean bat speeds from a previous study (Tabuchi et al., 2007). With this effect size and alpha level the researcher needed a sample size of $n = 10$ in order to detect differences.

Chapter Four

Results

The purpose of this study was to examine the effects of fatigue on softball hitting. Additionally, four objectives were addressed throughout testing. The objectives were to develop a functional fatigue protocol for maximal softball hitting as well as to determine relationships between muscular power and LBEV (linear bat-end velocity) and BBV (batted-ball velocity), power fatigue and hitting fatigue, and between body composition and fatigue. Results of the athlete information surveys, body composition assessments, WAnT (Wingate anaerobic power test), and FFP (functional fatigue protocol) were analyzed and compiled following completion of all data collection, with the purpose and objectives of the study addressed.

Descriptive statistics.

Results of the athlete information surveys revealed participants were two freshmen, two sophomores, and two seniors. Two participants reported their primary position as catcher, with one outfielder, pitcher, shortstop, and utility player. All participants were right-handed throwers, with five right-handed hitters and one left-handed hitter. Half of the participants classified themselves as power hitters, with the other half base hitters. No participants considered themselves to be slap hitters.

Functional fatigue protocol.

Hitting swings were analyzed from the FFP using Dartfish Teampro version 5.0 motion analysis software. Six swings were analyzed from both the pre- and post-test phases of the FFP, and swing angles (front and back elbow, wrist, bat, and back knee) and velocities (BBV and LBEV) were measured. Pre- and post-test angles and velocities were averaged, and an analysis of variance (ANOVA) with repeated measures was conducted. Results were reported in Table 2. Examination of descriptive statistics revealed the pre-test average angle of the wrist at ball contact as well as pre-test LBEV to be negatively skewed (-2.58 and -2.11, respectively) and leptokurtic (2.85 and 2.02, respectively). This violated the assumption of a repeated measures ANOVA of normally distributed data. Due to the robustness of the *F* statistic to such violations, the alpha level was not adjusted. Additionally, the researcher acknowledged an inflated alpha level with the use of multiple statistical tests. Outliers were also discovered for pre-test average wrist angle, LBEV, and BBV as well as percent body fat, which were shown in Figure 1. The researcher chose to keep the outliers in the analysis due to a limited sample size and the fact that outliers were real data points.

Significant ($p < .05$) differences were found in both LBEV ($F = 12.479$, $p = .017$) and BBV ($F = 11.856$, $p = .018$) with fatigue. LBEV had a 6.9% decrease (1.8 m/s) as a result of fatigue, while BBV decreased by 6.1% (1.6 m/s). No significant differences were discovered pre- and post-fatigue in any of the swing angles measured. Additionally, effect sizes were calculated for bat angles, back elbow, wrist, back knee, LBEV, and BBV. There was a large effect for both LBEV ($d = 1.5$) and BBV ($d = .8$). A moderate effect was found for angles at the back elbow ($d = .6$), wrist ($d = .6$), and back knee ($d = .5$). For bat angle there was a small effect ($d = .4$) for change from pre-to post-fatigue.

Ratings of perceived exertion.

Throughout the FFP, ratings of perceived exertion (RPE) were reported at the end of each phase. Initial test termination criteria included reporting an RPE of 18 on the Borg Scale. After observing the participants during the protocol, that test termination criteria was eliminated. The researcher perceived that the participants were capable of continuing the fatigue phase of the FFP, therefore if participants reported an RPE of 18 or higher, the phase was not terminated. While players were visibly fatigued, all participants completed the fatigue phase by hitting 100 pitched balls at a rate of one ball every three seconds. For the familiarization phase all participants reported an RPE of six. Mean RPE for the warm-up phase was 10.8 ± 2.7, for the rest phase was 7.5 ± 2.1, and mean RPE for the pre-test was 8.8 ± 2.3. RPE was taken each minute during the fatigue phase of the FFP (n = 5). Mean RPE in minute one was 11.0 ± 1.0, minute two 15.0 ± 1.4, minute three 16.4 ± 1.8, minute four 17.6 ± 1.7, and at the conclusion of the fatigue phase participants (n = 6) mean RPE was 17.2 ± 2.2. Post-test mean RPE was 16.0 ± 3.3.

Objectives.

In addition to the purpose of examining the effects of fatigue on softball hitting performance, objectives were formulated and addressed throughout this study. Objectives included developing the functional fatigue protocol, identifying relationships between muscular power and hitting velocities, fatigue as measured by the WAnT and the FFP, and between body composition and fatigue. Descriptive statistics for body composition (Table 3) and muscular power (Table 4) were reported.

Developing the FFP.

The primary objective for this research project was to develop a functional fatigue protocol for maximal softball hitting. The goal of this protocol was induce functional hitting fatigue in a situation, which directly simulated a softball hitting practice environment. Qualitative analyses of the protocol revealed that players were visibly fatigued following the conclusion of the fatigue phase of the FFP. Additionally, following completion of the FFP, players were asked how the protocol compared to a hitting practice environment. Each participant stated that it was similar to a softball hitting practice, while the rate of balls was faster than a typical practice.

Muscular power, LBEV, and BBV.

The second objective was to determine if a relationship existed between muscular power and LBEV and BBV. A Pearson's product moment correlation coefficient was conducted to examine the relationship between the variables. Results of the statistical test were reported in Table 5. No significant results were discovered, although non-significant relationships were discovered. Strong, correlations were found, with a negative relationship between peak power and BBV (r = -.73, p = .097) and positive relationship between LBEV and BBV (r = .77, p = .075). A moderate, negative correlation was noted between peak power and LBEV (r = -.68, p = .138).

Muscular fatigue.

The third objective was to determine if a relationship existed between fatigue as measured by the WAnT and hitting fatigue from the FFP. Percent change was calculated for muscular power, LBEV, and BBV. To discover the relationship between the variables, a Pearson's product moment correlation coefficient was conducted. Relationships were reported in Table 6, with no significant relationships noted.

Body composition and fatigue.

The final objective was to examine the relationship between body composition and fatigue. Body composition variables of percent body fat, lean tissue mass, and fat mass were utilized, while fatigue was defined by percent change in the WAnT, LBEV, and BBV. Results of the statistical test were reported in Table 7. A strong, positive, significant relationship was discovered between fat mass and percent body fat (r = .90, p = .016). Non-significant relationships were also found, with a strong, negative correlation between percent body fat and LBEV percent fatigue (r = -.76, p = .082). A moderate, negative correlation was discovered between fat mass and LBEV percent fatigue (r = -.50, p = .314). Finally, low correlations were discovered, with a negative correlations between lean tissue mass and BBV percent fatigue (r = -.42, p = .414) and fat mass and BBV percent fatigue (r = -.41, p = .416). Low, positive correlations were also noted between lean tissue mass and fat mass (r = .38, p = .453) and lean tissue and LBEV percent fatigue (r = .43, p = .401).

Chapter Five

Discussion

The purpose of this study was to examine the effects of a functional fatigue protocol on maximal softball hitting. Statistical analyses revealed significant decreases in LBEV (- 1.8 m/s) and BBV (- 1.6 m/s) as a result of fatigue. Performance in fastpitch softball is highly dependent on timing, with any alteration in hitting timing through decreased bat velocity being potentially detrimental to performance. The researcher found a decrease in LBEV of 1.8 m/s after the completion of the FFP very meaningful. The pitchers mound in NCAA softball is located 43 feet from home plate (Abrahamson, 2009), and an average pitcher throws approximately 60 mph (10.2 m/s). A ball thrown from that distance at that speed would reach home plate in 1.3 seconds. While the pitcher's mound is 43 feet away from home plate, the pitcher's circle has an 8-foot diameter, which is depicted in Figure 2. As long as a pitcher stays within the pitcher's circle, they can release the ball up to eight feet closer to the batter depending on their stride length. This would take the ball just over one second to reach the batter. In that 1.1-1.3 second time period, the batter has to decide if the ball is in or out of the strike zone, determine the location of the pitch, and recognize the type of pitch thrown (rise, drop, curve, screw, fast ball, change-up, etc.). With that being said, a decrease in LBEV from 26.2 to 24.4 m/s could greatly alter hitting performance.

Hitting form as well as both good and bad hitting habits that are developed in practice carry over into games. The FFP was designed to simulate a practice environment where players hit ball after ball without rest. As previously stated, changes in LBEV and BBV could decrease performance. Although results of this study indicated no significant differences in any of the swing angles measured as a result of fatigue, the researcher found the small changes in angles at ball contact to be meaningful. A slight change in angles at ball contact could alter the point of contact, potentially changing and decreasing hitting performance. Results of the present investigation contradicted previous findings when examining changes in joint angles as a result of functional fatigue in the overhead throwing motion (Mullaney et al., 2005; Murray et al., 2001; Tripp et al., 2004; Tripp et al., 2007a; Tripp et al., 2007b). This could be attributed to the use of a stationary batting tee for pre- and post-test swing analysis. While the batting tee was utilized to create a controlled pitch location for the hitters for the analysis, it essentially took out the timing aspect of hitting a pitched ball. In theory, when hitting a pitched ball with an overall decrease in bat velocity, initiating the swing at the same time as with a higher bat velocity, ball contact would occur at a different point in the swing, causing the ball to be miss hit. Miss hitting the ball could be a result of hitting the ball off the handle or the end of the bat instead of the barrel, or simply hitting at the wrong point of the swing. Consistently hitting at a decreased bat velocity could also cause the hitter to make biomechanical adaptations in an attempt to increase performance. Such biomechanical adaptations could be beneficial to short term performance, but could develop into bad habits in the long run. For example, if a batter hits an inside pitch with a decreased bat velocity using the same hitting form and timing as with a higher bat velocity, they will likely hit the ball off of the handle because the bat head did not get to ball contact as quickly, resulting in a weak ground ball to third base. A biomechanical adaptation a hitter might make to compensate in this situation would be to open up the hips and shoulders to clear their hands and allow the bat head to reach the inside pitch, potentially resulting in a line drive to left field. While in the short term, a solid hit was made, long term implications could be consistently pulling the shoulder off of the ball early causing the hitter to have difficulties hitting the outside pitch.

As stated by Gabbet et al. (2007), elite softball players were shown to have superior anticipation skills. In regards to BBV, the faster the ball travels, theoretically the greater chance that a hit would result in a base hit by an infielder with excellent sport specific anticipation skills. An overall decrease in BBV could cause a player to have a lower batting average or other statistical measure of hitting performance.

While proper biomechanical hitting form is a crucial aspect to hitting, hitting confidence plays a huge factor in overall performance. Success realized in practice often is applied in games. If a player is fatigued and experiences biomechanical changes causing them to not hit as well in practice, their confidence could decrease as a result of poor practice performance, which could affect confidence and ultimately performance in game situations.

Objectives.

After analyzing the purpose of examining the effects of a functional fatigue protocol on maximal softball hitting, the researcher examined the results of the four objectives developed for the research project. As previously stated, the objectives for the present investigation were the following.

1) To develop a functional fatigue protocol

2) To determine the relationship between muscular power and LBEV and BBV

3) To determine the relationship between power fatigue and hitting fatigue

4) To determine the relationship between body composition and fatigue

Developing the FFP.

The primary objective for the research project was to develop a functional fatigue protocol for maximal softball hitting. The FFP developed for the present investigation was an effective way to induce functional fatigue among NCAA Division II fastpitch softball players. Prior to the FFP, there was no known functional fatigue protocol which involved maximal baseball or softball hitting. The FFP provides a basis for future research to examine changes in hitting form as a result of functional fatigue. Although the FFP was effective in causing the athletes to become fatigued in a simulated hitting practice environment, minor alterations are necessary. The FFP should be conducted with each phase utilizing a pitched ball to add to practical application and allow hitting timing to play a factor in performance and form. Additionally, participants should have the opportunity to hit more than 100 balls in the fatigue phase without being informed of a terminal number of balls.

While the FFP was specifically designed for NCAA Division II fastpitch softball players, it could be altered and applied to softball players of all levels as well as baseball players. Future research should be conducted examining the protocol and its effectiveness baseball and softball players of different ages and skill levels.

Muscular power, LBEV, and BBV.

An objective for this research project was to determine if a relationship existed between muscular power and LBEV and BBV. Although no statistically significant relationships were discovered, the researcher considered the moderate correlations to be meaningful relationships. Those with greater muscular power had higher LBEV and BBV.

The WAnT was selected to measure muscular power because of the ability to calculate percent fatigue as with the FFP in addition to the thought that swing power is generated from the legs and lower body. While relationships were discovered between peak power and LBEV (r = -.68, p = .138) and BBV (r = -.73, p = .138), these results indicated that increases in peak power translated to decreased LBEV and BBV. This was the opposite of the researcher's hypothesis, therefore the researcher concluded that the WAnT may not have been the most appropriate power measure for predicting swing velocity due to the principle of specificity of training. In regards to daily training, speed and endurance work is performed doing some form of running, not cycling. Most of the participants expressed that they had not ridden a bike in years. Additionally, the planes of motion which cycling and hitting are performed are different, requiring use of different muscles. Cycling is an activity performed in the sagittal plane, while the majority of the softball swing is performed in the transverse plane. Future studies examining muscular power among softball hitting should examine various power measures in relationship to the hitting swing.

Muscular fatigue.

Another objective for the present investigation was to determine if a relationship existed between fatigue as measured by the WAnT and hitting fatigue from the FFP. No relationships were discovered between the fatigue measures. As previously stated, this can most likely be attributed to the specificity of the activities performed.

Body composition and fatigue.

The final objective for the research project was to examine the relationship between body composition and fatigue. A strong significant relationship was discovered between percent body fat and fat mass, while moderate non-significant inverse relationships were discovered between LBEV percent fatigue and percent body fat and fat mass. While meaningful, these relationships were opposite of what the researcher hypothesized. With increases in percent body fat and fat mass, participants had less percent fatigue in LBEV. Additionally, small non-significant relationships were present between lean tissue mass and LBEV percent fatigue. This indicated that those with greater lean tissue mass experienced greater fatigue in LBEV. Previous research among collegiate baseball players suggested that lean tissue mass was moderately related to performance variables of LBEV and BBV (Basile et al., 2007; Szymanski et al., 2009). While lean tissue mass was shown to be positively related to LBEV and BBV in the literature among baseball players, the prevalence of greater amounts of lean tissue mass meant greater hitting fatigue among the specific population tested for the present investigation. Further research should be conducted examining the role of body composition on softball hitting variables and fatigue.

Limitations.

As with any research study, the present investigation had limitations, starting with a small sample size ($n = 6$). This small sample size resulted in decreased statistical power, which decreased the probability to detect differences. Additionally, outliers could have greatly influenced results of the study. In regards to results of the objectives, in the researchers opinion the most skilled hitter had the highest percent body fat, and the individual with the greatest muscular power as measured by the WAnT had the lowest LBEV. With that being said, results should be read with caution and with a sample size of six, results should not necessarily be generalized.

The use of multiple statistical tests also created an inflated alpha level. Due to the robustness of the *F* statistic and the exploratory nature of the study, no adjustments were made to the alpha level.

Another limitation of the study was the timing of the testing. Testing took place at the end of the fall semester. Each participant completed the DXA and WAnT, then later reported to complete the FFP. The time between testing varied from 1-3 weeks between body composition and power testing and the FFP. While it was not likely that significant changes occurred in that time frame, the researcher acknowledged that it was a limitation to the study. Due to testing taking place during the fall semester, the athletes were participating in off-season strength and conditioning workouts as well as individual skill workouts with their coaching staff. While the researcher encouraged each participant to complete testing on a day when they had not participated in off-season workouts or practice, it was not possible due to scheduling conflicts and was therefore noted as a limitation. Although participation in workouts prior to completing testing was considered to be a limitation, it was also a daily reality for the athletes. On most days, off-season workouts occurred at 6:00 am followed by team practices or individual skill instruction in the afternoon. The lack of control for previous workouts the day of testing, while a limitation also adds to the external validity of the study. The situation in which the participants completed testing was very similar to an everyday practice and workout routine.

In regards to the FFP, the subjectivity of the use of Dartfish was also considered to be a limitation. While Dartfish was a effective motion analysis tool in identifying swing angles and velocities, the location of each angle was highly subjective. Reflective markers were placed on specific landmarks on the participants' joints to help control for variability, although due to the dynamic nature of the activity and loose clothing on the participants, those landmarks were often unusable. To control for variability in the analysis, the same technician performed all of the measurements to eliminate any possible intertechnician error.

Camera quality was also a limitation to the FFP analysis. Frame by frame analyses using Dartfish revealed that the exact point of ball contact was not captured for every swing. In this case, the researcher defined ball contact as the frame immediately preceding contact or at the point of ball contact.

Participants used team practice bats to hit pitching machine softballs during the FFP. The use of practice bats could have caused peak BBV to be underestimated due to the age and amount of use of the bats. Also, the use of pitching machine balls could cause a decreased BBV due to variables such as compression and coefficient of restitution (COR). To find the COR and compression of the pitching machine softballs, the researcher contacted the manufacturer of the ball. The manufacturer was unable to find the information. While specific values were unknown, the research assumed that pitching machine balls have less compression and a higher coefficient of restitution than an NCAA softball (400 lbs and .47) causing lower absolute velocities for BBV (Abrahamson, 2009).

Another limitation to this study was the use of subjective fatigue using Ratings of Perceived Exertion (RPE). As previously stated, while subjective fatigue was widely used in the literature, an RPE defining fatigue was not consistent (Davey et al., 2002; Davey et al., 2003; Tripp et al., 2004; Tripp et al., 2007a; Tripp et al., 2007b). It was due to this fact that it was eliminated from test termination criteria. Additionally, due to the exploratory nature of the study and limited number of softballs, participants were not allowed to hit more than 100 balls in the fatigue phase. After completing data collection, the researcher hypothesized that each participant would have hit more than 100 balls consecutively had they been given the opportunity.

Future research.

Future studies should be conducted examining the effects of fatigue on softball hitting form. The fatigue phase of the FFP should be altered, allowing participants to hit more than 100 balls if possible. Another recommendation for number of balls hit would be to not inform the athletes of how many balls they will be asked to hit, so that they do not have a goal number in mind. Test termination based on number of balls would vary based on the number of balls available. Based on observation of the hitters during the FFP, the researcher hypothesized that players would not exceed 200 balls hit at a rate of one ball every three seconds. Additionally, the FFP should be tested on multiple teams to increase the external validity of the results.

In regards to muscular power and body composition and their roles in hitting performance, additional research is warranted. Various measures of muscular power should be compared to discover which measure is the greatest predictor of velocities and performance. The influence of body composition on hitting performance should also be explored to discover if percent body fat or absolute lean tissue or fat mass has a greater effect on performance. Through further understanding of the aforementioned variables and their effects on fastpitch softball hitting, coaches, strength and conditioning specialists, and researchers can help to improve performance among NCAA Division II hitters.

Practical application.

The practical application from this research project for fastpitch softball players and coaches is to concentrate on the quality instead of quantity of swings taken in a practice setting. Biomechanical adaptations as a result of fatigue in a practice setting could carry over into a game, potentially inhibiting performance. Coaches should monitor players and have a specific practice plan prior to beginning each practice. Also, players should not rush through swings or drills simply to get finished with a specific task, again being aware of the quality of the swings taken rather than the number of swings.

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Table 1

Functional Fatigue Protocol (FFP)

Phase	Time	Balls/Seconds	Total Balls
Familiarization	≤ 1 minute	varies	≤ 10
Warm-up	3 minutes	1 ball/ 6 sec	30
Rest	3 minutes	0	0
Pre-test	1 minute	1 ball/ 10 sec	6
Fatigue	≤ 5 minutes	1 ball/ 3 sec	≤ 100
Post-test	1 minute	1 ball/ 10 sec	6

Table 2

Swing Angles and Velocities Pre- and Post- Fatigue

Variable	Pre-Fatigue ± SD	Post-Fatigue ± SD	*F*	*p*	*d*
Front Elbow	142.7 ± 9.9	144.3 ± 13.2	.363	.573	.2
Back Elbow	118.2 ± 9.4	124.0 ± 9.3	2.435	.179	.6
Wrist	81.3 ± 9.8	75.6 ± 9.3	2.044	.212	.6
Bat	67.1 ± 15.9	73.8 ± 14.9	2.812	.154	.4
Knee	138.8 ± 7.9	142.4 ± 6.3	1.580	.264	.5
LBEV	26.2 ± 1.2	24.4 ± 2.1	12.479	.017*	1.5
BBV	26.4 ± 1.9	24.8 ± 2.0	11.856	.018*	.8

Note. Front Elbow (degrees), Back Elbow (degrees), Wrist (degrees), Bat (degrees), Knee (degrees), Linear Bat-end Velocity = LBEV (m/s), Batted-ball Velocity = BBV (m/s). Pre-Fatigue (mean ± SD), Post-Fatigue (mean ± SD), Cohen's *d* (*d*).
*$p < .05$

Table 3

Body Composition Descriptive Statistics

Variable	Mean	SD	Minimum	Maximum
% Body Fat	28.7	3.4	26.0	35.0
Fat	43.8	8.0	34.9	56.8
Lean Tissue	101.6	9.1	89.4	114.2

Note. Percent Body Fat (%), Fat (lbs), Lean Tissue (lbs).

Table 4

Wingate Anaerobic Power Test (WAnT) Results

Variable	Mean	SD	Minimum	Maximum
Peak Power	528.0	140.4	388.6	765.4
Average Power	379.9	123.4	280.6	612.3
Minimum Power	278.8	112.7	194.3	495.2
% Fatigue	48.3	6.1	40.0	57.0

Note. Power expressed in Watts.

Table 5

Relationship between Muscular Power, BBV, and LBEV

Variable	1	2	3
1. PP	------	-.68	-.73
2. LBEV	-.68	------	.77
3. BBV	-.73	.77	------

Note. Peak Power (PP = kg · m / s), Pre-Linear Bat-end Velocity = LBEV (m / s), Pre-Batted-ball Velocity = BBV (m / s), $n = 6$.
*Indicates significant correlation ($p < .05$)

Table 6

Relationship between WAnT and FFP Fatigue

Variable	1	2	3
1. %Fatigue WAnT	------	-.10	-.13
2. %Fatigue LBEV	-.10	------	.09
3. %Fatigue BBV	-.13	.09	------

*Note.*Wingate Anaerobic Power Test (WAnT), Linear Bat-End Velocity (LBEV), Batted-Ball Velocity (BBV), $n = 6$.
% Fatigue = [(pre – post) / pre] · 100.
*Indicates significant correlation ($p < .05$)

Table 7

Relationship between Body Composition and Fatigue

Variable	1	2	3	4	5	6
1. LTM (lbs)	------	-.06	.38	-.06	.43	-.42
2. %BF	-.06	------	.90*	.01	-.76	-.26
3. Fat (lbs)	.38	.90*	------	.01	-.50	-.41
4. %Fatigue WAnT	-.06	.01	.01	------	-.10	-.13
5. %Fatigue LBEV	.43	-.76	-.50	-.10	------	.09
6. %Fatigue BBV	-.42	-.26	-.41	-.13	.09	------

*Note.*Lean Tissue Mass (LTM), Percent Body Fat (%BF), Fat Mass (Fat), Wingate Anaerobic Power Test (WAnT), Linear Bat-End Velocity (LBEV), Batted-Ball Velocity (BBV), $n = 6$.
% Fatigue = [(pre – post) / pre] · 100.
* Indicates significant correlation ($p < .05$)

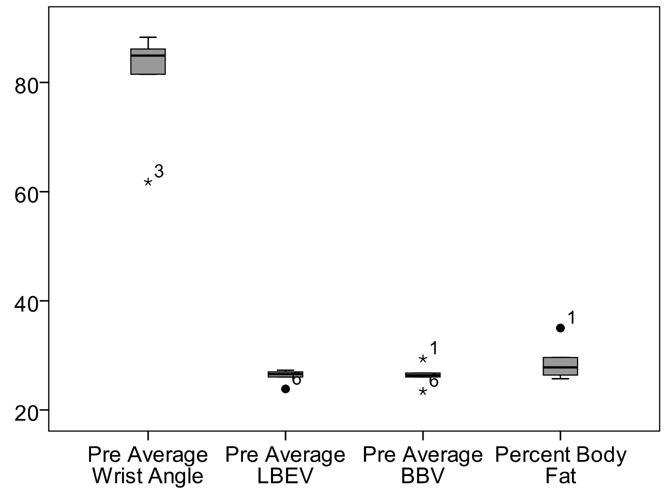

Figure 1. Reported outliers.

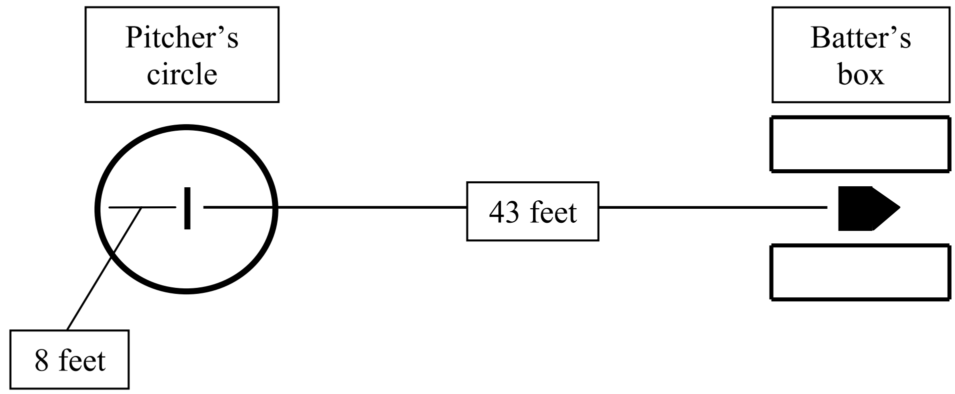

Figure 2. Softball field diagram.

Dear Ms. Bounds and Dr. Gray:

Re: Application for IRB Review of Research Involving Human Subjects

We have received your revised application (UCO IRB# 09113) entitled, *Effects of a functional fatigue protocol on maximal softball hitting,* and find all major stipulations in order. The UCO Institutional Review Board is pleased to inform you that your IRB application has been approved. An approved, stamped copy of the Informed Consent Form will be sent to you via campus mail.

Caveat: Add to the photo release form that their identities will be protected and that the photos will be destroyed at the termination of the study. Send a copy of the revision to our office before you begin. Also be sure to have the assisting personnel sign the IRB Personnel Form. All can sign one form if desired.

This project is approved for a one year period but please note that any modification to the procedures and/or consent form must be approved prior to its incorporation into the study. A written request is needed to initiate the amendment process. You will be notified in writing prior to the expiration of this approval to determine if a continuing review is needed.

On behalf of the Office of Research & Grants and UCO IRB, I wish you the best of luck with your research project. If our office can be of any further assistance in your pursuit of research, creative & scholarly activities, please do not hesitate to contact us.

Sincerely,

Jill A. Devenport, Ph.D.

Chair, Institutional Review Board

UNIVERSITY OF CENTRAL OKLAHOMA

Effects of a Functional Fatigue Protocol on Maximal Softball Hitting

Informed Consent

Purpose: The primary purpose of this research study is to examine the effects of a functional fatigue protocol on softball hitting form among NCAA Division II softball players. Research has shown that a decrease in sport specific joint angles and an overall decrease in performance can be a result of fatigue. Through knowledge of the effects that fatigue has on softball hitting form, coaches and players can know when practice is productive versus when too many swings are merely creating bad habits. A secondary purpose of this project is to assess the importance of lean tissue mass, fat mass, percent body fat, and abdominal adiposity to softball hitting performance and fatigue as measured through a functional fatigue protocol and the Wingate Anaerobic Power Test.

Procedures: First, you will be asked to fill out a short Athlete Information Survey following consent. Additionally, you will be asked to report on two separate occasions to perform a battery of tests for this research project. A functional fatigue protocol (FFP) for maximal softball hitting will be completed at a local batting cage where the UCO Softball team practices regularly. The FFP consists of six phases: familiarization, warm-up, rest, pre-test, fatigue, and post-test, and will take approximately 30 minutes to complete. The fatigue phase of the FFP will last for up to five minutes where you will be asked to hit a pitched ball using maximal effort every three seconds until you are fatigued. The FFP will be recorded using a digital video camera and later analyzed using Dartfish Video Analysis Software. In addition to the FFP, you will be asked to report to the Kinesiology Laboratory (WEL 125) for approximately one hour to complete various body composition measurements as well as the Wingate Anaerobic Power Test (WAnT). In regards to body composition testing, researchers will assess your waist (WC) and hip (HC) circumferences, height, weight, sagittal abdominal diameter (SAD), and perform a total-body Dual-Energy X-Ray Absorptiometry (DXA) scan. For the DXA scan, you will be asked to lie still on your back, and the measurement will take between seven and ten minutes. Following the body composition measurements, you will complete the WAnT, which will be conducted on a Monark Cycle Ergometer. The WAnT is a 30 second power test that involves maximal effort cycling with the resistance set at 8.6% of your body weight (kg). After all testing is complete, you may set up a time with the PI to go over you results and watch the testing film. Film analysis will be conducted on a separate date if you choose to take part in this.

Expected Length of Participation: You will be asked to participate for a total of an hour and a half, which will be broken up into two separate occasions. Approximately one hour will be spent in the Kinesiology Laboratory with the Athlete Information Survey, body composition testing, and the WAnT. The FFP will take approximately 30 minutes to complete at a local batting cage. If you so choose, an additional day of participation is offered to each research subject, where you will sit down with the researcher and go over the hitting film from the fatigue protocol. Film analysis will take approximately 30 minutes and is completely optional.

Potential Benefits: You will benefit through having access to a motion analysis of your hitting swing. The motion analysis software will break down your swing frame by frame so that you can see potential strengths and weaknesses of your hitting form. Additionally, peak power, average power, and rate of fatigue will be calculated from the results of the WAnT and given to you following data collection. In regards to body composition testing, you will know your bone density, percent body fat, lean tissue mass, and fat mass from your DXA scan. The additional anthropometric measures (WC, HC, SAD) can be used to identify potential risk for cardiovascular disease.

Potential Risks or Discomforts: The functional fatigue protocol involves up to five minutes of maximal hitting to fatigue, which could cause discomfort due to the intensity of the activity. Similarly, the WAnT is performed at a high intensity for 30 seconds and will cause you some discomfort. Risks associated with the use of the iDXA machine include exposure to a small amount of ionizing radiation (3.0μGy), which is the equivalent to the amount of radiation acquired in about 1/3 of a day in the natural environment. Radiation exposure has an accumulating effect and frequent exposures can be potentially harmful. Potential risks to the ovaries include delay in menstruation, genetic mutations, temporary sterility, and permanent sterility. These risks are associated with radiation exposure 150,000 to 3 million times greater than the exposure from a single iDXA scan (Bonnick & Lewis, 2006). An additional risk is the reddening of the skin which is associated with exposure to ½ million times more than the exposure from a single iDXA scan (Bonnick & Lewis, 2006). Any amount of radiation could be harmful to a fetus so if there is any chance that you might be pregnant, including unprotected sex within the last 60 days, you will not be allowed to complete the iDXA scan.

Medical and Mental Health Contact: If for some reason you experience an injury as a result of testing or the exercise program, the Principle Investigator will escort you to the Student Health Center which is located in the Wellness Center. The phone number for the Student Health Center is (405) 974-2317. The phone number for the Student Counseling Center is (405) 974-2215, which is located on the fourth floor of the Nigh University Center.

Contact Information of Researchers:

For any questions regarding the research study, please contact either the PI or Co-PI.

PI: Emilee Bounds	Co-PI: Michelle Gray
University of Central Oklahoma	University of Central Oklahoma
100 N. University Dr. Box #189	100 N. University Dr. Box #189
Edmond, OK 73003	Edmond, OK 73003
(405) 974-3110	(405) 974-5274
ebounds@uco.edu	rgray11@uco.edu

For questions about your rights as a research participant, contact:

Dr. Jill A. Devenport, Chair
UCO Institutional Review Board
100 N. University Drive # 159, ADM 216
Edmond, OK 73034
(405) 974-5479
irb@uco.edu

Explanation of Confidentiality: All data and information collected by either the PI or Co-PI. You will be assigned an identification number for data entry. After the data is entered into the computer, all code sheets will be destroyed. All information will be kept confidential and will not be shared with anyone.

Assurance of Voluntary Participation: Participation in this research project is completely voluntary. If there is any aspect of the testing or exercise program, which you do not want to participate in, simply inform the researcher. You may withdraw from the study at any point in time without penalty.

Affirmation of Consent: I hereby voluntarily agree to participate in the above tests and exercise program. I understand that there is no penalty for refusal to participate, and understand that I am free to withdraw my participation at any time without penalty. I have read and completely understand this informed consent, and I acknowledge that I am over the age of 18 years old.

Research Subject's Name: ____

Date of Birth: ____

Signature:___________________________________ Date:__________________________

Appendix C

Coach Consent

I, ________________________, head softball coach at the University of Central Oklahoma, grant Emilee Bounds, Primary Investigator, and Michelle Gray, Co-Primary Investigator, permission to utilize the UCO Softball team as a means to recruit research subjects for the present research study entitled, Effects of a Functional Fatigue Protocol on Maximal Softball Hitting.

Genny Stidham, Head Softball Coach Date

Emilee Bounds, Primary Investigator Date

Michelle Gray, Co-Primary Investigator Date

University of Central Oklahoma
Effects of a Functional Fatigue Protocol on Maximal Softball Hitting
PHOTO RELEASE FORM

The Primary Investigator for the research project titled, Effects of a Functional Fatigue Protocol on Maximal Softball Hitting, requests permission to take and use your photograph during this research study. Photos may be taken at any time during the study period. The photos may be used for promotional purposes to showcase the present research study, the Department of Kinesiology and Health Studies, the College of Education and Professional Studies, and/or the University of Central Oklahoma. Photos may be used in a variety of media, including newsletters, brochures, slide shows, multimedia presentations, display boards or web-sites. Your identity will be protected at all times when using your photographs. All pictures will be destroyed after all data dissemination is complete. No compensation is paid to individuals or organizations for this use. If you have any questions or concerns, please contact Emilee Bounds, PI at (405) 974-3110 or Michelle Gray, Co-PI at (405) 974-5274.

By signing below, I give permission for photographs to be taken of me during my participation in the present research study.

Name: ____

Phone/Email: ____

Signature: _________________________________ Date: ___________________

University of Central Oklahoma

Effects of a Functional Fatigue Protocol on Maximal Softball Hitting

VIDEO RELEASE FORM

For the study entitled, Effects of a Functional Fatigue Protocol on Maximal Softball Hitting video taping the Functional Fatigue Protocol is vital for data analysis. The researchers request your permission to video tape you during this aspect of the research study. In addition to data analysis, video tapes may be used for data dissemination purposes. As stated in the Informed Consent, all data will be kept confidential and will be stored using a code number assigned by the researcher.

By signing this video release form, I give the researchers permission to video tape my functional fatigue protocol.

Print Name Date

Signature Date

Effects of a Functional Fatigue Protocol on Maximal Softball Hitting

Athlete Information Survey

Athletic Classification ___________________

Primary Position ___________________

Secondary Position ___________________

What type of hitter are you? (*please circle one)*

Power Hitter Base Hitter Slap Hitter NA

Throw (*please circle one*) Right Left

Bat (*please circle one*) Right Left Both NA

If bats both right and left handed please indicate percentage hit on each side (i.e. 60/40 right to left handed) ____

If left handed, please indicate frequency of 'slapping.' ______________________

Bat Length (i.e. 33 in) __________________Bat Weight (i.e. 25 oz) __________________

Ethnicity (*please circle one*)*

Asian Black Hispanic White Other

*This information is obtained to compare your values to accepted norms for your ethnicity for your DXA scan.

Effects of a Functional Fatigue Protocol on Maximal Softball Hitting

Body Composition

WC (cm) ___________________Height (inches) ___________________

WC (cm) ___________________Weight (lbs) ___________________

HC (cm) ___________________SAD (cm) ___________________

HC (cm) ___________________SAD (cm) ___________________

Wingate Anaerobic Power Test (WAnT)

Weight (kg) ____________________ Resistance (wt kg ×.086) ________________

Warm-up (5 min) __________

Revolutions (every 5 seconds)

1 ___________

2 ___________

3 ___________

4 ___________

5 ___________

6 ___________

Cool down (5 min) _________

Appendix F

Effects of a Functional Fatigue Protocol on Maximal Softball Hitting

Functional Fatigue Protocol

Phase	Start Time	End Time	RPE (6-20)	Balls
Familiarization (0:00 to 1:00)	____________	____________	____________ (End of Phase)	______ (≤ 10)
Warm-up (1:00 to 4:00)	____________	____________	____________ (End of Phase)	______ (30)
Rest (4:00 to 7:00)	____________	____________	____________ (End of Phase)	N/A
Pre-test (7:00 to 8:00)	____________	____________	____________ (End of Phase)	______ (6)
Transition (10 seconds)	N/A	N/A	N/A	N/A
Fatigue (8:10 to Fatigue)	____________	____________	__ __ __ __ __ 1 2 3 4 5	______ (≤ 100)
Transition (10 seconds)	N/A	N/A	N/A	N/A
Post-test (1 minute)	____________	____________	____________ (End of Phase)	______ (6)

Borg Rating of Perceived Exertion (RPE) scale

6	No exertion at all
7	Extremely light
8	
9	Very light
10	
11	Light
12	
13	Somewhat hard
14	
15	Hard (heavy)
16	
17	Very hard
18	
19	Extremely hard
20	Maximal exertion