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Biomechanical Analysis of the Upper Extremity during Multiple Softball Pitches

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This Scholarly Project, submitted by Amy Bookless, Katelyn Bottelberghe, and Tara Petersen in partial fulfillment of the requirements for the Degree of Doctor of Physical Therapy from the University of North Dakota, has been read by the Advisor and Chairperson of Physical Therapy under whom the work has been done and is hereby approved.

(Graduate School Advisor)

(Chairperson, Physical Therapy)

PERMISSION

Title Biomechanical Analysis Of The Upper Extremity During Multiple Softball Pitches

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Signature(s) Katlyn W Bottleberghe
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Date 12·12·07

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ACKNOWLEDGEMENTS

Thanks Captain! We wouldn't have been able to steer the ship into port without ewe.
Smee, Shmee, and Smea

Thank you to the UND Softball pitchers and coaches. Without you, this study wouldn't have been possible.

Thank you to our family and friends. Your support through this journey has meant more than words can express.

ABSTRACT

Purpose: There are a large number of fast pitch softball participants including high school, college, Olympic, professional and recreational leagues. While a large number of studies describe the baseball pitch, there is a shortage of studies describing the windmill softball pitch. Therefore, the purpose of this study is to utilize electromyography (EMG) and motion analysis to determine the biomechanical factors of muscle recruitment, shoulder and elbow range of motion and joint velocities during the windmill softball pitch.
Subjects: Five Division II women's fast pitch softball pitchers, mean age 19 years, were included in the study. The player's pitching experience averaged 9.5 years.
Instrumentation: A ViconPeak motion analysis system using 8 MX40 cameras at a capture rate of 250 frames per second was used to collect the complete pitch. ViconPeak Workstation® software was used to label, reconstruct, and process the raw data. EMG data was collected at a frequency of 1000 Hz using bipolar, self-adhesive, pre-geled EMG surface electrodes. The data was rectified, normalized to the fast pitch EMG for each phase, and smoothed using RMS 50 with Noraxon MyoResearch XP software.
Procedure: The procedure and methods were explained to the subjects prior to informed consent. After informed consent, the subjects were instrumented with EMG electrodes and reflective markers. Subjects completed a self-selected warm-up similar to a practice or game. Pitchers performed five repetitions of each randomly assigned set of pitches.
Data Analysis: A repeated measures ANOVA was used to analyze all data. Statistical significance was set *a priori* at $\alpha < .05$
Results: No significant difference was identified for EMG activity between the type or phase of pitch. Kinematic data revealed significantly faster ball speed for the fastball and riseball compared to the dropball. The fastball and riseball demonstrated significantly higher shoulder internal rotation angular velocities compared to the changeup.
Conclusion and Clinical Implication: Pitch type and phase did not influence muscle recruitment as displayed by EMG, therefore a general training program is warranted. The fastball and riseball demonstrated significantly higher angular velocities for shoulder internal rotation which could explain the higher ball velocity. At the same time, lower softball angular velocities compared to baseball pitching may be offset by the increased pitch volume. This is often observed in softball pitchers which may be the primary impetus for injury. Future studies are recommended to investigate the effect of pitch release on forearm and wrist kinematics.

CHAPTER I

INTRODUCTION & LITERATURE REVIEW

Fast pitch softball is a popular sport among girls and women in the United States and around the world. Softball teams participate in the Olympics, at the professional and collegiate level, in tournaments, and at local fields. Every team needs at least one pitcher to compete, however many teams have several. The repetitive nature of a softball pitch places the athlete at risk for upper extremity injuries similar to those of baseball pitchers. While extensive research surrounds the overhand baseball pitch, few studies exist that investigate the activation of shoulder musculature during the windmill softball pitch. Characterization of the windmill softball pitch should provide insight into the biomechanical factors associated with the sport.

Purpose

The purpose of this study is to utilize electromyography (EMG) and motion analysis to determine the biomechanical factors of muscle recruitment, range of motion and joint velocities at the elbow and shoulder during the windmill softball pitch.

Significance

Providing information on the biomechanical factors involved in muscle recruitment during the different phases and different pitches of the windmill softball pitch for collegiate level players will assist physical therapist's working with softball athletes. This study can assist physical therapists, athletic trainers, and coaches in the development of prevention and treatment strategies for injuries sustained by the repetitive movements of the windmill softball pitch. Through the development of prevention programs based on the biomechanical analysis, this study may play a role in decreasing injury rates in collegiate softball pitchers.

Utilizing electromyography and motion analysis for the biomechanical analysis of movement produces a tremendous amount of data. Using biomechanical analysis, this study aims to answer the following research hypotheses:

- There is a significant difference in muscle activation quantity and patterns amongst the phases of the different types of softball pitches
- There is a difference in muscle activation between the windmill pitch used by softball players in this study and what has been reported in the literature from the overhand pitch used by baseball players
- There is a difference in shoulder and elbow angular velocities between the various pitch types.

Review of Literature

The origin of softball can be traced back to November, 1887 at Farragut Boat Club in Chicago, IL. Softball was initially played indoors, however in 1888 it moved outdoors to a small diamond and was called indoor-outdoor. George Hancock, known as the inventor of softball, published the first rules for indoor-outdoor in 1889.[15] The first women's softball team was formed in 1895 at Chicago's West Division High School. In 1965 the International Softball World Championships made women's softball an international game. In 1982 the first championship tournament was hosted by the National Collegiate Athletic Associating (NCAA) for women's softball. Today more than 600 NCAA colleges have women's softball teams with national championships being held in all three collegiate divisions.[4]

Participation in softball continues to increase in the United States and around the world. The Amateur Softball Association (ASA) reports that over 245,000 softball teams register annually and comprise more than 3.5 million players. Of the 245,000 teams that register with the ASA, over 83,000 of those teams are youth girls' fast pitch softball. Over 1.2 million girls register with the ASA annually.[4]

To date, there is a paucity of existing research on the biomechanical forces involved in fast pitch softball. Current literature typically groups baseball and softball pitchers as "throwing athletes" despite the difference between the two sports.[5] Although the position of pitcher in softball and baseball has the same name, several differences exist.[5,6,20] While baseball pitchers utilize an overhead throw, softball pitchers are masters at the underhand windmill pitch. A misconception regarding the underhand windmill softball pitch is that the technique minimizes the amount of stress on the athlete compared to the overhand pitch. This misconception results in windmill pitchers throwing a higher number of pitches without a lot of rest between games. Interestingly, softball pitchers are subjected to injuries similar to those of baseball pitchers. Injury patterns were observed by Loosli et al.[18] in twenty-four collegiate softball pitchers from 8 teams competing in the 1984 NCAA championship softball tournament. Nearly half (45%) of the pitchers reported an injury that caused the athlete to modify activity or miss a game or practice, a time-loss injury, at some point during the season. Of these time-loss injuries, 81% involved the upper extremity. Notably, pitchers with injuries or complaints averaged more innings pitched per season than uninjured pitchers.[18] In 2004, Hill and colleagues[16] conducted a survey on injury incidence and influence in collegiate softball pitchers in all three NCAA divisions. Chronic or overuse injuries were reported in 72.8% of pitchers in one academic school year. Of the injuries reported, 61.1% were directly caused by pitching, 58% resulted in lost time from competition and training, and 35% were shoulder injuries. A survey [16] conducted by the NCAA found 33% of injuries in games and practice were to the upper extremity, 10% of practice injuries were shoulder strains and tendonitis, and 10.8% of injuries occurred while pitching. [21] A study by Fleising et al. [12], reported 30% of softball pitchers sustained an injury causing them to modify or miss playing time. The most commonly injured area reported was the shoulder, comprising 11.2% of all softball reported injuries.

Youth, college, and professional baseball teams have limitations for innings pitched per week or number of pitches to minimize the risk of pitcher injuries.[32] Surprisingly, the ASA, the governing body for softball in the United States, does not limit the number of innings or pitches at any competitive level. In addition, there is a discrepancy between the number of pitchers on baseball teams compared to softball. The United States baseball roster for the 2006 World Baseball Classic consisted of a 30 player team. Of those 30 players, 14 men were pitchers. [31] In comparison, the 2008 women's United States National team boasts a roster of 18 top athletes. Out of those 18 players, only 5 were pitchers.[1] In 2007, the UND baseball teams roster consisted of 30 players, 12 of those players were pitchers while the women's softball team had 18 players, 6 of which were pitchers. One of those six pitchers was medically red-shirted prior to beginning of the study taking the team's roster down to 17. [30] Therefore, windmill softball pitchers are understaffed and overworked.

Many pitchers suffer injury due to incidence of pitch frequency, pitching with pain and pitching with fatigue. [34] According to a literature review on baseball pitching mechanics, pitching injuries are caused by breaking pitches such as curveballs and sliders. Contrary to popular belief, women's collegiate softball pitchers have a full repertoire of pitches including but not limited to the change up, curveball, screwball, dropball, riseball and fastball. Although baseball and softball pitches share similar names, the delivery of the pitch is drastically different. The phases of motion for a windmill softball pitch include wind up, stride, delivery, and follow-through. The wind up begins with initial movement until toe off of the lead foot. Many pitchers will hyperextend at the shoulder; however variations occur in pitching style as seen during nationally televised softball games. During the stride phase, the pitcher steps off of the pitching rubber with the contralateral foot to initiate forward translation of the body. The delivery phase is characterized by the arm accelerating forward with arm rotation and flexion of the elbow. During the final follow-through phase, the ball is released and arm motion stops to complete the pitch [6, 13,20]

The stages in the baseball pitch are different from the softball pitch. According to Whiteley,[34] there are six stages to a baseball pitch: windup, stride, arm cocking, arm acceleration, arm deceleration and follow-through. Baseball pitchers are allowed to choose from the 'set' or 'windup' positions. The set position consists of the pitcher standing and taking a stride towards home plate. The windup position consists of a short backward stride then a larger stride towards home plate. During the baseball pitch, the arm is first abducted followed by strong internal rotation produced by the pectoralis major muscle to develop power and speed for the pitch.[20] During the softball pitch the arm stays in the plane of the body and power is produced by the pectoralis major muscle as it adducts the upper extremity across the body. [20] Deceleration of the arm in the baseball pitch results from eccentric muscle action. The control of deceleration is more controversial for the softball pitch. A number of sources claim that deceleration is caused by contact between the throwing arm and the pitcher's hip.[13, 20, 23, 26] Maffet and colleagues [20] came to this conclusion after they found low amplitude muscle action after ball release. Following this article a number of other researchers [13, 23, 26] accepted the conclusion made by Maffet and colleagues [20] citing their work despite a study by Barrentine and colleagues in 1998 [6]. The study by Barrentine and colleagues[6] reported increased velocity of the shoulder joint which attributed to decelerating the arm. Peak shoulder extension torque was reached as elbow flexion was initiated causing the momentum transfer from the upper to the lower arm.[6] The momentum transfer should then result in peak acceleration of the distal segment augmenting the speed and force of the ball at pitch release.

Since baseball pitches are thrown overhand and softball pitches are thrown underhand, there is also a difference in the angular velocities reported between the two styles of pitching. The angular velocities displayed during the baseball pitch have been recorded in excess of 10,000 degrees per second.[34] Meister [23] reported that the arm rotates internally at velocities greater than 7000 deg/sec. The high speeds associated with the baseball pitch create difficulty in accurately recording joint velocities.

Specific angular velocities of the joints during a softball pitch have also been reported.[6, 33] Olympic pitchers throwing a riseball at peak angular velocity of 2190 ± 583 degrees/second during the late delivery phase. Elbow flexion had a peak angular velocity of 1194 ± 240 degrees/second after ball release while the angular velocity of elbow flexion at ball release was slightly higher at 1248 ± 431 degrees/second. [33] Collegiate and semiprofessional pitchers throw a fastball with maximum angular velocities of 880 ± 360 of elbow flexion and 5260 ± 2390 degrees/second of shoulder flexion.[6] The differences in angular velocities of baseball and softball pitchers could result in slower velocities of softball pitches compared to baseball. Many baseball pitchers throw at more than 120 km/hour (74.5 mph) while Olympic softball pitchers throw a riseball at approximately 97.2 km/hour (60.4 mph). [13,33] The fastest recorded softball pitch was by Australian international softball player Zara Mee, pitching at111 km/hr (68.9 mph)[9] but during the 1996 Atlanta Olympic games, there was a pitch recorded at 118 km/hr (73.3 mph).[10]

The high forces associated with the softball pitch place the players at risk for a multitude of other injuries. The most common injuries include the shoulder and low back.[16,18] Based on the results of the research and the high incidence of injury associated with softball pitching, further research is needed. Investigating the biomechanics of various softball pitches, incorporating EMG and motion analysis in the methodology, would be beneficial. Therefore the purpose of this study is to utilize EMG and motion analysis to determine the biomechanical factors of muscle recruitment, range of motion and joint velocities at the shoulder and elbow during the windmill softball pitch.

CHAPTER II

METHODOLOGY

This project was reviewed and approved by the University of North Dakota Institutional Review Board 200704-295 prior to the initiation of the study. (Appendix A)

Subjects

Division II women's fast pitch softball pitchers were recruited to participate in this research project. Participants over the age of 18 were accepted for participation in the study if they obtained the coaches consent and met the following guidelines: female pitcher for a collegiate team and no current injuries that limited ability to practice or play. Criteria of current injuries limiting practice or playing time, a position other than pitcher, and all redshirted players were used to exclude a volunteer's participation. Participation in this study was voluntary and prior to testing all subjects completed an informed consent form as well as an intake survey to establish level of experience and previous injuries. The subjects attended one day of testing in an indoor gymnasium wearing a tank top and shorts. Prior to beginning, study subjects received a verbal explanation of the study and were given an opportunity to ask any questions.

Instrumentation

Instrumentation for this study included motion analysis and electromyography hardware and software. The ViconPeak motion analysis system with 8 Vicon MX40 cameras (Vicon Motion Systems Inc, Lake Forest, CA) was configured to obtain optimal data capture. Self-adhesive, retro-reflective markers were placed bilaterally in a Helen Hayes marker configuration. Markers were placed over the subject's acromion, lateral epicondyle of the elbow, distal radius and ulna, back of the hand, anterior superior iliac spine, posterior superior iliac spine, greater trochanter, lateral femoral condyle, medial and lateral malleoli, and 5th metatarsal. The raw data was captured at 250 frames per second and saved using ViconPeak Workstation® software. The raw data were smoothed and processed using the Workstation® software. The cameras interfaced with the Vicon MXNet (Vicon) component for data collecting and storing on a desktop computer (Dell Precision 670 desktop, Dual Xeon 3.6 GHz, Windows XP). Data was displayed and processed using the Workstation® core processing software (Vicon).

The EMG data collection was performed using self-adhesive, pre-geled EMG surface electrodes over the following muscles: supraspinatus, infraspinatus, posterior deltoid, pectoralis major, middle trapezius, biceps brachii, and triceps brachii. The EMG data was collected through the ViconPeak system. Data analysis for the raw EMG data was performed on a laptop computer (HP Pavilion laptop, Pentium 4 processor at 3.0 GHz, Windows XP) using Noraxon MyoResearchXP software (Noraxon, USA, Scottsdale, AZ).

Procedure

Prior to the initiation of the study, EMG and motion analysis equipment was set up and tested by the researchers to ensure proper signal transmission and reception. The subjects were tested independently in the Hyslop Sports Center on the University of North Dakota campus in Grand Forks, ND. The purpose and procedure were explained to the participants prior to each participant signing a statement of informed consent, completing an intake survey and initiation of data collection.

Collection of EMG data required electrode site preparation, electrode placement, connecting and testing the equipment. The electrode site preparation was performed in a standardized fashion including removing excess hair from the electrode site with an electric razor, wiping the skin surface with 400 grit sandpaper, and wiping the area with isopropyl alcohol wipes. Electrode placement was determined by using standard electrode placement charts (Appendix B). Standard silver/silver chloride electrodes were placed in a bipolar configuration at the appropriate sites using an inter-electrode distance of 3.3 cm. Skin impedance was assessed to be under 10 kOhm using the Noraxon impedence analyzer (Noraxon). The electrodes were connected to the Telemyo 900 transmitter that was placed in a belt around the subject's waist. The EMG signals were transmitted to the Telemyo 900 receiver and stored on a desktop computer (Dell Inc.). The raw EMG data was later analyzed for each pitch phase using the MyoResearch XP software (NoraxonUSA).

Each subject performed a warm up similar in content and number of repetitions as a regular pitching session or game. Following the warm up, each pitcher completed 5 measured pitches for each of the following pitch types: riseball, dropball, change up, fastball, screwball and curveball. Data was collected during an entire pitch cycle for each pitch and stored in separate files. If a subject was unfamiliar with a pitch type in the study, the subject did not perform that pitch type.

Following the completion of the data collection, electrodes and motion analysis reflectors were removed from the subjects and the areas were cleaned with an isopropyl alcohol soaked towel.

Statistical Analysis

A repeated measures analysis of variance was used to determine a significance for the main effects of pitch type or pitch phase on the EMG activity and kinematics during the pitch (alpha<0.5). Post hoc testing was performed using Tukey's HSD where appropriate.

CHAPTER III

RESULTS

The subject group consisted of five adult female UND softball pitchers with an age range from 18 to 23 years old (mean age = 19.2 ± 2.2 years), average weight of 156 ± 9 lbs, and an average height of 69 ± 1 inches. The subjects reported playing competitive softball for a range of ten to seventeen years (mean years of total playing time = 13 ± 3 years), a range of seven to eleven years pitching (mean years of pitching = 9.5 ± 1.6), and years pitching for UND for a range of one to four years (mean years of UND playing time = 1.6 ± 1.3). Four of the pitchers were right handed and one pitcher was left handed. Two subjects reported previous injuries including shoulder blade pain when pitching and throwing in general in conjunction with tendinitis in both elbows and bicipital tendinitis two to three years previous. All of the subjects completed the entire study.

Electromyography

Each pitcher had the opportunity to perform all pitches within their usual choices for a game situation. All pitchers were able to throw a fastball, change up, riseball, and dropball. Only 3 of the 5 pitchers had developed the ability to deliver the screwball and curveball. Statistical analysis of the 4 pitch types common to all pitchers were assessed across the 4 phases of the various pitches.

To analyze the phases within the windmill softball pitch motion, the delivery was divided into four different phases. The initial phase of the windmill softball pitch, phase A occurs from the 6 o'clock to 3 o'clock arm position. The next two phases of the pitch are in the middle portion of the entire motion and are separated into phases B and C designated from the 3 o'clock to 12 o'clock position and the 12 o'clock to 9 o'clock position respectively. The last phase of the windmill softball pitch prior to delivery was designated as phase D and occurred from the 9 o'clock to 6 o'clock position at the shoulder.

There were no significant differences among the muscle activations during the different types of pitches and phases of the pitches when assessed by a repeated measures ANOVA. Although no statistically significant differences were identified in this small sample of collegiate women's softball pitchers, levels of EMG activity did vary among some muscles.

During the initial phase of the windmill softball pitch, the triceps brachii and pectoralis major demonstrated higher muscle activity than the other muscles near the shoulder joint. The infraspinatus and middle trapezius muscles displayed the least amount of EMG activity during the initial phase of the pitches. When normalized to the fastball delivery, the pitch with the most muscle activity was the riseball and the least amount of total muscle activity was the change up for this initial phase.

During the second phase of the windmill softball pitch, phase B, the total amount of muscle activity was much less. The muscles with the highest activity were the pectoralis major and posterior deltoid, while the triceps and biceps were the muscles with the least amount of activity. In comparison to the fastball, the most muscle activity was seen in the riseball. The lowest amount of muscle activity was seen in the dropball.

Phase C was designated as the motion from 12 o'clock to 9 o'clock during the windmill softball pitch delivery. During this phase, there is a beginning of a shift in muscle recruitment from the muscles in the arm and front of the chest to muscles located in the back and posterior shoulder. The most active muscles during this phase of the pitching delivery were the middle trapezius and infraspinatus. The least active muscles were the triceps brachii and biceps brachii. Although only three subjects demonstrated the dropball pitch, the highest amount of EMG activity occurred during the dropball delivery in comparison to the fastball. Meanwhile, the change up demonstrated the least amount of total EMG activity during the third phase of the pitching cycle.

Finally, phase D in the pitch delivery, from 9 o'clock to 6 o'clock, represents the beginning of the upper extremity preparing for the release of the ball to complete the pitch. The pectoralis major and middle trapezius muscles displayed the highest amount of muscle activity during this final phase of the pitching motion. The muscles with the least amount of activation were the posterior deltoid and triceps. When normalized to the fastball delivery the most amount of total muscle activation during the final phase of the delivery was observed during the dropball pitch, while the least amount of muscle activity was displayed during the change up pitch.

Overall, the most muscle activity observed during phases A and B was developed by the musculature of the arm and the anterior chest. The muscles most responsible for the increased activity were the biceps brachii, triceps brachii, and the pectoralis major.

Then, as the pitch delivery progressed to phases C and D, there was a shift in the amount of muscle activation as the posterior deltoid, infraspinatus, and middle trapezius became more prominent. The shifting muscle activity during the pitching cycle is best represented by the change up pitch delivery. (Table 1)

Table 1. Average Muscle Activity Across Phases of the Windmill Softball Pitch (%)

	Phase A	Phase B	Phase C	Phase D
Biceps Brachii	109.3 ± 10.7	99.2 ± 3.5	99.11 ± 15.2	95.9 ± 14.6
Triceps Brachii	123.9 ± 22.6	90.4 ± 24.8	87.17 ± 9.4	94.5 ± 6.0
Pectoralis Major	127.4 ± 21.5	113.2 ± 15.1	114.4 ± 25.1	139.3 ± 30.9
Posterior Deltoid	91.9 ± 6.7	104.3 ± 4.4	115.7 ± 25.9	86.6 ± 13.2
Infraspinatus	94.9 ± 8.0	101.9 ± 5.0	110. 7 ± 11.0	95.0 ± 4.8
Middle Trapezius	95.6 ± 4.4	100.1 ± 8.2	115.4 ± 16.0	112.5 ± 26.5

Data was also collect for the few pitchers who were able to demonstrate the screwball and the curveball deliveries. In general, the screwball demonstrated the most muscle activity across all phases for all muscles. The triceps muscle was most active for all phases of the screwball except phase D. In phase D, the triceps muscle activity decreased dramatically. The curveball demonstrated the trend of higher amounts of muscle activity noted in the arm and chest musculature during phases A and B switching to higher activity in the posterior shoulder and back muscles during phases C and D (Appendix B).

Kinematic Pitch Analysis

Each pitch attempt was captured by motion analysis equipment to analyze the kinematic variables associated with the pitch. The experimental design did not include a marker for the softball as it is often obscured by the subject's hand. Therefore, the wrist marker at the distal ulnar border was utilized to estimate the velocity of the ball at the point of pitch release (end of phase D). The highest estimated ball velocity for all five pitchers was observed during the delivery of the riseball.(Figure 1) The riseball and fastball velocities (16.5 +/- 1.9 m/sec and 16.3 +/- 1.5 m/sec respectively) were significantly higher than the dropball pitch (15.2±1.7 m/sec) ($F(3,12)=4.213$, $p<.05$). The average velocity for the change up pitch (14.4±2.9 m/sec) was the lowest but also had the highest standard deviation. Increasing angular velocities of the shoulder and elbow during the pitch delivery may translate into faster ball velocities. Kinematic analysis of shoulder flexion, elbow flexion and elbow extension were similar across all pitch types. The shoulder internal rotation velocity was significantly higher during the fastball and riseball pitches compared to the change up ($F(3,9)=4.236$, $p<0.05$). (Table 2) The remaining elbow and shoulder angular velocities were similar between all of the pitch types analyzed. (Table 2).

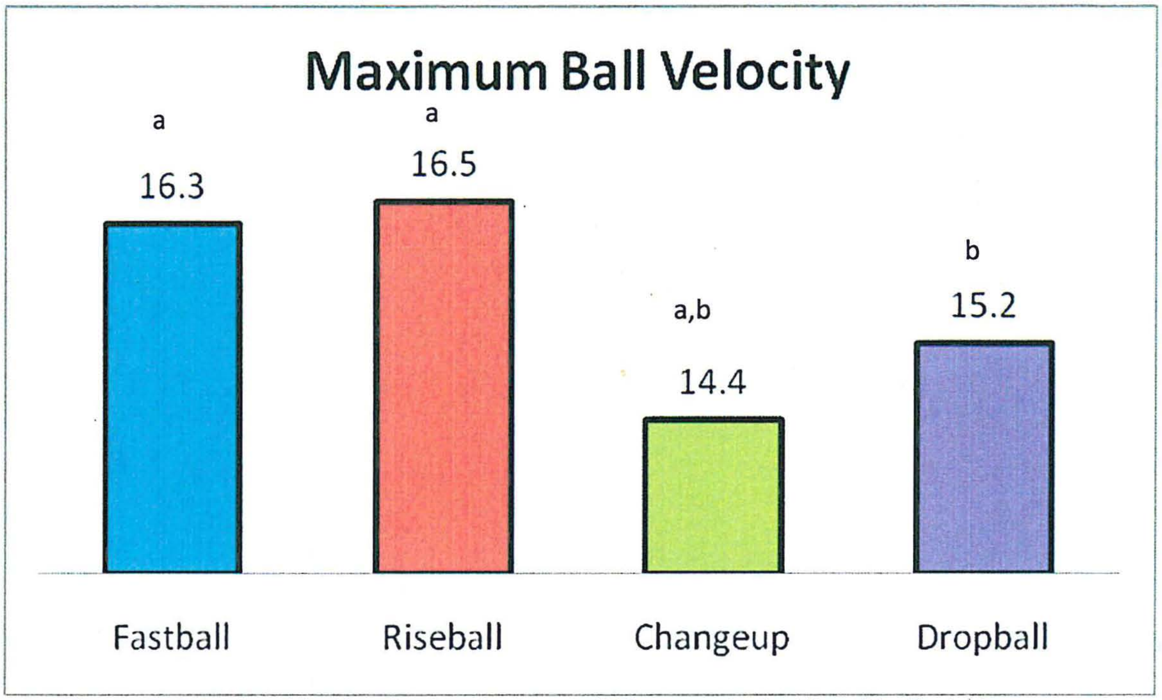


Figure 1. Maximal ball velocity during 4 different windmill softball pitches

Table 2: Angular Velocities (deg/s) during various windmill softball pitches

	Fastball	Riseball	Change up	Dropball	Screwball	Curveball
Elbow Flexion	811±219	786±271	417±30	709±583	762±407	865±401
Elbow Extension	603±80	626±102	561±129	577±48	571±238	663±476
Shoulder Flexion	995±321	1038±342	881±221	1093±332	1041±246	1024±401
Shld Internal Rotation	4024±1218[a]	3960±1252[a]	2752±1125[b]	3100±1522[a,b]	4030±969	6127±4284

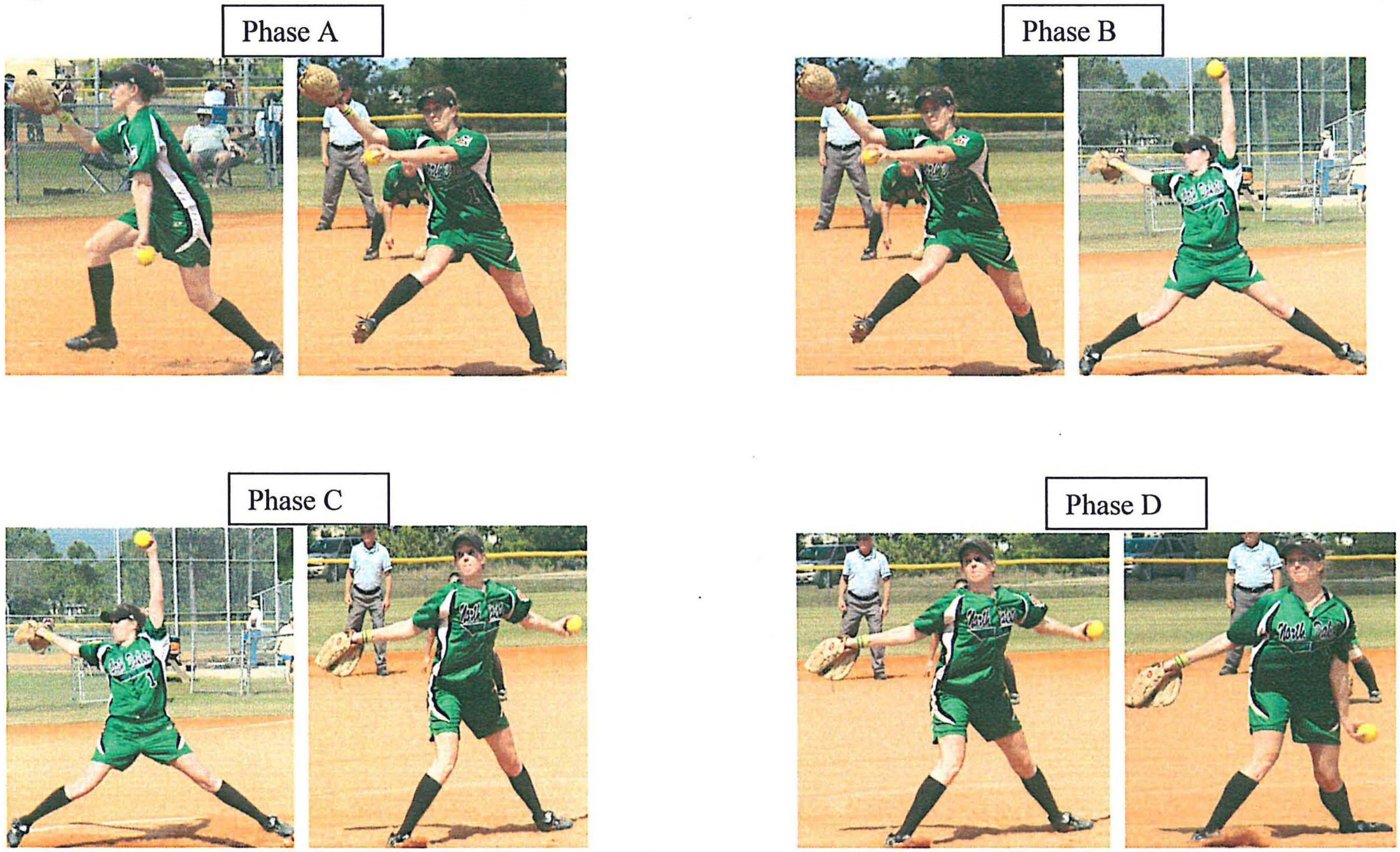
CHAPTER IV

DISCUSSION AND CONCLUSION

Five Division II female softball players performed various softball pitches to compare EMG muscle recruitment and angular velocities. Although differences were observed in muscle activity between the various pitches and phases, statistical significance was not obtained. During phases A and B the muscles of the arm and anterior chest demonstrated the most activity. Alternatively, the majority of the muscle activity in phases C and D was on the posterior aspect of the shoulder and chest. Kinematic analysis of the windmill softball pitch revealed significantly higher shoulder internal rotation angular velocities for the fastball and riseball pitches. Similarly, higher ball speeds were observed during the fastball and riseball pitches.

A characteristic of the windmill softball pitchers is variability during the windup and follow-through phases of the pitch.[20] While the ASA [4] pitching rules and regulations attempt to minimize the variability within the windmill pitch, the rules are most lenient in defining the windup and follow-through phases of the pitch. Since previous investigations have confirmed the variability within these two phases of the windmill pitch, the current study analyzed the core phases of the windmill pitch from the initial 6 o'clock arm position through 360 degrees of motion to the release point at the final 6 o'clock arm position (Figure 2).

Figure 2: Phases of the Windmill Softball Pitch.



Phase A: 6 o'clock to 3 o'clock

Immediately following the windup is the initial phase of the windmill softball pitch. The ideal components of this phase should include minimal internal rotation at the shoulder with horizontal adduction of the arm across the body as the arm is elevated through the first 90 degrees of shoulder motion. The movement should be rapid and the pitcher should keep the arm in close proximity to the body. The scapula protracts during this initial phase to assist with momentum generation in the arm. The elbow, on the other hand, should maintain a position of extension or minimal flexion to create a longer lever arm.

Maffet and colleagues [20] reported maximal firing of the infraspinatus and sufficient firing of the supraspinatus muscles during this phase of the windmill pitch. The infraspinatus was proposed to maintain internal rotation of the arm between the scaption and forward flexion plane while the supraspinatus assisted with humeral head centralization within the glenoid cavity.

In the current study, different types of pitches did not appear to influence the infraspinatus muscle motor unit recruitment as EMG activity was similar regardless of the pitch type. Therefore, the infraspinatus appears to be a consistent shoulder stabilizer required for all windmill softball pitch types. Interestingly, the current study revealed increased activity of the triceps brachii muscle when the subjects were performing the riseball or change up pitches. Although this activity was not significantly higher, the recruitment level of the triceps brachii was much higher than other phases of the windmill pitch. Finally, the pectoralis major muscle also revealed some variability in recruitment depending on the type of pitch delivered. The riseball and change up pitches displayed higher activities compared to the fastball but again this result was not deemed significant by statistical methods.

Phase B: 3 o'clock to 12 o'clock

The ideal presentation of the windmill softball pitch during this second phase should include the pitcher internally rotating the shoulder so the palm of the hand is directed away from the pitcher's face. The scapula initially upwardly rotates and begins to retract at the end of the phase in preparation for the power production of phases C and D. Again, the elbow should maintain a position of minimal flexion as the arm is brought through this phase.

The posterior deltoid, teres minor and infraspinatus were maximally recruited during this phase of the pitch according to Maffet and colleagues.[20] As the arm is elevated above shoulder height, the shoulder rotator cuff muscles and scapular stabilizers should become more active to provide power and stabilization. Although statistical significance was lacking, this study appears to support a decrease in total muscle activity compared to the fastball during this phase of the pitch. This may be due to rotation of the trunk helping to move the shoulder into flexion. The pectoralis major continued to show high levels of activity among the various pitch types. This muscle may be active during this phase to keep the arm in the plane with the body and to help with flexion of the arm overhead. When normalized to the fastball, the riseball continued to show the most total EMG activity allowing for generation of increased joint velocities.

Phase C: 12 o'clock to 9 o'clock

This phase of the windmill softball pitch occurs as the arm is brought from 12 o'clock to 9 o'clock by adducting the arm down toward the body. Due to rotations of the trunk and pelvis, the shoulder should be in a neutral rotation position. The scapula retracts and downwardly rotates to provide the pectoralis major with a biomechanical advantage during the last phase. The elbow should continue to maintain a position of extension during this part of the phase.

Maffet et al.[20] found that the muscle activity dropped in the posterior deltoid, infraspinatus and teres minor as the pitcher's arm transitioned from elevation to delivering force production. At the same time, the activity in the pectoralis major, subscapularis and serratus anterior muscles was reportedly increased. The current results support little influence of the type of pitch on pectoralis major, infraspinatus or middle trapezius activity. The results support similar activation of the primary muscles of force production and shoulder stabilization during this phase of the windmill pitch delivery.

Phase D: 9 o'clock to 6 o'clock

The ideal final phase of the windmill softball pitch, phase D, is very dependent on the type of pitch thrown. With all types of pitches, the elbow should remain straight to provide a longer lever arm---increasing the velocity of the pitch. The humerus continues to adduct, preparing for ball release. The variability is noted in the amount of rotation that occurs at the humerus. All the pitch types demonstrate some amount of internal rotation of the shoulder prior to ball release but the amount of rotation varies. The scapula reaches complete retraction during the initial part of this phase. As the phase progresses the scapula depresses and continues to downwardly rotate as the humerus adducts.

Maffet et al.[20] found that the pectoralis major, serratus anterior and subscapularis muscles continued the high levels of activity during this phase. They stated the pectoralis major acted to provide power while adducing and internally rotating the humerus. They established that the subscapularis assists with the internal rotation of the humerus while the serratus anterior stabilizes the scapula and maintains glenohumeral congruency.

In the current study, the pectoralis major muscle exhibited high levels of activity for all pitch types. The level of activity did not reach statistical significance but it is interesting to note that the riseball, change up and dropball developed higher EMG activity than the fastball. The pectoralis major is thought to provide the powerful delivery of the pitch. At the same time, the activity of the pectoralis major may also be activated to provide similar shoulder kinematics in an attempt to "fool" the batter. This may be best associated with the higher activity of the change up, in that the change up is a reduced speed pitch and therefore should not require as high of activation of the pectoralis major compared to the fastball pitch. The high amount of activity in the pectoralis major during the change up may be a way for windmill pitchers to develop similar pitch kinematics between pitch types thus disguising the type of pitch being delivered.

Research investigating the windmill softball pitch is limited to a handful of studies. Previous studies have identified EMG activity for the fastball and kinematics of the riseball.[6,20] The current study is the first to investigate both EMG and kinematic changes associated with different windmill softball pitch types. Unfortunately, there are methodological differences among the studies which preclude a comprehensive comparison of results. For instance, the study by Maffet et al.[20] used fine wire EMG and a minimal number of motion analysis markers (two markers on the arm and two on the spine) while the current study utilized surface electrodes and multiple motion analysis markers (three markers for the arm and six markers on the trunk). Fine wire electrodes can be more difficult to place and may reflect a biased sample of select motor unit changes within a homogeneous muscle. Surface electrodes can overcome the local sample bias. A minimum number of markers can be used to define segments for kinematic analysis. Increasing the number of markers can often produce more accurate results as the equations become more complex, relying on multiple camera viewing angles to reconstruct the markers and anatomical segments. In the current study, the bipolar surface electrodes and multiple motion analysis markers should have provided a heterogeneous EMG representation of the muscle activity and accurate kinematics.

Individual studies have assessed kinematics of the fastball and riseball pitch types. A softball study by Barrentine et al. [6] assessed the kinematics associated with the fastball pitch. The arm was found to reach maximal internal rotation velocity just prior to ball release while the trunk also assisted with the ball acceleration force. For the riseball, Werner et al.[33] assessed Olympic pitchers throwing during the 1996 Olympic Games. Increased speeds were observed when compared with the data from the Barrentine [6] study. Of note, the riseball had increased ball velocities compared to the fastball pitches.

Our study assessed the kinematics of the entire pitch cycle for all pitch types. Our data indicates that the fastball and riseball demonstrated significantly higher angular velocities than the dropball. This may be due to the longer follow through associated with the fastball and riseball that have more motion to complete The follow through in the dropball that maintains the 6 o'clock ball release position with pronation occurring during the follow through.

The current study assessed velocities during the entire pitch cycle without regard to the phases of the pitch, thus conclusions for peak velocities during various phases of the pitch cannot occur. The current study utilized an indoor gym setting without a pitching mound, similar to the Barrentine [6] study, while the Werner [33] study collected data during a game setting. Differences in the experimental setting could account for some of the reported differences between the studies. For instance, both Barrentine et al. [6] and Werner et al. [33] used a radar gun to assess ball speed. A radar gun was not available at our facility and therefore ball speed was estimated by assessing the velocity of the ulnar styloid marker in the sagittal plane of motion. The estimated ball velocity in our study may not reflect actual ball speed because it does not incorporate the entire body momentum into the speed. (Table 3)

Various pitch types have been studied for baseball pitching. In a study by Fleisig et al.[11,12] college age baseball pitchers threw a variety of pitches (Table 4). The study reported significantly elevated maximal shoulder internal rotation of the fastball, curveball and slider compared to the change up in college baseball pitchers. The highest internal rotation velocities were observed just prior to or immediately after the release of the ball. These results are consistent with the angular velocity patterns observed in our study. However, the softball pitch ball and angular velocities are less than the reported velocities for the baseball pitch. While the data indicates that softball pitchers throw at reduced speeds, the increased volume and frequency of pitching in fast pitch softball may potentiate the risk of injury. The ASA[4] does not set pitch or inning limits on softball

Table 3: Comparison of the windmill softball pitch kinematic data to previous studies.

Parameter	UND pitchers fastball	UND pitchers riseball	Werner et al.[33]	Barrentine et al.[6]
Ball velocity at release, m/s	10 ± 3	10 ± 2	27 ± 2	25 ± 2
Max velocity within pitch, m/s	16 ± 2	16 ± 2	—	—
Max elbow flexion ang vel, deg/s	811 ± 219	786 ± 272	1194 ± 240	880 ± 360
Max elbow extension ang vel, deg/s	603 ± 80	626 ± 102	705 ± 198	570 ± 310
Max shoulder flexion ang vel, deg/s	996 ± 322	1038 ± 342	—	5260 ± 2390
Max shoulder IR ang vel, deg/s	4024 ± 1218	3960 ± 1252	—	4650 ± 1200

pitchers. Softball pitchers will often throw multiple games during a tournament that often includes more than one game per day. This increased number of pitches may place the softball pitchers at the same or higher degree of risk for injury when compared to baseball pitchers.

Table 4: Comparison of Angular Velocities (deg/sec) for Baseball and Windmill Softball Pitches

	Our Study: Fastball n=5	Fleisig et al: Fastball n=21	Our Study: Curveball n=3	Fleisig et al: Curveball n=20	Our study: Change-up n=5	Fleisig et al: Change-up n=19
Ball Velocity (m/s)	10 ± 3	35 ± 1	12 ± 5	29 ± 1	11 ± 5	30 ± 1
Max Elbow Extension	603 ± 80	2210 ± 260	663 ± 476	2160 ± 230	561 ± 129	1970 ± 210
Max Shoulder IR	4024 ± 1218	6520 ± 950	6127 ± 4284	6480 ± 860	2752 ± 1125	5800 ± 780

Clinical Implications and Conclusions

The current study identified that pitch type and phase did not influence muscle recruitment as displayed by EMG during the windmill softball pitch. Therefore, to maintain a balance between the anterior and posterior shoulder musculature of the windmill softball pitcher, a general training program should be preferred to a focused program on specific muscles such as the internal or external rotators. The fastball and riseball demonstrated significantly higher angular velocities for shoulder IR, possibly explaining the higher ball velocity. Pitchers who primarily throw the fastball and riseball may be at greater risk of injury due to the higher angular velocities observed in these pitches. It is therefore important to monitor the types of pitches thrown and provide adequate strengthening for the athlete to prevent injuries. Due to the repetitiveness of the pitchers role it is important to develop an individualized program that meets the pitchers unique requirements and pitch selection.

It is advantageous for the elite or more experienced pitcher to deliver various pitches with similar kinematics but altered velocity or spin. Performing the pitch delivery in a consistent and similar manner, regardless of the pitch type, decreases the chance of the batter hitting the ball as the batter cannot predict the type of pitch approaching. The current study identified similar shoulder flexion and elbow flexion and extension angular velocities for many of the pitch types investigated. While baseball pitchers are coached to standardize the pitch delivery, differences in trunk position and knee movement have been observed between pitch types.[15] Differences in windmill softball pitching may be most apparent in the wrist and hand. The final phase of off-speed pitches requires release and follow-through positions which are dependent on pitch type. The altered forearm and wrist positions may subject the wrist and forearm soft tissues of the windmill softball pitcher to frequent stress. The frequent stress may accumulate, leading to time loss injuries. Future studies in softball should therefore assess more than shoulder motion, identifying differences in off speed pitches and possible implications for pitch related injuries. A healthcare professional could then use pitch type to develop both prevention and rehabilitation programs for windmill softball pitchers.

APPENDIX

APPENDIX A

REPORT OF ACTION: EXEMPT/EXPEDITED REVIEW

University of North Dakota Institutional Review Board

Date: 3/27/2007 **Project Number:** IRB-200704-295

Principal Investigator: Relling, David

Department: Physical Therapy

Project Title: Biomechanical Analysis of Upper Extremity Muscle Activity During Multiple Softball Pitches

The above referenced project was reviewed by a designated member for the University's Institutional Review Board on April 2nd, 2007 and the following action was taken:

☒ Project approved. **Expedited Review** Category No. 4
Next scheduled review must be before: April 1, 2008

☒ **Copies of the attached consent form with the IRB approval stamp dated** April 2, 2007 **must be used in obtaining consent for this study.**

☐ Project approved. **Exempt Review** Category No. ______
This approval is valid until ______ as long as approved procedures are followed. No periodic review scheduled unless so stated in the Remarks Section.

☐ **Copies of the attached consent form with the IRB approval stamp dated** ______ **must be used in obtaining consent for this study.**

☐ Minor modifications required. The required corrections/additions must be submitted to RDC for review and approval. **This study may NOT be started UNTIL final IRB approval has been received.**

☐ Project approval **deferred. This study may not be started until final IRB approval has been received.** (See Remarks Section for further information.)

☐ Disapproved claim of exemption. This project requires Expedited or Full Board review. The Human Subjects Review Form must be filled out and submitted to the IRB for review.

☐ Proposed project is not human subject research and does not require IRB review.
☐ Not Research ☐ Not Human Subject

PLEASE NOTE: **Requested revisions for student proposals MUST include adviser's signature. All revisions MUST be highlighted.**

☒ Education Requirements Completed. (Project cannot be started until IRB education requirements are met.)

cc: ✓ Chair, Physical Therapy

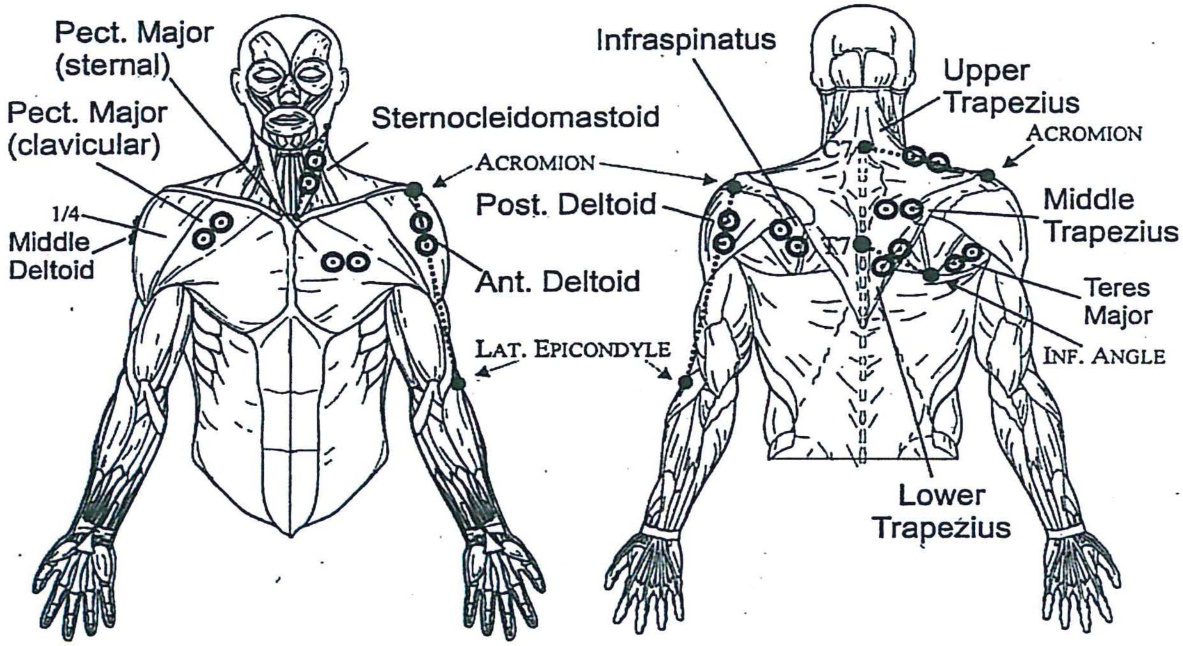
Alan J. Allery 4/2/07
Signature of Designated IRB Member Date
UND's Institutional Review Board

If the proposed project (clinical medical) is to be part of a research activity funded by a Federal Agency, a special assurance statement or a completed 310 Form may be required. Contact RDC to obtain the required documents.

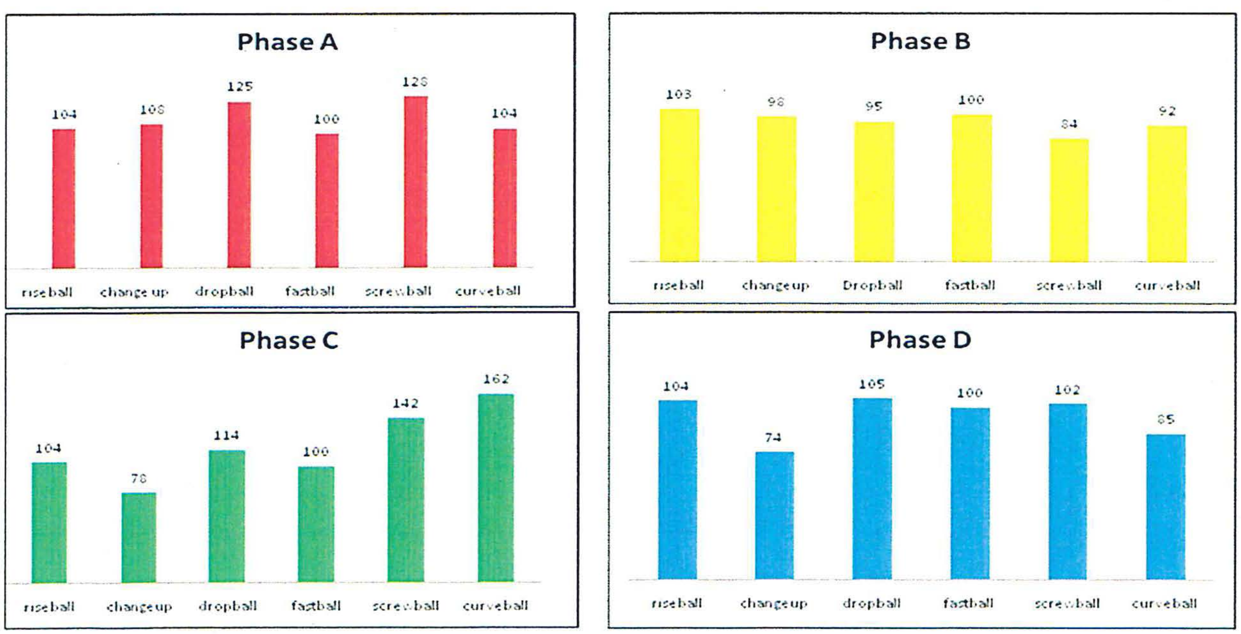
(Revised 10/2006)

APPENDIX B

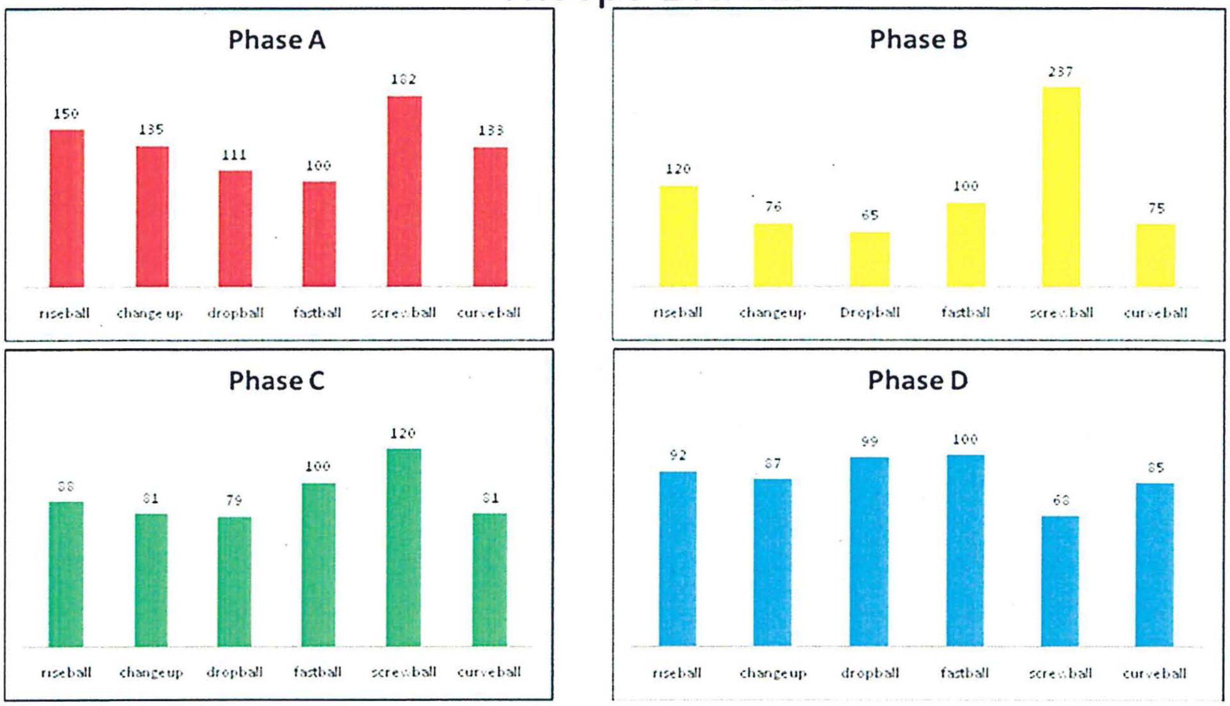
EMG Electrode Placement



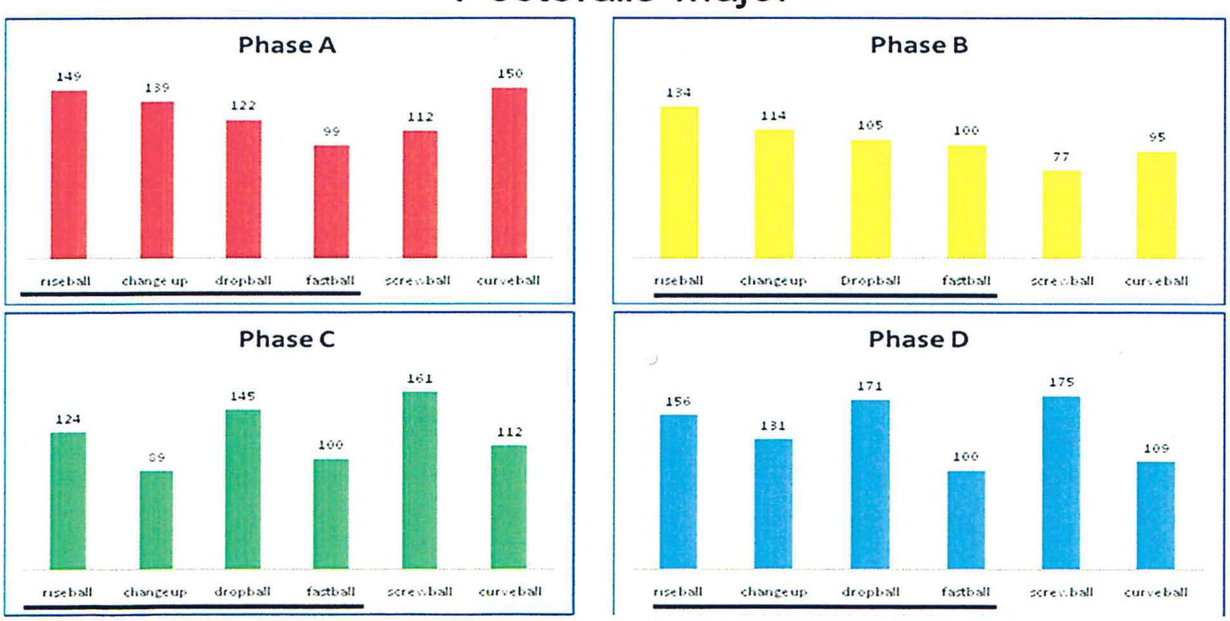
Biceps Brachii



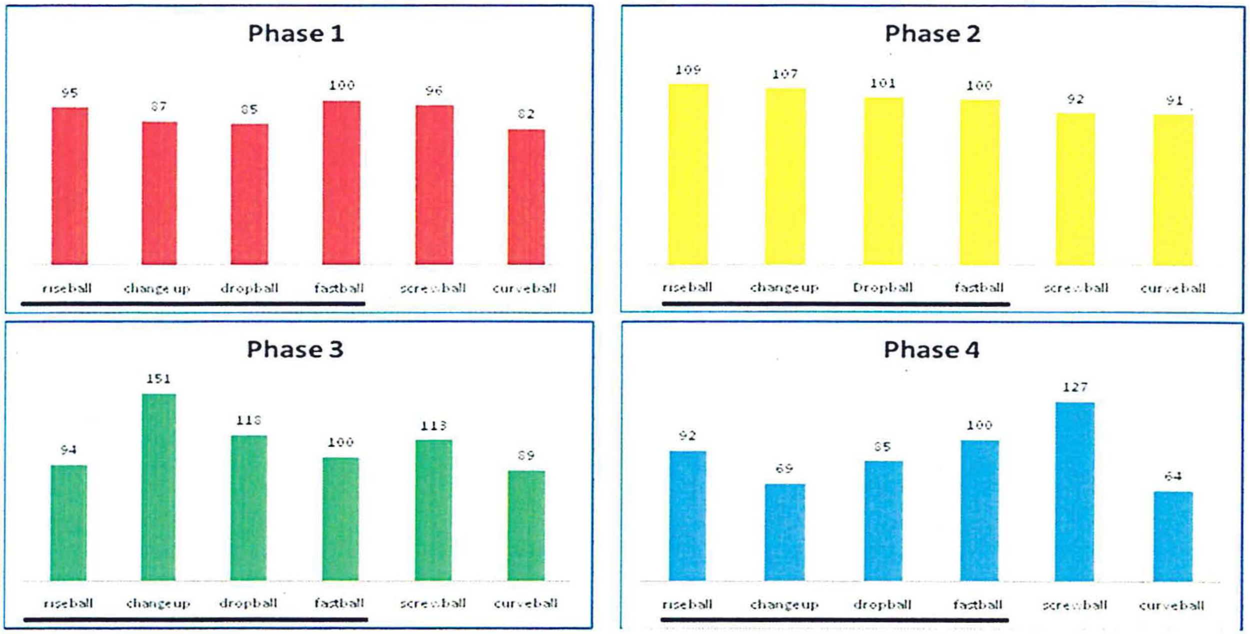
Triceps Brachii



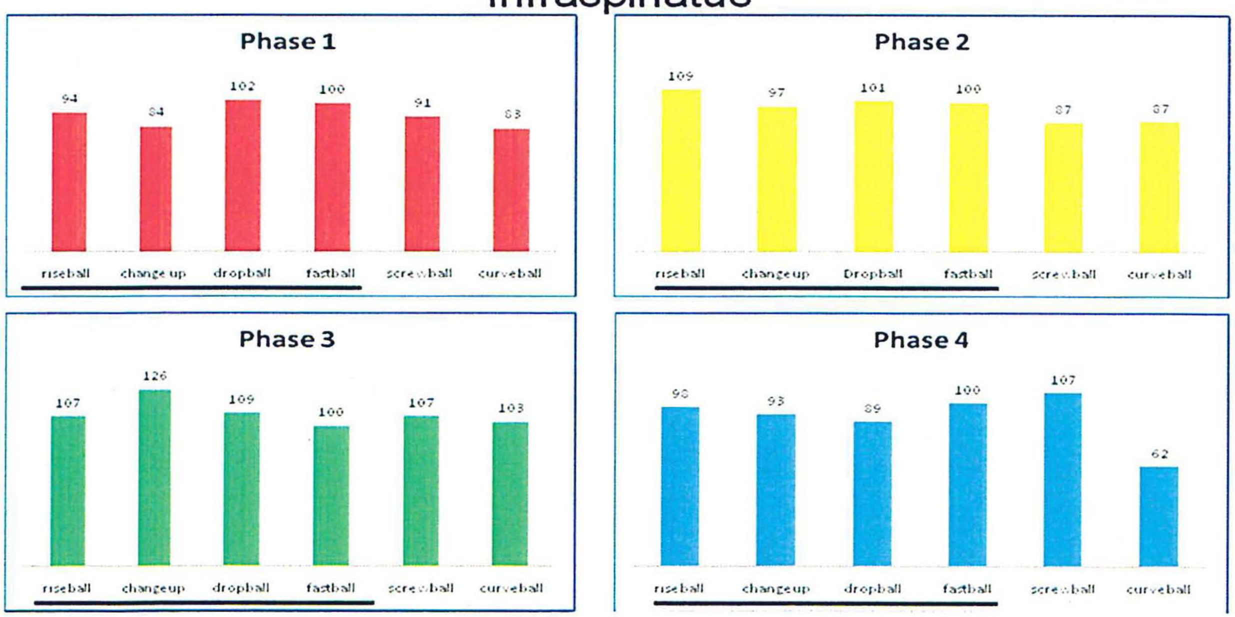
Pectoralis Major



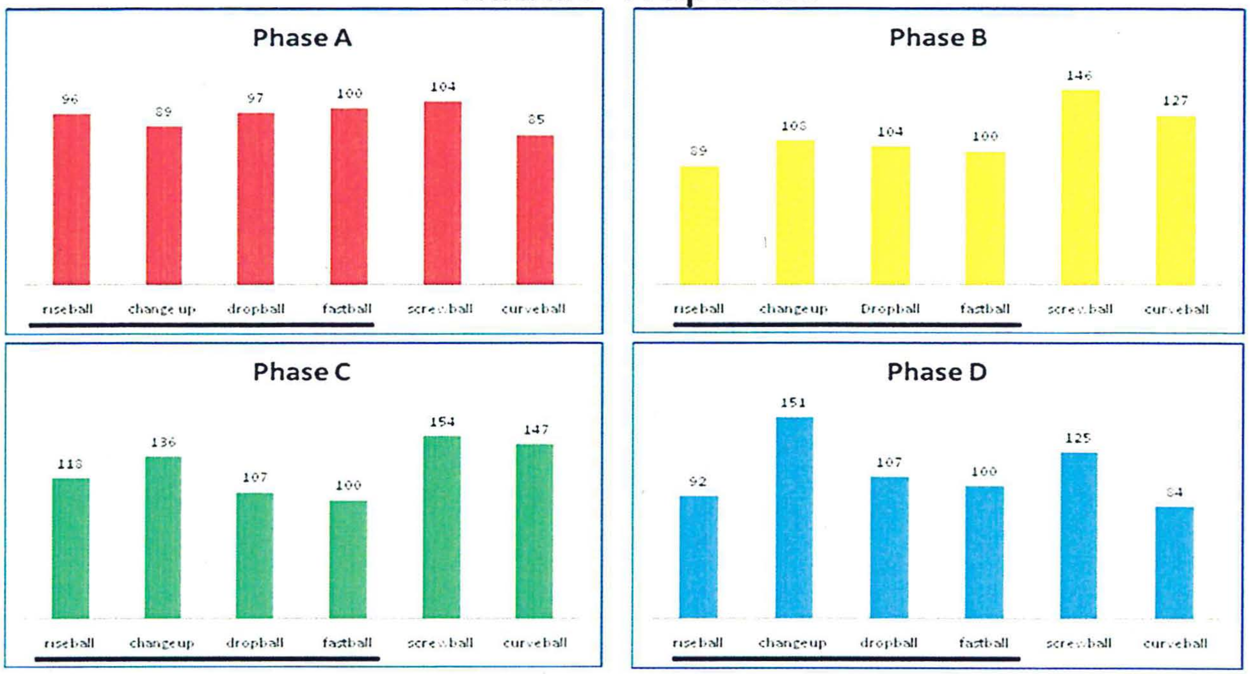
Posterior Deltoid



Infraspinatus



Middle Trapezius



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