

1999

# The Relationship Between a Functional Throwing Performance Test and Strength of Various Scapular Muscles

Karen L. Bos  
*Grand Valley State University*

Kellie S. Gehrs  
*Grand Valley State University*

A. Louise C. Hester  
*Grand Valley State University*

Follow this and additional works at: <http://scholarworks.gvsu.edu/theses>

 Part of the [Physical Therapy Commons](#)

---

## Recommended Citation

Bos, Karen L.; Gehrs, Kellie S.; and Hester, A. Louise C., "The Relationship Between a Functional Throwing Performance Test and Strength of Various Scapular Muscles" (1999). *Masters Theses*. 708.  
<http://scholarworks.gvsu.edu/theses/708>

This Thesis is brought to you for free and open access by the Graduate Research and Creative Practice at ScholarWorks@GVSU. It has been accepted for inclusion in Masters Theses by an authorized administrator of ScholarWorks@GVSU. For more information, please contact [scholarworks@gvsu.edu](mailto:scholarworks@gvsu.edu).

**THE RELATIONSHIP BETWEEN A FUNCTIONAL  
THROWING PERFORMANCE TEST  
AND  
STRENGTH OF VARIOUS SCAPULAR MUSCLES**

By

Karen L. Bos  
Kellie S. Gehrs  
A. Louise C. Hester

**MASTER'S PROJECT**

Submitted to the Department of Physical Therapy  
at Grand Valley State University  
Allendale, Michigan  
in partial fulfillment of the requirements  
for the degree of

**MASTER OF SCIENCE IN PHYSICAL THERAPY**

**1999**

# **THE RELATIONSHIP BETWEEN A FUNCTIONAL THROWING PERFORMANCE TEST AND STRENGTH OF VARIOUS SCAPULAR MUSCLES**

## **ABSTRACT**

The purpose of this study was to determine the relationship between the strength of the upper trapezius, middle trapezius, lower trapezius, and serratus anterior, and overhead throwing accuracy in 52 female collegiate softball players. The correlation between manual muscle testing (MMT) and hand-held dynamometry (HHD) was also examined. The Functional Throwing Performance Index (FTPI) was used to measure throwing accuracy. Spearman's correlation analysis demonstrated no correlation between the strength assessments and throwing accuracy, as measured by the FTPI. Moderate correlations were found between MMT and HHD strength assessments of the lower and middle trapezius and serratus anterior muscles. A poor correlation was found between the two types of strength assessments of the upper trapezius muscle. The results of this study do not support the premise that scapular muscle strength and throwing accuracy are related. Although a moderate statistically significant correlation was found between MMT and HHD, clinical significance was poor. Further research is necessary to substantiate these findings.

## **ACKNOWLEDGEMENTS**

**We would like to thank the Physical Therapy Department at Grand Valley State University for the use of their facility and equipment. We would also like to thank all the participating universities and their athletes for their willingness to partake in our study and the use of each respective facility. We would like to express our gratitude and thanks to all the members of our committee, Barb Hoogenboom, Gordon Alderink and Paul Stephenson, for their suggestions, guidance, and support on our quest for knowledge.**

**A special thanks to Cathy Harro for taking the time to train us on the use of the Nicholas hand-held dynamometer and to let us borrow her dynamometer during the data collection.**

**Thank you to spouses, family and friends for their encouragement and patience throughout this experience. Thank you to Kevin Valdes for the artistic rendition of the phases of throwing.**

## DEFINITION OF TERMS

**Active insufficiency-** occurs when a muscle which crosses two or more joints produces simultaneous movement at each joint and a length is reached at which the muscle no longer produces useful force

**Closed kinetic chain-** movement of the proximal body parts while the distal segments remain fixed

**Concentric-** a muscle contraction resulting in shortening of the muscle

**Eccentric-** a muscle contraction resulting in lengthening of the muscle

**Force couple-** results when the divergent pull of forces produced by muscles acting together create a pure rotation

**FTPI-** Functional Throwing Performance Index

**HHD-** Hand-held dynamometer/dynamometry

**ICR-** Instant center of rotation: The axis of rotation at any particular moment in the motion

**Kinetic chain-** linkage of a series of joints in a manner such that motion at one joint leads to motion at an adjacent joint

**Length/tension-** the direct relationship that exists between the tension development in a muscle and its length. There is an optimal length at which a muscle can develop maximal tension

**MMT-** Manual muscle test/testing

**Nicholas Manual Muscle Tester-** a hand-held device for objectively quantifying eccentric and isometric muscle strength

**Plyometrics-** provides training for explosive power by developing the stretch-shortening cycle of a muscle

**Scapular plane-** lies at a right angle to the glenoid fossa; at rest it lies obliquely between the frontal and sagittal planes, 30 degrees anterior to the frontal plane.

**Scapulohumeral rhythm-** the combined motion of the scapula and humerus which occurs during arm elevation

**Synergist-** a muscle that contracts at the same time and has a similar action to the agonist (example: Brachioradialis acting with brachialis to perform elbow flexion)

# TABLE OF CONTENTS

	Page
ABSTRACT.....	i
ACKNOWLEDGMENTS.....	ii
DEFINITION OF TERMS.....	iii
LIST OF TABLES.....	vii
LIST OF FIGURES.....	viii
LIST OF GRAPHS.....	ix
LIST OF APPENDICES.....	x
<b>CHAPTER</b>	
1. INTRODUCTION.....	1
2. LITERATURE REVIEW.....	5
Kinetic Chain Principle in Throwing .....	5
The Scapula .....	6
Positions and Motions .....	7
Scapulohumeral Rhythm .....	8
Force Couples Within the Shoulder Complex.....	10
Muscular Activity .....	11
Overhead Throwing .....	14
Phases of an Overhead Throw .....	15
Wind-Up .....	17
Stride .....	17
Arm Cocking .....	17
Arm Acceleration .....	17
Arm Deceleration .....	18
Follow-Through .....	18
Role of the Scapula in Throwing .....	18
Angular Velocities .....	23
Strength Assessment .....	24
Manual Muscle Testing .....	24
Hand-Held Dynamometry .....	28

Isokinetic Testing .....	31
Athletic Performance.....	32
Warm-Up .....	33
Functional Tests for the Upper Extremity .....	34
Davies' Functional Throwing Performance Index .....	34
Softball Distance Throw .....	35
3. METHODS AND MATERIAL.....	37
Subjects .....	37
Materials .....	38
Procedures .....	39
Data Analysis .....	44
4. RESULTS.....	45
5. DISCUSSION.....	49
Functional Throwing Performance Index.....	49
Extraneous Factors to Accuracy.....	52
Contributors to Functional Stability.....	53
Muscle Strength.....	54
Limitations.....	55
Recommendations for Further Research.....	57
Conclusion.....	57
REFERENCES.....	59
APPENDICES	
A. Contact Letter .....	65
B. Pre-test Questionnaire .....	66
C. Acceptance Criteria .....	68
D. Consent Form .....	69
E. Parent Information Letter .....	71
F. Warm-Up Protocol .....	72
G. Instruction for Strength Assessment .....	73
H. Instruction for Functional Throwing Performance Test .....	75
I. Modified Functional Throwing Performance Test Protocol .....	77
J. Kendall's Muscle Strength Grades .....	78
K. Screening Evaluation/Data Collection Form .....	79



## LIST OF TABLES

	Page
Table 1: Demographic Descriptive Statistics for Age, Height, and Weight.....	45
Table 2: Descriptive Statistics for Handedness and Player Position.....	45
Table 3: Relationship Between Muscular Strength Using MMT and Throwing Accuracy.....	46
Table 4: Relationship between Muscular Strength Using HHD and Throwing Accuracy.....	46
Table 5: Colton's Guidelines for Evaluating Correlational Coefficients.....	46
Table 6: Kuzma's Guidelines for Interpreting Probability Values.....	47
Table 7: Correlation between Strength Measurements Obtained Using MMT and HHD for Studied Scapular Muscles.....	48

## LIST OF FIGURES

	<b>Page</b>
<b>Figure 2-1: Instantaneous Center of Rotation Movement during Arm</b>	
<b>Elevation.....</b>	<b>13</b>
<b>Figure 2-2: Throwing Phases .....</b>	<b>16</b>
<b>Figure 2-3: Factors that Influence Functional Stability of the Shoulder Girdle</b>	
<b>During Throwing .....</b>	<b>19</b>

## LIST OF GRAPHS

	Page
Graph 1: Throwing Accuracy for Each Testing Site.....	51

## **LIST OF APPENDICES**

<b>APPENDIX</b>	<b>Page</b>
A. Contact Letter.....	65
B. Pre-test Questionnaire.....	66
C. Acceptance Criteria.....	68
D. Consent Form.....	69
E. Parent Information Letter .....	71
F. Warm-Up Protocol.....	72
G. Instruction for Strength Assessment.....	73
H. Instruction for Functional Throwing Performance Test.....	75
I. Modified Functional Throwing Performance Test Protocol.....	77
J. Kendall's Muscle Strength Grades.....	78
K. Screening Evaluation/Data Collection Form.....	79

## **CHAPTER 1**

### **INTRODUCTION**

One of the most demanding sports activities using the upper extremity is the throwing motion. The various anatomical components involved in the overhead throwing motion must be performed in a coordinated fashion in order to produce an accurate throw. Each articulation of the shoulder complex, the acromioclavicular, sternoclavicular, glenohumeral, and scapulothoracic, plays an integral part in the production of this movement. Scapulohumeral rhythm is the term used to describe the concurrent movements of the glenohumeral and scapulothoracic articulations during arm elevation. This rhythm serves two functions: to position the glenoid fossa for optimal articulation with the humeral head, and to provide a good length-tension relationship in the scapular muscles which act on the humerus.<sup>1</sup> Of the many muscles that act on the scapula to achieve these two functions, the serratus anterior and the upper and lower trapezius work synergistically to upwardly rotate the scapula during elevation of the arm. The middle trapezius contracts eccentrically to control the change in the scapular position produced by the upper and lower fibers of the serratus anterior.<sup>1</sup>

Weakness of scapular muscles has been identified as a contributor to glenohumeral dysfunction and decreased functional performance.<sup>2</sup> Therapists have often overlooked scapular muscle strength as a main contributor to functional performance and have failed to incorporate scapular muscle strengthening in the treatment of throwing athletes. Therefore, it is necessary to explore scapular muscle strength from both

preventive and rehabilitative perspectives and to examine how the stability of the scapular muscles relates to the mobility of distal segments, and ultimately, throwing performance and accuracy.

Past studies<sup>3,4</sup> have established the effects of weakness of the glenohumeral rotator muscles on the altered biomechanics of an overhead throw. Correlations have been found between biomechanical alterations, such as scapular winging<sup>5</sup> and an increased lateral translation of the scapula on the thoracic cage, and decreased shoulder function.<sup>4,6</sup> This excessive lateral scapular position places the glenoid more anteriorly, thereby placing stress on the anterior shoulder structures, potentially leading to shoulder impingement syndrome and anterior shoulder instability.<sup>5,6</sup> Researchers<sup>7-9</sup> have isokinetically tested the strength of the internal and external rotators of the glenohumeral joint and correlated musculoskeletal weakness or imbalance of these muscles with increased injury risk. Previous research, however, has failed to consider the strength of the scapular stabilizers as vital precursors to glenohumeral rotator function.

As an adjunct to range of motion and strength testing, functional performance can aid a clinician in the determination of an athlete's ability to perform the demands of their sport.<sup>10</sup> Performance tests of upper extremity function may enhance the clinical decision-making process. Davies has developed a clinically oriented throwing accuracy test called the Functional Throwing Performance Index (FTPI).<sup>11,12</sup> Past research<sup>13</sup> has investigated the relationship between throwing accuracy and arm dominance. One relationship that remains to be explored is the relationship of a thrower's scapular muscle strength to a functional test such as accuracy or precision of throws.

For physical therapists and athletic trainers involved in the rehabilitation of shoulder girdle injuries of a throwing athlete, the question of whether or not accuracy is affected by the strength of the scapular muscles may impact the components of a rehabilitation program. Along with the potential addition of exercises to strengthen scapular muscles, rehabilitation could include closed chain activities. Closed chain approximation or compression through the shoulder girdle may facilitate the muscular stability around the joint by stimulating the proprioceptive mechanoreceptors.<sup>14</sup> Finally, plyometrics<sup>6</sup> and task-oriented sport specific skills, such as throwing at a target, could be gradually introduced to minimize the risk of reinjury. For athletes and coaches, the inclusion of scapular strengthening in preseason training and conditioning programs could maximize throwing accuracy in noninjured athletes and thus contribute to improvement of the athlete's overall sports performance.

The purpose of this study was to investigate the relationship between the strength of four scapular muscles: serratus anterior, upper, middle, and lower trapezius, as measured by manual muscle testing (MMT) and hand-held dynamometry (HHD), and the throwing accuracy of female college softball players as assessed by a modified version of Davies' FTPI.<sup>12</sup> A second purpose was to investigate the relationship between strength testing measured by MMT and HHD. Believing that the strength of the studied muscles may affect the action of an overhead throw, the authors proposed the following null hypotheses for investigation: 1) no relationship exists between the strength of the serratus anterior, upper, middle, and lower trapezius as measured by MMT and throwing accuracy as measured by the modified FTPI, 2) no relationship exists between the strength of the serratus anterior, upper, middle, and lower trapezius as measured by HHD and throwing

accuracy as measured by the modified FTPI, 3) no relationship exists between the strength of serratus anterior, upper, middle, and lower trapezius assessed by MMT and the strength of the same muscles as measured by HHD.

Results of this study may guide those who work with overhead throwing athletes for both prevention of injuries to the shoulder complex and rehabilitation of existing conditions.



## **CHAPTER 2**

### **LITERATURE REVIEW**

#### **Kinetic Chain Principle in Throwing**

The term "kinetic chain" is a principle that describes how energy and momentum are transferred sequentially through a series of rigid body segments during a coordinated human motion.<sup>3,15</sup> In throwing, the kinetic chain originates at the ankle/foot and progresses to the knee, hip, pelvis, trunk, shoulder girdle, elbow, hand, and finally to the ball. By conserving and transferring momentum, the kinetic chain maximizes the velocity and direction of the hand and fingers while preventing the shoulder and elbow joints from being overloaded. The stored energy is ultimately transferred to the ball. If any segment of the chain is not functioning properly, energy may not be transferred efficiently, thereby potentially contributing to a decrease in performance and predisposing throwers to injury.

The four articulations that make up the shoulder girdle complex are the glenohumeral joint, acromioclavicular joint, sternoclavicular joint, and scapulothoracic articulation. The scapulothoracic articulation helps provide a stable foundation for the upper extremity through muscular support. During an overhead throw, this articulation functions as a bridge by transferring the energy of the trunk to the upper extremity. Hence, without the stability that the scapulothoracic articulation provides, the functional mobility of the arm is reduced.

The proximal and distal joints of the upper extremity play significantly different roles in throwing.<sup>13</sup> The proximal joints, as defined by Hore and colleagues to be the

shoulder, elbow, and wrist, place the hand in the proper position and orientation for throwing a ball, and insure that maximum velocity is imparted to the object.<sup>13</sup> These proximal joints determine the trajectory of the hand in space, which may contribute to throwing accuracy. The distal segments, as defined by Hore to be the hand and fingers, grip and release the ball. The motion of the ball is influenced by both the paths of hand translation and finger orientation as the ball rolls along the fingers during release. In summary, Hore and associates state that alterations in a thrower's hand trajectory are produced by variability of the rotations of the proximal joints of the upper extremity. Therefore, achievement of accuracy depends on control of variability of rotation of these same joints. Moreover, dysfunction of the muscles acting on the scapula may contribute to an increase in the variability of scapular position, and subsequently the position of other proximal and distal joints. The overall accuracy of throwing may thus be affected.

### The Scapula

The scapula is a large, flat, triangular shaped bone that forms the posterior portion of the shoulder girdle.<sup>16</sup> The main functions of the scapula are to position the glenoid for optimal articulation with the humeral head during arm motion and to provide a stable base for the articular surface of the humeral head to roll and slide on during arm elevation.<sup>1</sup> To provide a stable base, the scapular muscles must dynamically move the glenoid into various positions for efficient glenohumeral movement.<sup>5</sup> Simultaneously, the glenohumeral rotator muscles contract eccentrically to stabilize the humeral head while the distal segments, including the forearm, wrist and hand, move. Strength of scapular

musculature is important because scapular control is critical for optimal glenohumeral joint function during overhead movements.<sup>6,17</sup>

### Positions and Motions

Normal medial/lateral resting position of the scapula on the posterior thorax is about two inches lateral to the vertebral column. Superior/inferior position is between the second through seventh ribs. Davies and co-workers<sup>11</sup> have developed a modified lateral scapular slide test (MLSST) to describe evaluation of the resting position of the scapula. A measurement between the inferior angle of the scapula and the spinous process of T7 is taken bilaterally. The values obtained from each side are then compared; a difference greater than 1 cm is considered excessive and represents scapular asymmetry.

The scapulothoracic articulation is considered a physiologic rather than a “true” joint because it lacks a joint capsule and ligamentous restraints; the exception being where the scapula pivots about the acromioclavicular joint. The sternoclavicular joint provides the only true structural attachment of the upper limb girdle to the thorax.<sup>1</sup>

The main motions of the scapula are elevation-depression, abduction-adduction (protraction-retraction), and upward-downward rotation. Movement of the scapula on the thorax does not occur in isolation, but rather requires movement at the sternoclavicular (SC) and the acromioclavicular (AC) joints. For this reason when the hand is fixed, the scapulothoracic articulation forms the base of a true closed kinetic chain along with the SC and AC joints.<sup>1</sup>

Elevation and depression occur as a result of the scapula moving superiorly or inferiorly along the rib cage. Abduction and adduction result when the scapula slides

along the rib cage either away from or toward the vertebral column. Upward rotation is the result of the glenoid fossa tilting upward, while downward rotation occurs as the glenoid fossa tilts downward.<sup>1</sup>

While the aforementioned motions are the dominant motions of the scapula, two other motions also exist. These motions are scapular winging and scapular tipping. Scapular winging occurs as the vertebral border of the scapula moves posteriorly to enable the scapula to maintain contact with the thorax during abduction and adduction. The scapula follows the contour of the rib cage as it rotates about a vertical axis at the AC joint. Scapular tipping allows the scapula to maintain contact with the contour of the rib cage during elevation and depression. The inferior angle of the scapula moves posteriorly around a coronal axis at the AC joint.<sup>1</sup>

### Scapulohumeral Rhythm

“The shoulder is the most mobile joint in the human body, sacrificing stability for a large arc of motion”.<sup>18</sup> The scapulothoracic articulation and the glenohumeral joint are essential in contributing to a maximal range of humeral elevation. In 1934, Codman<sup>19</sup> termed the composite movement of the humerus, scapula, and the clavicle as “scapulohumeral rhythm”. Scapulohumeral rhythm allows for a large range of shoulder motion without as great a compromise in stability as would result if only one joint contributed to the full range of motion. As a result of scapulohumeral rhythm, joint congruency increases by maintaining optimal alignment between the humeral head and the glenoid fossa. A decrease in shear forces thus occurs at the glenohumeral joint. Finally, scapulohumeral rhythm prevents active insufficiency of the glenohumeral

muscles by maintaining a good length-tension relationship of the muscles acting on the humerus.<sup>1</sup> The deltoid muscle relies on movement of the scapula as it elevates the humerus past 90 degrees of shoulder abduction. Without the assistance of the scapular rotators, the deltoid pulls the scapula into downward rotation and the arm can only be raised 60-75 degrees.<sup>1</sup> Scapulohumeral rhythm therefore prevents active insufficiency of the deltoid by upwardly rotating the scapula to assist in maintaining the muscle in a lengthened position over the full range of arm abduction.

As the arm is elevated, the relative amount of glenohumeral and scapulothoracic motion varies depending on the position of the humerus. During the first 60 degrees of flexion or 30 degrees of abduction of the humerus, the scapula acts as a stabilizer, while the main motion occurs at the glenohumeral joint. As elevation increases, the scapula contributes relatively more to the movement and the ratio of glenohumeral joint to scapular contribution nears 1:1. Toward the end of full abduction, the glenohumeral joint again contributes more than the scapula, with a ratio of 5:4 being reported.<sup>1</sup> Many authors<sup>1</sup> have thus reported an overall ratio of 2:1 to describe the relation between glenohumeral and scapular contribution. Bagg and Forrest<sup>20</sup> have reported other values for the overall humeral-to-scapular ratio as 1.25:1 to 1.33:1. These researchers found that in the most common pattern of scapulohumeral rhythm there are three phases that occur as the arm abducts. Phase one occurs as the arm abducts from 20.8-81.8 degrees, the middle phase occurs at 81.8-139.1 degrees, and the third phase occurs at 139.1-170 degrees. They identify the middle phase as the one in which the scapula is the greatest contributor to arm abduction. This contribution is possibly due to the large moment arms

of the scapular rotators in relation to the moment arms of the deltoid and supraspinatus muscles, respectively<sup>20</sup>.

McQuade and Smidt<sup>21</sup> studied external resistance and its effect on scapulohumeral rhythm during arm elevation in the scapular plane. They found that heavier external loading of the shoulder increased the scapulohumeral rhythm from 1.9:1 to 4.5:1 as the arm elevated. Contemporary research demonstrates that the conventional 2:1 ratio may not accurately reflect the scapulohumeral rhythm under dynamic conditions.

### Force Couples within the Shoulder Complex

Two force couples have been identified as essential for producing normal mechanics of rotation and elevation of the shoulder. Rotation that occurs at the scapulothoracic articulation is controlled by the force couple of the trapezius and serratus anterior. Elevation that occurs at the glenohumeral joint is controlled by the deltoid/rotator cuff force couple.<sup>22</sup> For the purpose of the current study, the authors have chosen to focus on the role of the scapulothoracic force couple that produces normal scapular rotation.

Inman and coworkers<sup>23</sup> believe that three forces are required for rotation to occur at the glenohumeral joint and the scapulothoracic articulation. The first force is supplied by the upper trapezius and acts in an upward direction, providing a compressive force to counteract the pull of gravity on the shoulder girdle. Two other forces contribute to the scapular couple. One force pulls medially near the acromion process while the other pulls in an anterolateral direction from the inferior angle of the scapula. The serratus

anterior is the major contributor to the anterolateral force. The medially applied force is both passive and active. The active component is supplied by the three portions of the trapezius while the passive component is due to antagonistic pressure of the clavicle. The supportive and rotatory components essential for scapular rotation are supplied by the medial force.

Muscular Activity: The serratus anterior, upper, middle, and lower trapezius, rhomboids, and levator scapulae regulate scapular rotation.<sup>24</sup> The upper and lower trapezius combine with the upper and lower portions of the serratus anterior to produce an upward rotation force of the scapula. The upper trapezius and upper serratus anterior form one segment of the force couple that drives the scapula into upward rotation as the arm is elevated. The upper trapezius is generally thought to be more critical in producing the upward rotation of the scapula when the arm is abducted, while the serratus anterior produces more of the upward rotation when the arm is flexed.<sup>1</sup> The lower trapezius and lower serratus anterior form the other segment of the force couple and also aid in upward rotation. While the upper trapezius and serratus anterior act as prime movers for scapular upward rotation, they also have an important function as synergists to stabilize the scapula as the deltoid acts at the glenohumeral joint.<sup>1</sup> The deltoid muscle pulls on its' origin and insertion equally, and with both ends free, the lighter of the two, in this case the scapula, should move first. However, if the deltoid acted on the scapula rather than the heavier humerus, the scapula would rotate downward rather than the humerus elevating. Before the humerus could elevate, the deltoid would become actively insufficient as it shortened and rotated the scapula downward. Fortunately, the upper

trapezius and serratus anterior prevent the scapula from moving into downward rotation during deltoid contraction.

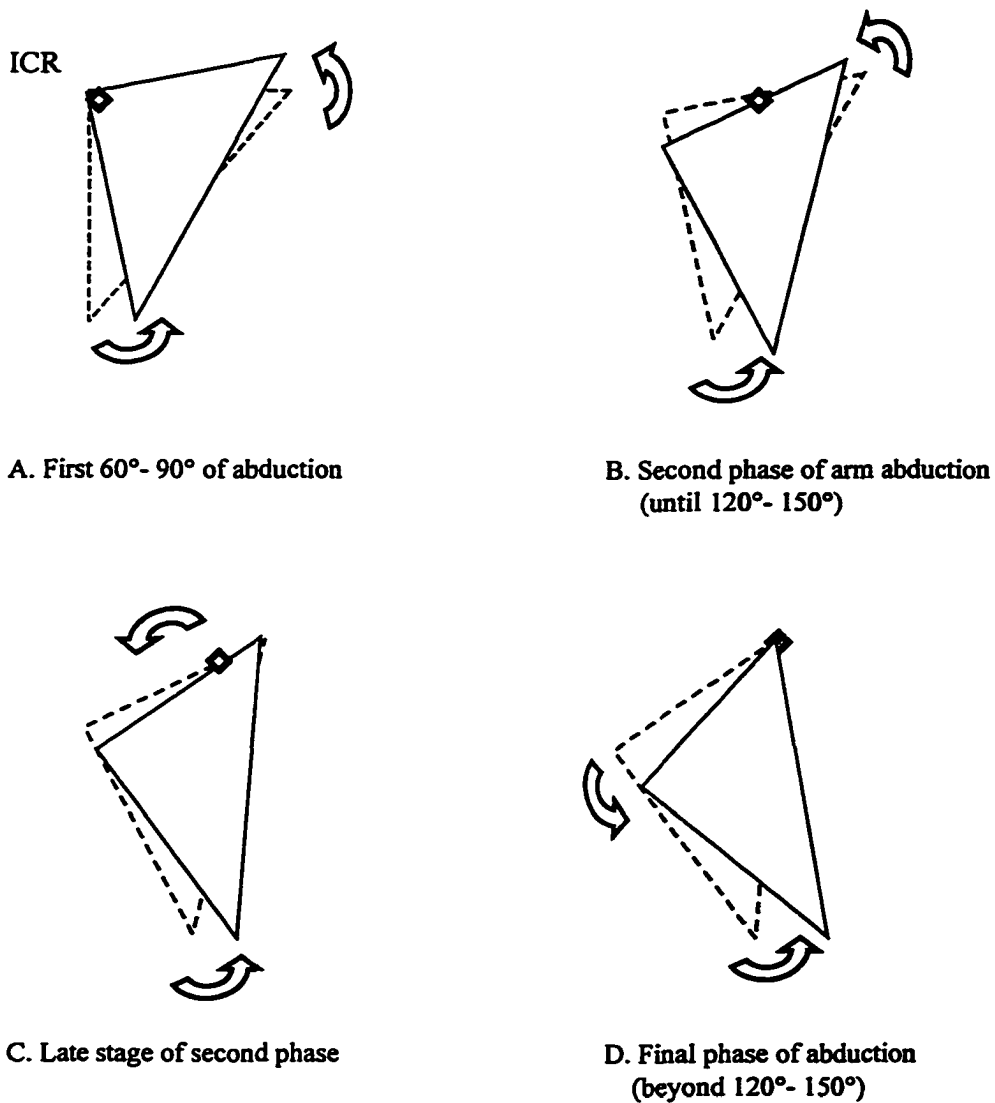
In a study by Bagg and Forrest,<sup>22</sup> the upper, middle, and lower portions of the trapezius, as well as the lower serratus anterior, were studied to determine electrical activity during shoulder abduction in the scapular plane. The upper trapezius exhibited an initial increase in activity that leveled off somewhere between 15 and 45 degrees of elevation and remained at this level until an angle between 90 and 120 degrees. The activity then increased again until a maximum level was reached at the termination of elevation. The middle trapezius showed an overall increase in activity throughout the range until maximum elevation was reached. There was a plateau phase where muscle activity did not increase markedly, but the location of this plateau varied from individual to individual. The lower trapezius demonstrated relatively little activity until about 90 degrees of elevation, at which time there was a rapid increase in activity until maximum humeral elevation. The lower serratus anterior showed a gradual increase in activity initially, with a plateau occurring at about 90 degrees. This was followed by yet another gradual increase until the greatest activity occurred at maximum elevation.

Bagg and colleagues<sup>22</sup> concluded that the plateau phase in muscular activity could be related to a change in the location of the scapular instantaneous center of rotation (ICR), which migrates from the scapular spine towards the AC joint as the arm is elevated. The plateau may indicate that the rotator muscles are adjusting to this migration. It would therefore seem important to consider the location of the ICR in the matter of scapular rotation. As the ICR moves toward the AC joint, the lower trapezius has an increased mechanical advantage related to its rapid increase in activity. At the



same time, the upper trapezius is at a mechanical disadvantage and loses its ability to work as a scapular rotator, while continuing to provide scapular support. It is possible that the migration of the ICR allows the lower trapezius to augment rotational force during the middle phase of arm elevation and to accommodate for any loss in rotational force as the upper trapezius loses its mechanical advantage (Figure 2-1).<sup>22</sup>

**Figure 2-1: Instantaneous Center of Rotation Movement during Arm Elevation**



The upper trapezius and lower serratus anterior also have lengthened force arms in the middle phase of arm abduction as compared to the deltoid and supraspinatus muscles. However, during this phase the activity of the upper trapezius and lower serratus anterior plateaus. At this same time, lower trapezius activity is increasing rapidly. In the third phase of abduction there is an overall decrease in the scapular contribution to humeral elevation. At this point the ICR is located near the AC joint, resulting in a decrease in the rotatory force arm of the upper trapezius. The upper trapezius now acts to support the shoulder girdle, while the lower trapezius and lower serratus anterior continue to function as an upward rotatory force couple acting on the scapula. The middle trapezius is able to develop a downward rotatory force in this third phase of abduction due to the new location of the ICR. The middle trapezius is thus acting to oppose the upward rotatory force of the lower trapezius and lower serratus anterior. The decrease in scapular rotation in the third phase may therefore be due to both a decrease in upper trapezius activity and the downward rotatory force of the middle trapezius.<sup>22</sup>

### Overhead Throwing

Despite the fact that gender influences have been recognized for many years, male performance during athletics is still considered the norm.<sup>25</sup> Past literature on overhead throwing athletes has focused on male baseball pitchers, football quarterbacks, and javelin throwers.<sup>3,4</sup> Pedagana and coworkers<sup>26</sup> studied the relationship between upper extremity strength and throwing speed in 8 male, professional baseball players. Using the Cybex II isokinetic instrument, the strength of the glenohumeral abductors, adductors,

flexors, extensors, internal and external rotators, horizontal abductors and adductors, elbow flexors, extensors, supinators, pronators, and wrist extensors and flexors were measured. Their findings indicate that the elbow and wrist extensors have a more direct relationship to throwing speed than the other tested muscle groups. However, the authors did not assess the scapular muscles, thus, overlooking their importance to throwing performance.

In one of the few studies that looked at female throwing athletes, Atwater<sup>27</sup> studied gender differences in release positions during various throwing events, including softball. She found that males and females had different degrees of arm abduction and trunk flexion in all throwing events. An additional study of female throwers investigated shoulder muscle firing patterns during the windmill softball pitch in ten collegiate pitchers. Maffet and colleagues<sup>28</sup> found that despite differences between the windmill and baseball styles of pitching, several similarities were revealed. The pectoralis major and serratus anterior muscles worked synergistically and seemed to have similar functions in both pitching techniques. The subscapularis muscle was pivotal for dynamic anterior glenohumeral stabilization and as an internal rotator in both pitches.

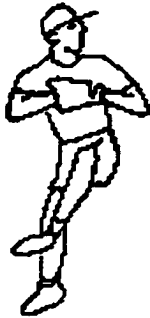
Further research in the fields of sports physical therapy and biomechanics is needed to investigate how gender influences throwing mechanics and to establish data on the firing patterns of muscles in various throwing techniques for female athletes.

### Phases of an Overhead Throw

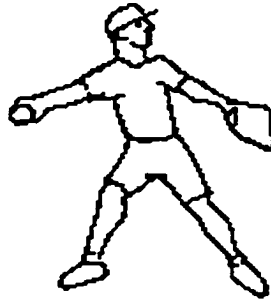
Overhead throwing is a continuous, coordinated motion. However, for the sake of biomechanical analysis, researchers<sup>1,3,13,15</sup> have divided the overhead throwing motion

into several phases. Although researchers have named the phases differently, there is agreement among them that six can be defined: wind-up, stride, arm cocking, arm acceleration, arm deceleration, and follow-through.<sup>1,3</sup> Because of the lack of a female throwing model, the six phases of overhead throwing will be discussed as described for male baseball throwers (Figure 2-2).<sup>3,6,15</sup>

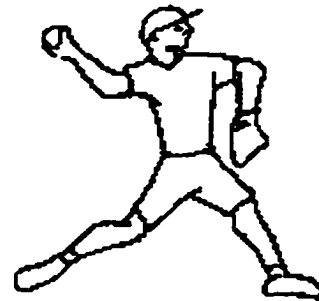
**Figure 2-2: Throwing Phases**



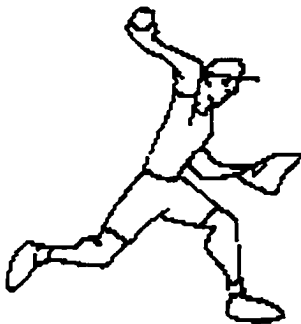
**A. Wind- up**



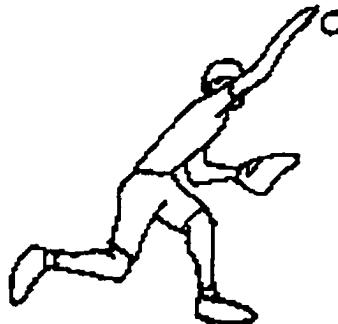
**B. Stride**



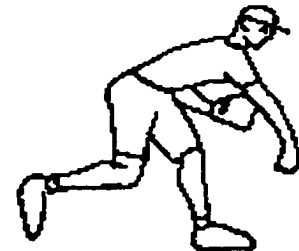
**C. Arm cocking**



**D. Arm acceleration**



**E. Arm deceleration**



**F. Follow-through**

**Wind-Up:** During the wind-up phase, the thrower flexes the knee of the lead leg while holding the ball in front of the chest. With the exception of pitchers, the lead leg is lifted very little.<sup>15</sup>

**Stride:** The stride phase begins when the lead leg extends at the knee and hip, thereby moving it toward the target. Next, the arms abduct from each other and produce a "stretching" of the body. This stretching stores energy in connective tissues, muscles, and tendons for utilization in later stages. In the stride phase, the deltoid and supraspinatus muscles abduct the throwing shoulder, while the rotator cuff muscles (infraspinatus and teres minor) externally rotate the arm. The upper trapezius and serratus anterior upwardly rotate the scapula for optimal articulation with the humeral head. Concentric action of the elbow flexor muscles result in elbow flexion, while the wrist and fingers go from a position of slight flexion to hyperextension. The stride phase ends upon foot contact of the lead leg.<sup>15</sup>

**Arm Cocking:** Arm cocking commences the third phase, which terminates at maximum shoulder external rotation. The key scapular muscles acting during this phase are the levator scapulae, serratus anterior, trapezius, rhomboids. Their function is to stabilize the scapula and position the glenoid for subsequent stages. Additional critical events that occur during this phase are pelvic and upper trunk rotation toward the target.<sup>15</sup>

**Arm Acceleration:** The arm acceleration phase occurs between maximal shoulder external rotation and ball release. In this phase, the trunk is flexed from hyperextension to neutral as the ball is released, while the lead knee begins to extend to provide a stable base for trunk rotation. The primary active muscle groups include the internal and external rotators of the glenohumeral joint, trapezius, serratus anterior, rhomboids, and

levator scapulae. Finally, to decelerate elbow extension, the elbow flexors are activated. In the hand, the wrist flexors initially fire eccentrically to slow down the wrist, but then switch to a concentric action to flex the wrist and impart maximal transfer of energy onto the ball as it is released.<sup>15</sup>

**Deceleration:** Arm deceleration lasts from ball release to maximum shoulder internal rotation. The trunk and hips flex further while the lead knee and the throwing elbow extend to almost zero degrees. In the upper extremity, the arm horizontally adducts as it decelerates. This is accomplished by the action of the infraspinatus and supraspinatus, teres minor and major, latissimus dorsi, and posterior deltoid muscles.<sup>15</sup>

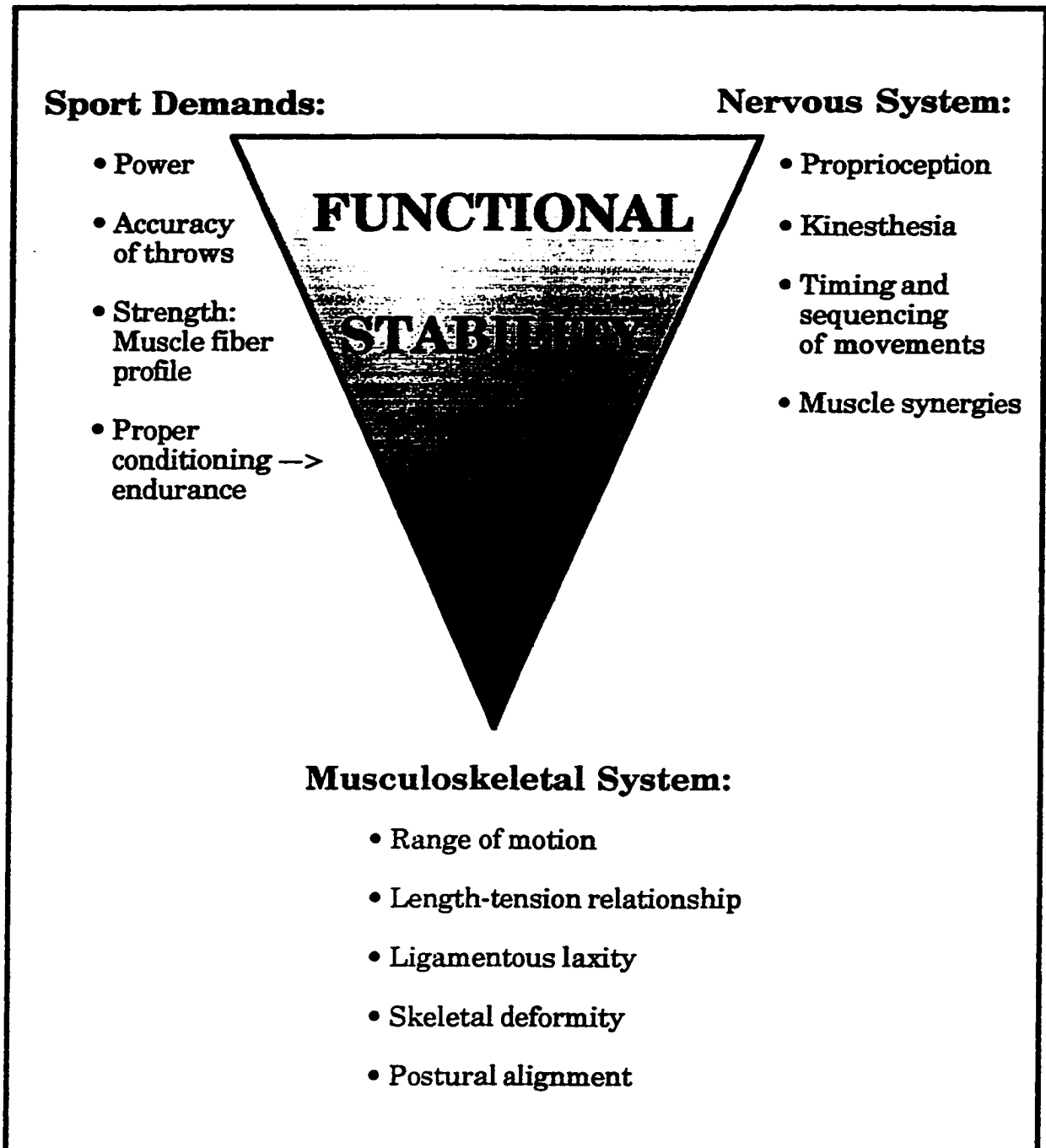
**Follow-Through:** The last stage in the overhead throwing motion is the follow-through. It begins at maximum shoulder internal rotation and ends when the arm reaches maximum adduction. The posterior shoulder muscles continue to decelerate the adducting arm, while the middle trapezius and rhomboids decelerate the scapula. The serratus anterior is, however, the most active scapular rotator during this phase, contracting concentrically.<sup>15</sup>

### Role of the Scapula in Throwing

Since proper glenohumeral joint positioning and efficient muscle performance both rely on the position of the scapula, it is important to evaluate the role of the scapula in the throwing motion. Stability, as achieved by the scapular stabilizers, provides appropriate functional support during throwing. The concept of functional stability is an interaction between the nervous and musculoskeletal systems and the demands imposed by the sport. The complex factors that influence the functional stability about the

glenohumeral complex during the throwing motion are depicted in Figure 2-3 and will be explained in the following section.

**Figure 2-3: Factors that Influence Functional Stability of the Shoulder Girdle During Throwing**



Functional stability is accomplished through the balance of static (passive) and dynamic (active) stabilizers.<sup>2</sup> Although as a whole the shoulder girdle has several “passive stabilizers” (i.e., bony geometry, ligaments and cartilage), the scapulothoracic articulation is unique in its lack of ligamentous and cartilaginous attachments to the thorax.<sup>2,17</sup> In spite of the fact that the acromioclavicular joint provides a ligamentous support of the scapula via the clavicle, the stabilization of the scapula on the thorax must also rely on dynamic stabilizing muscles and atmospheric pressure.<sup>17</sup> Optimal dynamic control of the scapula is obtained by proper timing and sequencing of the scapular stabilizers, which enable the distal segments of the upper extremity to move in a coordinated fashion.<sup>11,14</sup> The scapular muscles must fire consistently during all phases of throwing to allow the muscles attaching to the scapula to work efficiently. Unbalanced force couples impair glenohumeral motion, which could lead to decreased performance or an increased risk of injury.<sup>4</sup> The posterior scapular stabilizing muscles have a graded, coordinated firing pattern that contributes to stabilization and control of the forces around the shoulder girdle during throwing. When there is a muscle length or strength imbalance around the scapulothoracic articulation, inefficient force production in the throwing motion may result. To achieve optimal muscle efficiency during throwing, the humerus must be positioned properly and there must be a balance of the muscles around the glenohumeral joint.<sup>4</sup>

Upper, middle, and lower trapezius, levator scapulae, rhomboids, serratus anterior, and pectoralis minor all provide both stability and mobility of the scapula against the thorax.<sup>4,17</sup> These muscles stabilize the scapula, producing a firm anchor for efficient concentric or eccentric activity of the internal and external rotators of the



glenohumeral joint. This relationship is important because the glenohumeral rotators that attach to the scapula play an integral role in the throwing motion. Proper scapular alignment during overhead throwing also provides efficient muscle activity by creating optimal length-tension relationships between muscle fibers of the deltoid and rotator cuff.<sup>4</sup> Research has shown that an inefficient length-tension relationship between these muscle groups interferes with optimal firing patterns during their rapid concentric and eccentric contractions during throwing. This may lead to a hindrance in throwing performance or an increased risk of injury.<sup>17</sup>

An analysis of the six phases of throwing can be used to demonstrate the importance of various scapular stabilizers at points throughout the throwing motion. Specifically, the upper and lower trapezius, rhomboids, and serratus anterior work concentrically during the early phases of wind-up and cocking to anchor the scapula in a position of retraction and elevation. If the scapula is not fully retracted during the wind-up and cocking phases, there may be a loss of energy storage in the glenohumeral muscles, including pectoralis major, and the external rotators. This loss may prevent optimum force production in the acceleration phase of throwing because the arm is initially placed in a more anterior position. Throwing mechanics are ultimately altered and a decrease in performance or an increase in the risk of glenohumeral injury results. Furthermore, insufficient scapular elevation, which can result from strength deficits in the trapezius and serratus anterior, decreases the acromial elevation and thereby leads to an increased risk of rotator cuff impingement and an alteration in the normal throwing position of the glenohumeral joint.<sup>4</sup> The serratus anterior is the most active shoulder muscle in the cocking phase, firing eccentrically to control and decelerate retraction of

the scapula.<sup>17</sup> Trapezius activity is generally low in this phase, indicating its role in providing supplemental scapular stabilization to improve the rotational action of the serratus anterior.<sup>24</sup> The middle trapezius and rhomboids are active and work to oppose the motion created by the serratus anterior.<sup>15</sup> Serratus anterior is also active in late cocking to provide upward rotation and protraction of the scapula, allowing it to move with the horizontally adducting humerus.<sup>15</sup>

During the stride phase, the upper trapezius and serratus anterior upwardly rotate the scapula to position the glenoid for the humeral head.<sup>1,24</sup> Research has shown that weakness<sup>11</sup> or fatigue<sup>17</sup> of these muscles hinders upward rotation of the scapula during humeral elevation, altering the position of the glenoid, and leading to an increased risk for subacromial impingement syndrome. Upward rotation of the scapula is critical in placing the rotator cuff at a mechanical advantage over the deltoid complex, which is a much larger muscle group. As the arm is abducted, the activity of the rotator cuff reaches its peak output around 70 degrees of arm elevation. It has been proposed that rotator cuff activity peaks at this degree of elevation due to the need for depression of the humeral head, or equivalently, upward rotation of the glenoid fossa, and thus the scapula.<sup>1</sup> If the trapezius and serratus anterior fail to upwardly rotate the scapula as the humerus is elevated, the deltoid dominates over the rotator cuff, with the resultant gliding of the humeral head superiorly during the overhead throwing motion.<sup>17</sup>

In the acceleration phase, the rotator cuff, trapezius, serratus anterior, rhomboids, and levator scapulae are all active at high levels.<sup>15</sup> As the arm begins deceleration, the lower trapezius and rhomboids act eccentrically while the serratus anterior acts concentrically to provide scapular stability.<sup>15</sup> The serratus anterior again has the highest

level of activity of the scapular rotators in the follow-through phase as it contracts either concentrically or isometrically. The middle trapezius and rhomboids are also active in this phase and fire eccentrically to decelerate scapular protraction.<sup>15</sup> This eccentric activity acts to absorb the forces generated during follow-through to prevent massive injury to the arm.<sup>4</sup> In conclusion, it is apparent that the scapular stabilizers play an important role in placing the scapula in an appropriate position during an overhead throw.

### Angular Velocities

The principle of the conservation of angular momentum helps explain why such large forces are placed upon the dynamic and static structures of the shoulder girdle complex during overhead throwing. This law states that the angular momentum will remain constant in a system that has a net torque equal to zero.<sup>15</sup> The angular momentum is the product of rotational inertia and angular velocity. As the angular momentum is transferred from the thrower's larger base segments, the pelvis, hip, and trunk, to the smaller segments, the shoulder, elbow, and wrist, the rotational inertia decreases simultaneously with an increase in angular velocity.<sup>15</sup> The total angular momentum within the system is thus conserved as it is transferred from one segment to another. As an example of an angular velocity generated during arm acceleration in baseball pitchers, the internal rotators contract concentrically, producing internal rotation velocities of 7000-8000 degrees/second. During the same phase, a maximum shoulder horizontal adduction velocity of 500-600 degrees/second is reached. Another example occurs halfway through the acceleration phase of baseball pitching as the peak elbow angular velocity reaches 2400 degrees/second.<sup>29</sup> Any change in the torques acting upon

the joints involved in overhead throwing may potentially lead to a decrease in performance or injury.<sup>15</sup>

### Strength Assessment

Objective measurement of muscle strength plays an integral part in the physical therapy examination. Knowledge of muscle strength provides valuable information on determining functional impairment, differential diagnosis, treatment planning, and patient prognosis.<sup>30-32</sup> Several methods can be used clinically to determine a subject's muscular strength: MMT, dynamometric testing, isokinetic testing, tensiometry, and functional testing.<sup>31,33,34</sup> Current research has yet to ascertain the best method for obtaining accurate and reliable strength measurements and what techniques are best suited for specific populations.

### Manual Muscle Testing

MMT, first used by Lovett in 1912, is the most common clinical method of strength assessment.<sup>31,35-39</sup> Several standardized protocols<sup>31,33</sup> exist, advocating specific testing positions and grading scales. Kendall<sup>31</sup> qualifies strength by measuring a subject's active range of motion against gravity, and with gravity eliminated if necessary, and against external resistance applied by the examiner. Strength is graded on an ordinal scale from 5 (full range of motion against gravity with maximal resistance) to 0 (no palpable contraction). In the fourth edition of *Muscles: Testing and Function*, Kendall introduced a comparative scale ranging from 0 to 10 that eliminated the plus and minus strength grades in her original scale. For example, the "Fair +" muscle grade can be

numerically represented as 3+/5 or 6/10 (see Appendix J for these scales and the operational definitions of each grade).<sup>31</sup>

Proponents of MMT<sup>31,33</sup> state that benefits of use include: (1) quickness in measuring, (2) ease of measuring, (3) no need for expensive equipment- the examiner's hands are used as the assessment tool, and (4) convenience- it requires minimal set-up time and subject preparation. Kendall and Daniels & Worthingham argue that clinicians with a comprehensive understanding of muscle functions and actions, joint motions, and experience in testing techniques are able to utilize MMT as an objective instrument to measure a subject's strength.<sup>31,33</sup>

On the other hand, several researchers<sup>36,40-42</sup> argue that MMT is a "semiquantitative method of measurement" because some of the muscle grades rely on the examiner's perception of the subject's strength. In particular, the muscle strength grades above 3 (Fair) are said to be subjective. Other variables that increase the subjectivity of MMT are: (1) the subject's gender, height, weight, and age,<sup>43</sup> (2) the line of force application, (3) duration of the contraction,<sup>39</sup> (4) subject fatigue, (5) speed of force application, (6) interaction between examiner and subject, (7) type of instructions given, and 8) the tone of the tester's voice.<sup>36</sup>

One important criteria for any clinical tool is reliability, i.e. the consistency of a measurement.<sup>44</sup> Despite the common usage of MMT, its reliability has been studied minimally in previous research.<sup>36,45,46</sup> Iddings and coworkers<sup>47</sup> found that while examiners differ in training and testing techniques, MMT is still a reliable tool in the clinical assessment of strength.

Wadsworth and associates<sup>48</sup> studied the intrarater reliability of MMT and HHD using the Chatillon unit. The studied population consisted of 11 inpatients (ages 26-70) receiving physical therapy at a hospital. All subjects had muscle strengths that were graded at least “fair” with Kendall’s system. The studied muscle groups included shoulder abduction, wrist and elbow extension, and hip and knee flexion. The results show high intrarater reliability for both testing methods, which compares favorably to the findings reported by Iddings et al. Wadsworth and associates also report that MMT is less discriminating than HHD in detecting small differences in strength. Other researchers<sup>36</sup> reported that the MMT ratings obtained by 10 skilled examiners on post-polio children were within one grade in 90.6% of the trials.

In contrast, Beasley<sup>41</sup> investigated the knee extensor strength of post-poliomyelitis children and normal subjects using MMT and a quantitative force gauge. The results showed that the same MMT grade was given bilaterally, even for differences in strength of up to 25% between the sides. In 1986, Bohannon<sup>35</sup> studied the knee extension strength of 50 patients with neuromuscular and musculoskeletal disorders using MMT and dynamometry. He found that the MMT and dynamometric scores were positively correlated, suggesting that both methods measure the subject’s strength. He also calculated the subjects’ percentage scores of “normal” using healthy subjects with normal MMT grades in accordance with Kendall’s protocol. When the MMT and dynamometric percentage scores were compared, Bohannon found a statistical difference. This supported the research by Beasley.

In a study by Mulroy and coworkers,<sup>38</sup> they investigated the accuracy of female and male clinicians using MMT to assess knee extensor strength in nineteen subjects

diagnosed with postpolio syndrome. Maximum knee extension torque of the subjects and a maximal vertical push capability of the examiners were obtained using a Lido dynamometer. The findings indicated that female clinicians' ability to detect quadriceps weakness was limited by the tester strength, as seen by maximal vertical push forces corresponding to only 60% and 40% of the isometric knee extension forces generated by a group of normal males and females. The female examiners graded appropriately in 30 of 38 tests. Thus, the investigators stated that "most of the muscle test grades, however, were appropriate, given the examiners' upper extremity strength".

Information regarding the validity of MMT is sparse. As Bohannon's study noted, MMT and dynamometric scores were positively correlated, suggesting that both methods may be valid tools for strength assessment.<sup>30</sup> Another study by Aitkens et al<sup>40</sup> reported similar findings. These researchers compared the MMT technique and quantitative isometric strength measurements (QIS) in a population of 25 patients diagnosed with neuromuscular diseases. A force transducer measured the peak force production during a maximal volitional isometric contraction. A significant positive relationship was found between the assessment techniques, thereby supporting Bohannon's claim. However, the correlation was not strong enough to state that the two methods were equivalent. The researchers concluded that MMT yielded significant variable grades and that the QIS method was the preferable research technique.

Further research is needed to establish the reliability and validity of MMT as an assessment tool for strength, yet "current research is minimally devoted to examine these contradictory findings from 30-40 years ago".<sup>46</sup>

## Hand-held Dynamometry

A clinical alternative to manual muscle testing is HHD. In 1982, Marino and coworkers<sup>37</sup> of the Institute of Sports Medicine and Athletic Trauma (ISMAT), New York, developed a hand-held device, ISMAT Manual Muscle Tester. Using 128 subjects with a known lower extremity pathology, manual assessment of muscle groups was compared to the results obtained with the ISMAT device. The results from the ISMAT device were consistent with the examiners' perception of muscle weakness ( $p < 0.001$ ). This pioneer study has sparked many other investigations<sup>30,32,34,40,42,45,48-52</sup> into the reliability and validity of HHD.

Three types of hand-held dynamometers have been described in current literature<sup>42,45</sup>: modified sphygmomanometer, spring gauge dynamometers, and strain gauge dynamometers. A spring gauge is an instrument that, in a limited range, registers force values (0 to 27 kg) that correspond linearly to certified weights by using springs. A strain gauge, on the other hand, is an instrument that converts mechanical energy to electrical energy via a load cell, and then displays the peak voltage signal in force units. The sensitivity of certain spring dynamometers is reported to be 0.5 lb., whereas some strain gauge dynamometers can detect loads to 0.01 lb.<sup>45</sup> Using certified weights up to 55 lbs., Andrews and Bohannon<sup>53</sup> compared the accuracy of spring and strain gauge dynamometers. Pearson product moment correlations were calculated between the weights measured by each device. The results indicate that coefficients between the measurements of strain and spring gauge dynamometry were 0.98 or above. Furthermore, strain gauges were accurate over extended periods of time (provided the battery was adequately charged) whereas the spring gauges grew inaccurate as their



springs wore out.<sup>53</sup> In summary, past studies have established high reliability due to the sensitivity and accuracy of strain and spring dynamometry.

Factors that influence the reliability of HHD include: (1) the strength and experience of the tester- the examiner must be able to isometrically hold a contraction against the dynamometer while the subjects maximally contract for 4-5 seconds,<sup>38,45,51</sup> (2) the placement of the dynamometer- perpendicular to the tested limb segment, (3) the testing position- gravity corrections must be made,<sup>50</sup> (4) the timing of the test, (5) the amount of verbal, visual, and auditory feedback, and (6) the testing technique- a “break test” or a “make test.”<sup>45</sup> A break test is similar to the technique used in MMT; the subject isometrically holds a maximal contraction while the examiner holds the dynamometer on the limb and attempts to “break” the isometric contraction.<sup>45</sup> During a make test, the examiner holds the dynamometer stationary on the limb while the subject exerts a maximum isometric force of the body part on the dynamometer. Forces recorded during break tests are generally greater than those recorded during make tests.

Gender, body weight, and grip strength were shown to affect the examiner’s ability to stabilize a spring hand-held dynamometer when testing the strong muscle groups of a male subject.<sup>48</sup> The researchers reported that female testers with weak grip strengths or with low body weights were unable to isometrically hold against the stronger male subjects. Research by Wikholm et al<sup>51</sup> also support that differences in the examiner’s inherent strength level will affect the reliability of hand-held dynamometric measurements.

Current studies agree that the intrarater reliability of HHD is high to excellent as seen by Pearson’s correlation coefficients greater than 0.90. Bohannon<sup>42</sup> performed test-

retest reliability of HHD strength testing on 18 muscle groups in 30 neurologically impaired patients. He found that all correlations were significant except those of the hip and shoulder abductors. Pearson's correlation coefficients ranged from 0.84 to 0.99. Numerous other investigators<sup>45,54,55</sup> have shown similar intrarater reliability (coefficients > 0.90) for HHD.

Agre and coworkers<sup>49</sup> tested the strength of eleven muscle groups in four healthy subjects using a portable dynamometer. They reported high intrarater reliability correlation coefficients ranging from 0.88 to 0.97 for upper extremity muscle groups, and interrater reliability coefficients ranging from 0.88 to 0.94. However, the intrarater reliability values for lower extremity muscle groups ranged from -0.20 to 0.96. Magnusson and colleagues<sup>56</sup> compared nine healthy subjects' strength of shoulder abductors using HHD, Nicholas Manual Muscle Tester, and a Cybex II isokinetic dynamometer. Following warm-up, the subjects performed six maximal trials on each of five days, separated by 1 to 2 weeks. The intraday correlation coefficients of individual trials ranged from 0.82 to 0.995 for the Nicholas tester and interday correlational values ranged from 0.94 to 0.98. In a similar study, Sullivan and associates<sup>52</sup> investigated the reliability and validity of HHD by assessing the isometric strength of the external rotator muscles in 14 healthy male subjects. The HHD values were obtained using a Spark instrument and compared to maximal isometric values obtained by a Cybex II isokinetic dynamometer. The authors reported high intrarater reliability coefficients for the Spark dynamometer ( $r=0.986$ ) and Cybex II ( $r=0.993$ ), respectively.

Another proposed factor that influences the reliability of the HHD is the placement site. McMahon, Burdett, and Whitney<sup>50</sup> investigated the effect of placement

site on the reliability of HHD strength assessment of shoulder abductors in 30 subjects.

Three placement sites were used: (1) 10 cm proximal to the olecranon process, (2) 2.5 cm proximal to the olecranon process, and (3) just proximal to the ulnar styloid process.

They reported the highest reliability for measuring shoulder abductor strength in the most distal site, just proximal to the ulnar styloid process.

In a review article on using HHD for strength assessment, Andrews<sup>45</sup> made several recommendations on how to increase the reliability of HHD. First, Andrews stated that novice HHD users should report the mean of two or three trials. In addition, he recommends that testers who are experienced using the dynamometer and who exhibit good to excellent intrarater reliability do not need multiple testing trials to assess the muscle strength. Bohannon<sup>57</sup> reported that four measurements are not necessary, as the fourth trial has been shown to be lower than the mean of the first three. In conclusion, current research indicates that high interrater reliability coefficients ( $> 0.90$ ) are attainable provided the testers have experience with the use of the instrument and the testing technique.

### Isokinetic Testing

Other than MMT and HHD, few objective strength assessments of the scapulothoracic joint exist in current literature. One exception is isokinetic testing using a fixed speed of movement with an accommodating resistance.<sup>11,34</sup> Isokinetic testing permits the quantification of torque, work, and power while safely applying resistance at the subject's comfort level.<sup>34,58</sup>

The fastest test velocity available on most commercial isokinetic instruments lies within the range of 450-500 degrees/second. The one exception to this is an instrument manufactured by Merac that reportedly produces a test velocity of 1000 degrees/second.<sup>59</sup> In this light, isokinetic test velocities do not approach the large angular velocities of joint movement found during throwing activities.<sup>34,59</sup>

Using isokinetic testing, reliable assessment of muscle groups is limited to the cardinal planes of motion.<sup>59</sup> Since the composite motion of the scapula during throwing cannot be simplified into one cardinal plane, testing of the involved joints can not be performed in a functional pattern of movement. For this reason and because angular velocities produced during throwing are 5-10 times greater than the fastest test velocity of most commercial isokinetic equipment,<sup>59</sup> the authors have opted not to use isokinetic testing as a means of measuring the scapular strength in the studied population.

### Athletic Performance

Athletic performance can be described in terms of the specificity of training principle. This principle states that improvements in strength, endurance, and power are specific adaptations to imposed demands of the training regime.<sup>60</sup> Exercise programs should thus simulate the desired functional demands of the athlete's sport in order to maximize the performance.<sup>61</sup>

A common paradox of sports physical therapy is the inability to convert specific clinical measurements of impairments to an athlete's overall function. Rehabilitation, just like training, must be performed within the context and demands of the athlete's specific sport. The injured throwing athlete is commonly progressed from strengthening

and stretching activities to a “return to throwing protocol.” Return to throwing is ultimately determined by the athlete’s pain and shoulder function.<sup>18</sup> Although return to throwing protocols are a necessary component in the rehabilitation of an injured throwing athlete, these protocols are not designed to measure performance.

Researchers have identified several factors that have the potential to result in an increased risk of injury or a decrease in athletic performance. Small skeletal or muscular deficiencies can produce significant and cumulative effects on shoulder function and can increase the risk of injury.<sup>24</sup> An alteration in the normal positioning of the scapula leads to altered biomechanics of the shoulder and may result in a decrease in performance.<sup>5</sup> Poor conditioning and fatigue can lead to a change in the mechanics of the throwing arm, and this often leads to increased risk of injury or hindrance of performance.<sup>11,17</sup> Poor neuromuscular control can also lead to a dysfunctional shoulder, which will result in poor athletic performance.<sup>11</sup> Glenohumeral distraction secondary to laxity can lead to mechanoreceptor damage, proprioceptive deficits, and glenohumeral instability,<sup>11</sup> which may also decrease performance. Other facets that may alter athletic performance include nutrition, hydration, and the athlete’s inner motivation.

### Warm-Up

The use of general body warm-up procedures has been traditional in sports and has been advocated by many rehabilitation professionals as the means for preparing the body physiologically and psychologically for exercise.<sup>62</sup> The main purposes of warming up have been to raise both the general body and the deep muscle temperatures and to stretch collagenous tissues to permit greater flexibility. This reduces the possibility of

muscle tears and ligamentous sprains and helps to prevent muscle soreness.<sup>62</sup> Therefore, the authors have implemented this concept by having the subjects warm up prior to strength and accuracy testing.

### Functional Tests for the Upper Extremity

In addition to procedures such as range of motion and strength testing, clinicians often compliment the physical evaluation with a functional test. Although “functional performance tests cannot detect specific abnormalities,”<sup>10</sup> they still provide valuable insight to the overall function of an athlete. Because most functional tests mimic the stresses experienced during athletic events, these tests incorporate factors such as a subject’s willingness to perform the test and, indirectly, the athlete’s perception of pain. In current literature, there are several functional tests for the lower extremity, such as the single leg hop test for distance and the 6 meter timed hop.<sup>10,63</sup> To date, however, there is no standardized, sports specific functional test that would tie strength measurements of the upper extremity, including the scapular muscles, to throwing performance and accuracy.<sup>15,63</sup>

Davies’ Functional Throwing Performance Index: Davies has developed a clinically oriented Functional Throwing Performance Index (FTPI) to complement the physical examination.<sup>11,12</sup> This test consists of a target, a 20 inch circumference playground ball, a timed number of throws, and a statistical analysis of the results (see Appendix B). Using this protocol, Davies tested 100 healthy male subjects and initiated the gathering of normative data. In an unpublished study by Quincy,<sup>11</sup> the reliability of the FTPI was found to be 0.91. In their Master’s thesis, Rankin and Roe<sup>64</sup> used 10 healthy nonathletic

subjects and found the test-retest reliability of the FTPI over a four week period to be 0.83. However, a larger sample size would be needed to establish the reliability of the FTPI. To date, no studies have addressed the issue of validity of the FTPI.

Davies' FTPI makes an effort to fill a void in the functional testing of throwing athletes. Validity data do not exist on the FTPI, nor is there any published reliability data. Consequently, the authors have modified the FTPI by using a standard sized softball in place of the playground ball for the object to throw. The authors believe that a 20-inch circumference ball is grasped, thrown, and released differently than a softball; any improvement on the FTPI may therefore not give a true indication of how the softball player will perform during her sport. By using the athlete's sport specific ball, the forces placed on the shoulder complex during the FTPI approximate the forces that the athlete normally experiences during game and practice situations. By altering the protocol, the normative data set forth by Davies and Rankin and Roe was no longer directly applicable to data collected when not following the exact test.

Softball Distance Throw: Another functional test of the upper extremity is the softball distance throw.<sup>65</sup> In this test, the subject performs both a submaximal and maximal warm-up throw prior to three maximal testing trials. The distance of the throw is measured in inches and the mean of the three trials is determined. However, this test may not provide the throwing athlete and coach with useful, sport-specific information as it is very rare that a softball player maximally throws only for distance, without aiming for the glove of another player. This test is more a measure of power, which is not the main concern in the softball thrower. This test was therefore not used in this study.

In summary, the results of this study will add to the literature on female throwing athletes, strength testing, and scapular muscle performance by investigating the relationship between two separate strength assessment techniques of four scapular muscles and throwing accuracy. The first technique used was MMT due to its wide clinical use. HHD was also used, as this has been suggested to be a more objective tool when compared to MMT. As an adjunct to strength testing, the authors incorporated a functional throwing test to determine how athletic performance is related to the strength of the studied muscles.



## **CHAPTER 3**

### **METHODS AND MATERIALS**

#### Subjects

A convenience sample of 55 female softball players was obtained for this correlational study by contacting the athletic directors and/or coaches of colleges and universities located within 60 miles of Grand Rapids. These sites included: Grand Valley State University, Western Michigan University, Calvin College, Hope College, Aquinas College, and Grand Rapids Community College. This contact was initiated first by a phone call, and then with an informational letter (Appendix A).

All subjects accepted for this study were on the team roster for one of the colleges listed above, and were between the ages of 18 and 22. Players whose primary position was listed as infielder or outfielder were included; pitchers were excluded because repetitive underhand throwing may result in muscle development that differs from that of non-pitchers. Subjects reporting an upper extremity or low back injury within the past year, which kept them from participating in practice/competition for more than one week, were excluded. Any report of glenohumeral dislocation/subluxation resulted in exclusion from the study due to potential glenohumeral joint instability. Subjects were also excluded if they demonstrated static scapular asymmetries of greater than two centimeters as measured from the inferior scapular angle to the spinous process of the seventh thoracic vertebrae. This measuring technique is in accordance with Davies' static scapular alignment procedure<sup>11</sup> with the exception that a two centimeter

asymmetry, rather than one, was still considered acceptable since the researchers had not had extensive practice using the procedure.

Potential subjects completed and signed a pre-test questionnaire (Appendix B). All participants accepted for this study (see Appendix C for acceptance criteria) signed a consent form before proceeding (Appendix D). In order to maintain anonymity, each subject was given an identification number to be used throughout the study.

### Materials

For the screening exam, a digital scale was used for measuring each subject's weight. A standard measuring tape was used to measure each subject's height and to determine the presence of scapular asymmetries. To externally identify the anatomical point of resistance for testing the middle and lower trapezius and to identify asymmetries of the scapulae, the researchers used a washable marker. During the warm-up activity, a standardized softball was used.

A portable plinth was used to position the subject for testing the strength of the middle and lower trapezius of each subject's reported dominant throwing arm. For the upper trapezius, a chair was used to position the subject for strength testing. Two exercise mats were used to position the subject during the testing of serratus anterior. The specific details of the subject positioning are described in the following section.

Strength of the studied muscles was tested using a calibrated Nicholas hand-held dynamometer (Lafayette Instrument- Model 01160, P.O. Box 5729, 3700 Sagamore Parkway North, Lafayette, Indiana, 47903). A piece of 0.7 centimeter width foam was

placed between the subject's skin and the dynamometer to minimize discomfort throughout the strength testing.

A modified version of Davies' FTPI was used to determine each subject's throwing accuracy (Appendix I). The equipment needed for the FTPI, as described by Davies, included: a tape measure and a roll of sports tape to mark the 15 foot line, a stopwatch to time throwing intervals, and a one foot by one foot square target positioned four feet off the ground. The researchers used a standard sized softball in place of the 20-inch circumference rubber playground ball used by Davies.

### Procedures

Prior to the study, an expert (over 1000 hours of experience using the instrument) trained the researchers for 2 hours in the use of the Nicholas HHD. The researchers then practiced HHD clinically during 4 weeks. One of the researchers, LH, attained approximately 20 hours of experience using the Nicholas HHD prior to the data collection.

A preliminary study was conducted in which eight subjects performed a warm-up activity, were strength tested, and performed the FTPI. The eight subjects all had some previous softball experience. One researcher, chosen arbitrarily, tested the strength of each studied muscle on the eight subjects using the Nicholas HHD and MMT. The remaining two researchers both tested the middle trapezius of each subject using the Nicholas HHD in order to determine which of the three researchers was the most consistent in its use. Each tester was blinded to the HHD reading when performing a strength test. Since all three researchers had comparable clinical experience using MMT,

the one who exhibited the highest consistency with the HHD strength tested all subjects for both types of muscle tests during the study. The consistency was determined by manually entering the data from the preliminary study into SPSS version 8.0 for WINDOWS Release 97. The mean and standard deviations were computed for each tested muscle with respect to each individual researcher. Since the expert was not present during the preliminary study, the data analysis was based on the measurements obtained by the three novice researchers. The data analysis revealed similar means of the HHD scores for each researcher. However, the standard deviations were lowest for one researcher, LH, and therefore she was chosen to perform all the strength testing during the actual study.

Data collection was performed during the preseason of the 1997-1998 school year on the campus of each college/university. The subjects were instructed to wear shorts, T-shirt, sports bra, and tennis shoes for the testing, and to bring their softball glove for the warm-up activity. One subject was tested at a time. Each participant's consent form and pre-test questionnaire were reviewed by the researchers for any information that may exclude her from the study. If a reason for exclusion existed based on the questionnaire, the subject was informed of the reason and assured her exclusion was for her own safety and well-being. Height and weight measurements were taken for each subject, followed by a screening evaluation. This evaluation consisted of gross active range of motion of the cervical spine, shoulder, and elbow, and a measure of static scapular position using Davies' static scapular alignment procedure. To test gross active range of motion, the subject was asked to duplicate the movements of the researcher performing the assessment. The researcher proceeded to bring her chin to her chest, look up at the

ceiling, turn her head to look over each shoulder, and bring each ear towards each shoulder as an assessment of active range of motion of the cervical spine. To assess shoulder range of motion the researcher then raised both arms straight in front of her and brought them above her head, lowered them to her sides, reached up to touch the back of her head, and reached down and behind her back as if to touch her scapulae. Finally, she flexed and extended each elbow and turned each palm up and then down to assess elbow supination and pronation.

To assess static scapular position, a washable marker was used to place a spot at the inferior angle of both scapulae. The distance was measured and compared between the spinous process of the seventh thoracic vertebrae and each inferior angle. Additionally, one researcher measured five centimeters proximal to the radial styloid process of each subject's dominant arm, and made a mark to indicate the site for manual resistance during strength testing. Results of the screening evaluation were recorded on a form created by the researchers (Appendix K). Following the screening evaluation, if a reason existed to exclude the subject from the study, she was informed of that reason and assured she was excluded for her own safety and well-being. In this study, three subjects were excluded based on a failure to pass the screening evaluation.

For a warm-up activity, the subject stood 30 feet away from one of the researchers and performed a series of 25 overhead throws using a standard sized softball (Appendix F). Following the warm-up, the strength of the upper, middle, and lower trapezius, and the serratus anterior of each participant's reported dominant throwing arm were assessed. This included three measurements using the Nicholas HHD (a mean value was computed) and one MMT score (see Appendix G for instructions during strength assessment). The

examiner was blinded to the HHD readings during the strength assessments. Three HHD scores were obtained per tested muscle as recommended for novice examiners.<sup>30</sup> Only one MMT score was obtained as the examiner may have been biased to consecutive scoring. Strength was determined by using the “break test” method to allow for a valid comparison between MMT and the Nicholas dynamometer. The “break test” measures the peak force produced by each muscle when performing an isometric contraction against resistance supplied by the tester. The tester “broke” the isometric contraction through 75% of the available range of motion. Prior to each session of data collection, a coin was tossed to determine if MMT or dynamometry would be performed first. Once established, the method of strength assessment alternated from subject to subject. The order in which the studied muscles were tested was randomized to prevent any learning effects. Between each muscle test there was a thirty-second rest period.

The Nicholas dynamometer was calibrated each testing day per the Nicholas calibration protocol. In addition, the dynamometer was reset to 0.0 kg between each trial. The MMT was performed and graded using Kendall’s techniques for positioning, monitoring, stabilization, and grading schema (Appendix J). Results from the two strength tests were recorded on a data recording sheet that was produced by the researchers (Appendix K).

When strength testing the lower and middle trapezius, the subject was prone on the portable plinth and manual resistance was applied five centimeters proximal to the radial styloid process. To test the lower trapezius, the subject externally rotated her arm and held it at approximately 160 degrees abduction with the scapula retracted. The examiner provided stabilization just superior to the scapular spine to eliminate any

substitution of the upper trapezius. If the examiner felt the upper trapezius substituting during the test, the test was terminated. The subject was given a thirty second rest before repeating the test. To test the middle trapezius, the subject held her arm in 90 degrees abduction with the scapula retracted and the arm externally rotated so that the thumb pointed straight up. If at any time during testing of the lower or middle trapezius the subject flexed her elbow or rotated her arm, the test was terminated. The subject was given thirty seconds to rest, and the test was repeated. When testing the upper trapezius, the subject was seated in a chair, shrugged the shoulder of her throwing arm, and stabilized herself with the opposite hand by placing it on the underside of the chair. Manual resistance was applied on the top of the shoulder at the acromion process. For assessment of serratus anterior, the subject was supine on a mat and held the upper extremity in 90 degrees of shoulder flexion, scapular protraction, elbow extension, and the palm facing up. Manual resistance was applied over the proximal palm so the force was directed vertically through the forearm.

Following strength assessment using both the Nicholas dynamometer and the MMT, the modified FTPI was administered to each subject to measure the throwing accuracy of her reported dominant throwing arm (Appendices H and I for instructions and protocol). The subject first performed a warm-up that consisted of four gradient sub-maximal throws, (25, 50, 75, 100% of controlled volitional effort) followed by five maximal throws at the target. Three tests, each consisting of thirty seconds, were then performed. The subject was instructed to throw as many times as she could in each thirty-second interval. If the target fell or became unusable due to damage, the interval was terminated and repeated after the target was replaced. There was a thirty-second rest

between each trial. The total number of throws in the thirty seconds, as well as the number of throws that landed within the target, were counted and entered on a data collection sheet (Appendix K).

### Data Analysis

The mean of three Nicholas dynamometric trials, MMT scores, and the mean of three throwing tests were used for statistical analysis. The researchers manually entered the data into SPSS, version 8.0, for WINDOWS Release 97. Descriptive statistics were computed for the age, height, weight, arm dominance, and playing position of each subject. Spearman's rank correlation coefficients were calculated between the strength of the scapular muscles using the Nicholas dynamometer and throwing accuracy and the MMT and throwing accuracy. Finally, for each tested muscle Spearman's correlational coefficients were determined between the values obtained by MMT and HHD. The researchers chose a significance level of  $p < 0.05$ .

Spearman's rank correlational coefficient was chosen as the statistical test for several reasons. First, the studied sample of subjects did not follow a normal distribution, therefore a nonparametric statistical test, such as the Spearman's rank correlational coefficient, was indicated. Second, since the data contained a noncontinuous, ordinal variable, i.e. the MMT scores, the Spearman's correlational coefficient was the most appropriate statistical test for this type of data.



## CHAPTER 4

### RESULTS

Descriptive statistics of the study sample are presented in Tables 1 and 2. Forty-eight subjects (92.3%) were right handed and 4 subjects (7.7%) were left-handed. Of the 52 subjects, 35 players stated that their primary playing position was in the infield, whereas the remaining 17 subjects played primarily in the outfield.

**Table 1: Demographic Descriptive Statistics for Age, Height, and Weight**

<i>Subject Characteristic</i>	<i>Minimum</i>	<i>Maximum</i>	<i>Mean</i>	<i>SD</i>
<b>Age (yr.)</b>	18.0	22.0	19.3	1.15
<b>Height (in.)</b>	60.0	71.0	65.7	2.28
<b>Weight (lbs.)</b>	108.0	184.0	148.6	14.2

*N=52 subjects*

*SD=Standard deviation*

**Table 2: Descriptive Statistics for Handedness and Player Position**

<b><i>Number of subjects</i></b>	<b><i>52</i></b>
<b>Right handed subjects</b>	<b>48 (92.3%)</b>
<b>Left handed subjects</b>	<b>4 (7.7%)</b>
<b>Infield players</b>	<b>35 (67.3%)</b>
<b>Outfield players</b>	<b>17 (32.7%)</b>

Table 3 summarizes the results of the Spearman's coefficients of correlation between MMT and throwing accuracy. Spearman's correlational coefficients between HHD and throwing accuracy are presented in Table 4. In defining the degree of correlation between two variables, the researchers followed the general guidelines for

health science studies as set forth by Colton.<sup>66</sup> These guidelines and their interpretations are presented in Table 5. These results demonstrated little to no degree of relationship between either strength assessment and throwing accuracy as measured by the FTPI.

**Table 3: Relationship Between Muscular Strength Using MMT and Throwing Accuracy**

<i>Muscle Tested</i>	<i>Spearman's rank correlation</i>	<i>P Values</i>
Upper trapezius	$r_s = 0.067$	$p = 0.635$
Middle trapezius	$r_s = 0.074$	$p = 0.600$
Lower trapezius	$r_s = 0.210$	$p = 0.135$
Serratus anterior	$r_s = 0.152$	$p = 0.281$

**Table 4: Relationship Between Muscular Strength Using HHD and Throwing Accuracy**

<i>Muscle Tested</i>	<i>Spearman's rank correlation</i>	<i>P Values</i>
Upper trapezius	$r_s = 0.032$	$p = 0.822$
Middle trapezius	$r_s = 0.175$	$p = 0.216$
Lower trapezius	$r_s = 0.162$	$p = 0.252$
Serratus anterior	$r_s = 0.103$	$p = 0.468$

**Table 5: Colton's Guidelines for Evaluating Correlational Coefficients**

<i>Value of Correlation (<math>r_s</math>)</i>	<i>Interpretation</i>
0.00 – 0.25	Little or no degree of relationship
0.25 – 0.50	Fair degree of relationship
0.50 - 0.75	Moderate to good degree of relationship
0.75 – 1.00	Good to excellent degree of relationship

The decision to reject or not reject the null hypotheses was based on the two-tailed test of significance. Table 6 summarizes Kuzma's guidelines for interpretation of probabilities in health science research.<sup>67</sup> All probability values between the strength assessments (MMT and HHD) and throwing accuracy were greater than 0.05. For

example, in the relationship between MMT of the upper trapezius and throwing accuracy, there was a 63.5% probability that the observed correlation was the result of chance or error. The calculated probability values were thus not significant enough to reject the first two null hypotheses. Therefore, the null hypotheses stating that there is no relationship between the strength of the studied scapular muscles as measured by MMT or HHD and throwing accuracy as measured by the FTPI were not able to be rejected.

**Table 6: Kuzma's Guidelines for Interpreting Probability Values**

<i>Probability Value (p)</i>	<i>Interpretation</i>
> 0.05	Result not significant
< 0.05	Result is significant
< 0.01	Result is highly significant

Table 7 summarizes the results of the Spearman's rank order correlation between manual muscle testing and hand-held dynamometric measurements of the four studied muscles. The results demonstrated a moderate to good degree of relationship between the scores of MMT and handheld dynamometer (HHD) of the lower trapezius ( $r_s=0.689$ ), middle trapezius ( $r_s=0.635$ ), and serratus anterior ( $r_s=0.566$ ). A fair degree of correlation ( $r_s=0.332$ ) was found between the two types of strength assessments of the upper trapezius. The probability values between MMT and HHD were all less than 0.016, suggesting a 98.4% probability that the observed correlations between the two variables were real, i.e. not due to chance or error. Therefore, the third null hypothesis stating that there is no relationship between the strength assessments as measured by MMT and HHD was rejected.

**Table 7: Correlation Between Strength Measurements Obtained Using MMT and HHD for Studied Scapular Muscles**

<i><b>Muscle Tested</b></i>	<i><b>Spearman's rank correlation</b></i>	<i><b>P Values</b></i>
<b>Upper trapezius</b>	$r_s = 0.332$	$p = 0.016$
<b>Middle trapezius</b>	$r_s = 0.635$	$p = 0.000$
<b>Lower trapezius</b>	$r_s = 0.689$	$p = 0.000$
<b>Serratus anterior</b>	$r_s = 0.566$	$p = 0.000$

*$r_s$  = Spearman's rank order correlation*

*$p$  = significance level*

## CHAPTER 5

### DISCUSSION

A great deal of research has been devoted to studying the strength and neuromuscular control of the rotator cuff, including the role it plays in the overhead throwing motion. Little research, however, has been published which examines the strength of the scapular musculature, and how it may affect the overhead throw.

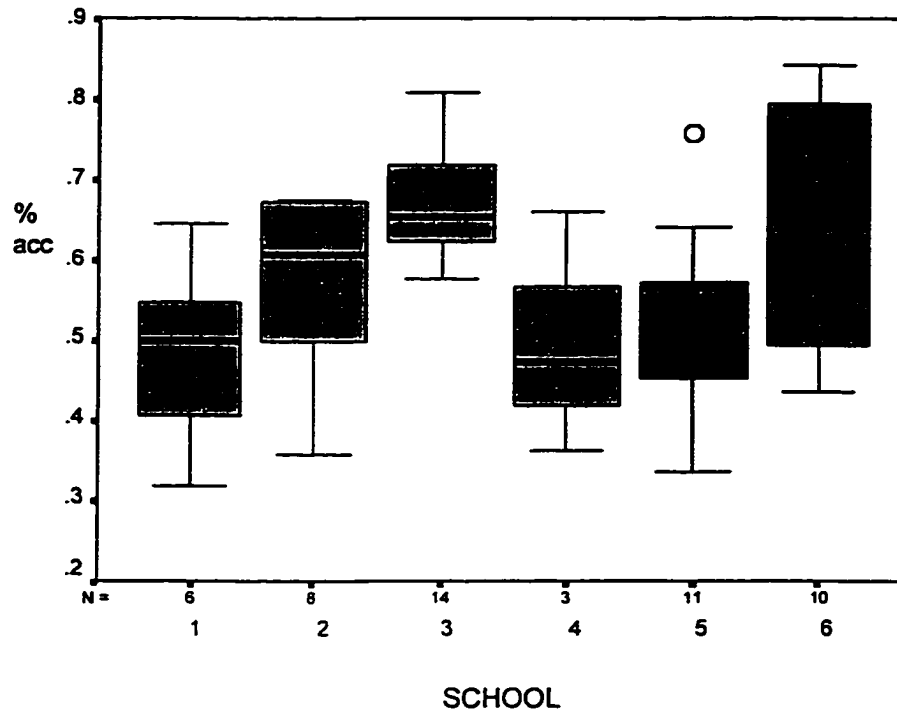
The main purpose of this study was to determine if a relationship existed between the muscular strength of four scapular stabilizers and overhead throwing accuracy in female softball players. The results of this study suggest that the strength of the upper trapezius, middle trapezius, lower trapezius, and serratus anterior has little or no correlation with throwing accuracy as measured by the FTPI. The authors propose several reasons which may account for the fact that little correlation was found.

#### Functional Throwing Performance Index

The authors were able to further examine the collected data on the level of competition by comparing throwing accuracy for each testing site. Graph 1 represents the mean throwing accuracy as measured by players at different levels of competition. The overall, average accuracy for all subjects was 58.6%. While no statistical analysis was performed for each testing site, the authors note that the greatest mean accuracy was found in players competing at the highest division of collegiate athletics. School 3 was

the only Division I school, school 1 was the only Division II school, and schools 2, 4, 5, and 6 were Division III.

**Graph 1: Throwing Accuracy for Each Testing Site**



The Functional Throwing Performance Index was used to assess throwing accuracy in softball players. This test may not have been a valid tool to measure accuracy in intercollegiate softball players, as the average accuracy reported across all subjects was 58.6 percent. Because intercollegiate athletes were tested, one would expect they could not perform adequately for competition with only an average accuracy of 58.6 percent. Had the test been a valid tool for measuring accuracy, the authors expect the average accuracy would be much higher. Neither the validity nor reliability of this test have been established in published literature. In the few studies that investigated the FTPI, normal

populations of male subjects were utilized. The test has not been used on a healthy, athletic population, and therefore may not have adequate sensitivity to measure throwing accuracy in intercollegiate softball players. Furthermore, the researchers modified the original FTPI protocol to more closely simulate the throw performed by the softball player, and this may also have altered the validity of the test. Currently, there are no published sports specific functional tests that link strength measurements of the upper extremity to throwing performance and accuracy. For this reason the researchers were limited in the choice of a test to use as a measure of functional ability in the throwing athlete.

In retrospect, the researchers feel the FTPI does not adequately resemble the requirements of throwing for the female softball player. The target used was only one foot by one foot. Furthermore, the target was stationary. In reality, a player on the field has a much larger target, as the receiving player can move and adjust the position of her glove in order to catch the ball. When players are on the field, they typically have a glove on one hand and throw with the opposite arm. While performing the FTPI, subjects did not have a glove on the nondominant hand. This may have altered throwing mechanics of subjects who were accustomed to throwing with a glove on the opposite hand. Finally, the FTPI advocates a distance of fifteen feet to test the accuracy, yet a softball player rarely throws the ball from a distance of only fifteen feet. A more valid test for accuracy in this population may entail having the subject throw from a much greater distance and using a larger size of the target. Having the subject wear a glove during the test would allow the subject to perform in a situation which more closely resembles performance on

the field. These changes would make the test more closely approximate the skills a player would exhibit while throwing to another player during practice or competition.

#### Extraneous Factors to Accuracy

Failure to establish a relationship between the strength of the four scapular muscles studied and throwing accuracy may also be due to the number of factors that may contribute to throwing accuracy. The researchers recognize that proprioception, neuromuscular control, genetics, physical factors, all the individual components that make up the human kinetic chain, level of competition, practice time, coaching, years of experience may all contribute to throwing accuracy. Isolating one contributing factor, such as scapular muscle strength, may be insufficient to establish a relationship with throwing accuracy due to the complexity and interrelationship of these other factors. The throwing motion requires several components, such as flexibility, speed, power, coordination, and proper biomechanics. An alteration in any of these factors may consequently lead to changes in throwing accuracy.

Several measures may be required to determine the most important contributor to the overhead throwing motion. When examining the throwing motion, the entire kinetic chain from the foot to the fingers must be explored. The shoulder and arm are responsible for less than 48 percent of the kinetic energy required during throwing.<sup>68</sup> The remainder of the force which transfers to the throw is generated by the legs and trunk. It may therefore be appropriate to somehow measure the overall strength of the entire kinetic chain or multiple component parts, and correlate this with throwing accuracy.



When examining contributions to throwing accuracy, proprioception deserves attention. Unfortunately an accurate assessment of proprioception requires complex machinery which was not available for this study. Another measure would be to look at other physical factors, such as overall strength, flexibility, and conditioning, which would require excessive testing of various modes. A questionnaire could also be used to examine contributing factors such as practice time, years of experience, coaching style, and level of competition.

### Contributors to Functional Stability

Functional stability is essential for the throwing athlete. For optimal sport performance, the static and dynamic stabilizers of the shoulder girdle complex must be in balance. Dynamic stabilizers of the glenohumeral joint include the rotator cuff, the deltoid, and the long head of the biceps.<sup>69</sup> It may therefore be appropriate to assess the strength of these muscles as a whole, as any weakness may lead to instability and poor performance. Along with muscular support, dynamic stability is also aided by neuromuscular control, including both joint position sense (proprioception) and the ability to produce sufficient muscle contraction to prevent shoulder subluxation.<sup>2,69</sup> Passive stabilizers including the glenohumeral joint capsule and ligamentous supports also contribute to functional stability. The authors did not screen for glenohumeral capsular laxity in this study, but this should be addressed when examining overall functional instability of the shoulder complex. In prior studies<sup>9</sup> it has been shown that the throwing athlete with instability often exhibits neuromuscular imbalances. Further

research may be appropriate to determine the correlation between these imbalances and throwing accuracy.

### Muscle Strength

A second purpose of this study was to examine the relationship between scapular muscle strength as measured by MMT and by HHD. The researchers found a moderate to good correlation between these two strength measurements of the middle trapezius, lower trapezius, and serratus anterior muscles. These results are similar to those by Bohannon<sup>30</sup> who reported a positive relationship between MMT and dynamometric scores. Bohannon reported a correlational value  $\tau = 0.744$  for word MMT scores and actual HHD test scores and a correlation value  $\tau = 0.787$  for theoretical percentage MMT scores and calculated HHD percentage test scores. Based on these results, Bohannon reported a high correlation between MMT and HHD, suggesting both techniques measure strength.<sup>30</sup> This has important implications for the clinician, because MMT is the standard way to measure strength in the clinic. MMT, however, has a subjective component, as it requires clinicians to determine the degree of resistance they provide and the ability of the patient to withstand this resistance. HHD, on the other hand, is a more objective measure of strength. A good correlation between the two measures may help to establish the validity of using either method as a means of assessing strength in the clinical setting. Portney and Watkins<sup>70</sup>, however, recommend using a reliability coefficient of 0.90 or higher to indicate clinical significance. Using this higher value as a determinate of clinical significance would then alter our findings, so that the researchers would not have shown a

clinically significant correlation between MMT and HHD. Because MMT is the standard way to measure strength in the clinic, further research is needed to validate its use. MMT and HHD scores of the upper trapezius had little to no correlation. This may, in part, be due to the fact that all subjects scored between 4+ and 5 for MMT. The distribution of MMT scores was vary small in comparison with the other muscles tested, for which there was a wide range of MMT scores obtained. Because the upper trapezius was rated a strong muscle in all subjects tested, HHD was more sensitive to small variances in strength, and therefore recorded a wider range of values in comparison with MMT.

### Limitations

The researchers recognize several limitations to the study. The researchers only tested four of the scapular stabilizers. While the four studied muscles play pivotal roles in optimal positioning of the glenoid fossa, other muscles are involved in scapular control. Other scapular muscles to consider in further research include the levator scapulae, rhomboids, latissimus dorsi, and pectoralis minor.

While the researcher performing the strength testing on each subject was trained by a clinician that had well over 1000 hours of clinical practice with the Nicholas hand-held dynamometer, the researcher failed to achieve 1000 hours of practice. This value is recommended to establish a clinician's expertise in the use of the HHD.<sup>45</sup> To maximize reliability, the authors chose to use one researcher for the performance of all HHD measurements.

The researchers used a lateral slide test to measure scapular symmetry. Because the technique was new to the researchers, the ability to measure scapular position may not

have been as accurate as if someone more experienced with the technique had performed it. Because the researchers had limited experience with the test, they did use a variance of 2 centimeter, rather than 1 centimeter, to designate asymmetry. While screening was performed for scapular symmetry, subjects were not screened for small skeletal, muscular, or ligamentous/capsular abnormalities. Any of these factors may alter the biomechanics of the throwing arm, and thus change throwing accuracy.

As was stated previously, there is no published data regarding the reliability or validity of Davies FTPI. Because of this fact, the materials used in the accuracy test were altered to more closely resemble the throwing demands of the subjects tested. The changes made to the test may have altered the results obtained by the researchers. Had the original protocol, as devised by Davies, been followed, similar results may not have been obtained. The researchers, however, believe that the alterations made were important to allow the subjects to simulate a more functional throwing situation, a throw similar to one they would perform in practice or a game. The normative accuracy values obtained by Davies, Quincy<sup>11</sup>, and Rankin and Roe<sup>64</sup>, can therefore not be applied to this study. The normative accuracy values obtained were based on a small sample size, and may not be appropriate to use regardless of the modifications made in the present research.

A final limitation of the study is the generalization of results to other populations. The researches only studied a sample of collegiate female softball players in West Michigan. These results may therefore not apply to all overhead athletes, or even to softball players of different gender or age groups or in different geographic areas.

### Recommendations for Further Research

While the results of this study did not show a strong correlation between strength of the four scapular muscles and throwing accuracy, several areas for further research are suggested. Further research is needed to establish the validity and reliability of the FTPI. Research into other measures for functional performance of the upper extremity should also be examined, as well as the development of a performance test suitable for the higher functioning throwing athletic population. Other possible contributors to throwing accuracy, as discussed previously, should also be studied. Further research into differences between genders during the task of throwing is also needed.

### Conclusion

The purpose of this study was to examine the correlation between the strength of four scapular stabilizers and throwing accuracy. While the researchers failed to demonstrate a strong correlation between these two variables, they still believe these muscles are important to consider when designing a rehabilitation program for the overhead throwing athlete. The authors recommend that scapular musculature should still be considered for the throwing athlete due to their importance in providing scapular stabilization. Weakness of the scapular musculature has been implicated as a possible contributor to decreased functional performance.<sup>2</sup> Research, however, fails to support these arguments with results to correlate muscular strength with a functional performance assessment. The relationship of scapular stability to functional performance has yet to be proven, and until research can provide further evidence on this topic it is not possible to draw definitive conclusions linking scapular instability with poor performance. However, until further research is able to determine the most important contributors to the throwing

motion and accuracy, the authors believe all contributors deserve equal consideration in assessment and subsequent treatment protocols.

As part of this study, the researchers also investigated the relationship between manual muscle testing and hand-held dynamometry for measuring strength in the athletic population. A moderate to good correlation was found between the two measures of strength, thus supporting the use of manual muscle testing in the clinical setting.

Overhead throwing is one of the most demanding sports activities an athlete can perform. In order to be successful in the pursuit of excellence in sports involving overhead throwing, the athlete needs to be aware of all the factors that contribute to the throwing motion. Awareness of, and the ability to train those components that are lacking, can aid in increasing the performance of the athlete. Muscular strength is one component that is very important to the athlete, as a variety of muscles are involved in the throwing motion, providing both stability and mobility. Scapular stability, a single component involved, has been examined in this study. Looking at factors which contribute to stability, and enhancing those factors which are inadequate, may lead to a decreased rate of injury and an increase in athletic performance. Further research is needed to provide answers as to which components have the greatest impact on the throwing motion. At the present, taking a multivariate approach to treatment and training regimens, whereby a variety of factors are examined, may lead to the most favorable outcome in rehabilitation and optimal athletic performance.

## REFERENCES

1. Norkin CC, Levangie PK. *Joint Structure & Function – A Comprehensive Analysis*. 2<sup>nd</sup> ed. Philadelphia, PA: F.A. Davis Company; 1992.
2. Wilk KE, Arrigo CA, Andrews JR. Current concepts: The stabilizing structures of the glenohumeral joint. *J Orthop Sports Phys Ther*. 1997;25(6):364-379.
3. Fleisig GS, Barrentine SW, Escamilla RF, Andrews JR. Biomechanics of overhand throwing with implications for injuries. *Sports Medicine*. 1996;21(6):421-437.
4. Kibler BW. Role of the scapula in the overhead throwing motion. *Contemp Orthopaedics*. 1991;22(5):525-533.
5. Paine RM, Voight M. The role of the scapula. *J Orthop Sports Phys Ther*. 1993; 18(1):386-391.
6. Arroyo JS, Hershon SJ, Bigliani LU. Special considerations in the athletic throwing shoulder. *Orthop Clin North Am*. 1997;28(1):69-77.
7. Jobe FW, Moynew DR, Tibone JE. An EMG analysis of the shoulder in pitching. *Am J Sports Med*. 1983;11:3-5.
8. Jobe FW, Moynew DR, Tibone JE. An EMG analysis of the shoulder in pitching: A second report. *Am J Sports Med*. 1984;12:218-220.
9. Glousman RE, Jobe FW, Tibone JE, Moynew D, Antonelli D, Perry J. Dynamic electromyographic analysis of the throwing shoulder with glenohumeral instability. *J Bone Joint Surgery*. 1988;70:220-226.
10. Bolgia LA, Keskula DR. Reliability of lower extremity functional performance tests. *J Orthop Sports Phys Ther*. 1997;26(3):138-142.
11. Davies GJ, Dickoff-Hoffman S. Neuromuscular testing and rehabilitation of the shoulder complex. *J Orthop Sports Phys Ther*. 1993;18(2):449-458.
12. Davies GJ. Protocol for Functional Throwing Performance Index. *Workshop Compendium*; 1995.
13. Hore J, Watts S, Tweed D, Miller B. Overarm throws with the nondominant arm: Kinematics of accuracy. *J Neurophysiology*. 1996;76(6):3693-3704.
14. Sullivan PE, Markos PD. *Clinical Decision Making in Therapeutic Exercise*. Stamford, CT: Appleton & Lange; 1995.

15. Zachazewski JE, Magee DJ, Quillen WS. *Athletic Injuries and Rehabilitation*. Philadelphia, PA: W. B. Saunders Company; 1996.
16. Gray H, Pick T, Howden R, eds. *Gray's Anatomy*, 15<sup>th</sup> ed. New York, NY: Barnes & Noble; 1995.
17. Regan D. The role of scapular stabilization in overhead motion. *Strength and Conditioning*. 1996;18(1):33-38.
18. Hulstyn MJ, Fadale PD. Shoulder injuries in the athlete. *Clinics in Sports Med*. 1997; 16(4):663-679.
19. Codman EA. Rupture of the supraspinatus tendon and other joint lesions in or about the subacromial bursa. In: Codman EA (ed). *The Shoulder*. Boston, MA: Thomas Todd; 1934.
20. Bagg SD, Forrest WJ. A biomechanical analysis of scapular rotation during arm abduction in the scapular plane. *Am J Phys Med Rehabil*. 1988;67:238-245.
21. McQuade KJ, Smidt GL. Dynamic scapulohumeral rhythm: The effects of external resistance during elevation of the arm in the scapular plane. *J Orthop Sports Phys Ther*. 1998;27(2):125-137.
22. Bagg SD, Forrest WJ. Electromyographic study of the scapular rotators during arm abduction in the scapular plane. *Am J Phys Med Rehabil*. 1986;65(3):111-124.
23. Inman VT, Saunders JR, Abbott JC. Observations on the function of the shoulder joint. *J Bone Joint Surgery*. 1994;26(A):1-30.
24. Bradley JP, Tibone JE. Electromyographic analysis of muscle action about the shoulder. *Clinics in Sports Med*. 1991;10(4):789-797.
25. Pearle A. *The Female Athlete*. Champagne, IL: Human Kinetics; 1994.
26. Pedegana LR, Elsner RC, Roberts D, Lang J, Farewell V. The relationship of upper extremity strength to throwing speed. *Am J Sports Med*. 1982;10(6):352-354.
27. Atwater AE. Cited by: Fleisig GS, Barrentine SW, Escamilla RF, Andrews JR. Biomechanics of overhand throwing with implications for injuries. *Sports Med*. 1996; 21(6):421-437.
28. Maffet MW, Jobe JW, Pink MM, Brault J, Mathiyakom W. Shoulder muscle firing patterns during the windmill softball pitch. *Am J Sports Med*. 1997;25(3):369-374.



29. Fleisig GS, Escamilla RF, Andrews JR. Biomechanics of throwing. In: Zachazewski JE, Magee DJ, Quillen WS. *Athletic Injuries and Rehabilitation*. Philadelphia, PA: W. B. Saunders Company; 1996.
30. Bohannon RW, Andrews AW. Interrater reliability of hand-held dynamometry. *Phys Ther*. 1987;67(6):931-933.
31. Kendall FP, McCreary EK, Provance PG. *Muscles: Testing and Function*, 4<sup>th</sup> ed. Baltimore, MD: Williams & Wilkins; 1993.
32. Wadsworth CT, Krishnan R, Sear M, Harrold J, Nielsen DH. Interrater reliability of manual muscle testing and hand-held dynamometric muscle testing. *Phys Ther*. 1987; 67(9):1342-1347.
33. Daniels L, Worthingham C. *Muscle Testing: Techniques of Manual Examination*, 3<sup>rd</sup> ed. Philadelphia, PA: W.B. Saunders; 1980.
34. Davies GJ, Ellenbecker TS. Application of isokinetics in testing and rehabilitation. In: Andrews JR, Harrelson GL, Wilke KE. *Physical Rehabilitation of the Injured Athlete*. Philadelphia, PA: W.B. Saunders Company; 1998.
35. Bohannon RW. Manual muscle test scores and dynamometer test scores of knee extensor strength. *Am J Phys Med Rehabil*. 1986;67:390-392.
36. Frese E, Brown M, Norton BJ. Clinical reliability of manual muscle testing – middle trapezius and gluteus medius muscles. *Phys Ther*. 1987;67(7):1072-1077.
37. Marino M, Nicholas JA, Gleim GW, Rosenthal P, Nicholas SJ. The efficacy of manual assessment of muscle strength using a new device. *Am J Sports Med*. 1982; 10:360-365.
38. Mulroy SJ, Lassen KD, Chambers SH, Perry J. The ability of male and female clinicians to effectively test knee extensor strength using manual muscle testing. *J Orthop Sports Phys Ther*. 1997;26(4):192-199.
39. Nicholas JA, Sapega HK, Kraus H, Webb JN. Factors influencing manual muscle testing in physical therapy. *J Bone Joint Surg*. 1978;60(A):186-190.
40. Aitkens S, Lord J, Bernauer E, Fowler WM, Lieberman J, Berck P. Relationship of manual muscle testing to objective strength measurements. *Muscle & Nerve*. 1989; 12:173-177.
41. Beasley WC. Influence of method on estimates of normal knee extensor force among normal and postpolio children. *Phys Ther Rev*. 1956;36:21-41.

42. Bohannon RW. Test-retest reliability of hand-held dynamometry during a single session of strength assessment. *Phys Ther.* 1986;66(2):206-209.
43. Saraniti AJ, Gleim GW, Melvin M, Nicholas JA. The relationship between subjective and objective measurements of strength. *J Orthop Sports Phys Ther.* 1980;2(1):15-19.
44. Rothstein JM, Echtertnach JL. *Primer on Measurement: An Introductory Guide to Measurement Issues.* Alexandria, VA: American Physical Therapy Association; 1993.
45. Andrews AW. Hand-held dynamometry for measuring muscle strength. *J Human Muscle Performance.* 1991;1(1):34-50.
46. Lamb RL. Strength Testing. In: Rothstein JM (ed). *Measurements In Physical Therapy – Clinics In Physical Therapy, vol. 7.* New York, NY: Churchill Livingstone; 1985.
47. Iddings DM, Smith LK, Spencer WA. Muscle testing-part 2. Reliability in clinical use. *Phys Ther Rev.* 1961;41(4):249-256.
48. Wadsworth CT, Nielsen DH, Corcoran DS, Phillips CE, Sannes TL. Interrater reliability of hand-held dynamometry: Effects of rater gender, body weight, and grip strength. *J Orthop Sports Phys Ther.* 1992;16(2):74-81.
49. Agre JC, Magness JL, Hull SZ, Wright KC, Baxter TL, Patterson R, Stradel L. Strength testing with a portable dynamometer: Reliability for upper and lower extremities. *Arch Phys Med Rehabil.* 1987;66:454-458.
50. McMahon LM, Burdett RG, Whitnes SL. Effects of muscle group and placement site on reliability of hand-held dynamometry strength assessment. *J Orthop Sports Phys Ther.* 1992;15(5):236-242.
51. Wikholm JB, Bohannon RW. Hand-held dynamometer measurements: Tester strength makes a difference. *J Orthop Sports Phys Ther.* 1991;13(4):191-198.
52. Sullivan SJ, Chesley A, Herbert G, McFaul S, Scullion D. The validity and reliability of hand-held dynamometry in assessing isometric external rotator performance. *J Orthop Sports Phys Ther.* 1988;10(6):213-217.
53. Bohannon RW, Andrews AW. Accuracy of spring and strain gauge hand-held dynamometers. *J Orthop Sports Phys Ther.* 1989;2:323-325.
54. Bohannon RW. Measurement and nature of muscle strength in patients with stroke. *J Neurs Rehab.* 1997;11:115-125.
55. Nicholas JA. Characterization of a strength measurement device. Proceedings of the Orthopaedic Research Society, 33<sup>rd</sup> annual meeting. Jan. 19-22; 1990.

56. Magnusson SP, Gleim GW, Nicholas JA. Subject variability of shoulder abduction strength testing. *Am J Sports Med.* 1990;18:349-353.
57. Bohannon RW. Hand-held dynamometry: Stability of muscle strength over multiple measurements. *Clin Biomechanics.* 1987;2:74-77.
58. Wilk KE, Arrigo CA, Andrews JR. Standardized isokinetic testing protocol for the throwing shoulder: The throwers' series. *Isokinetic and Exercise Science.* 1991;1(2):63-71.
59. Perrin DH. *Isokinetic Exercise and Assessment.* Champagne, IL: Human Kinetics Publishers; 1993.
60. Kisner C, Colby LA. *Therapeutic Exercise-Foundations and Techniques,* 3<sup>rd</sup> ed. Philadelphia, PA: F.A. Davis Company; 1996.
61. Anderson MK, Hall SJ. *Sports Injury Management.* Media, PA: Williams & Wilkins; 1995.
62. Arnheim DD, Prentice WE. *Principles of Athletic Training,* 8<sup>th</sup> ed. Mosby – Year Book, Inc; 1993.
63. Lewis CB, McNeerney T. *Clinical Measurement of Functional Outcomes – The Functional Outcomes Tool Box.* Mclean, VA: Learn Publications Inc; 1997.
64. Rankin SA, Roe JR. *Test – retest reliability analysis of Davies' clinically oriented Functional Throwing Performance Index (FTPI) over extended time intervals.* Lexington, KY: University of Kentucky; 1996. Thesis.
65. Heidersteit BC, McLean KP, Davies GJ. The effects of isokinetic vs. plyometric training on the shoulder internal rotators. *J Orthop Sports Phys Ther.* 1996;23(2):125-133.
66. Colton T. *Statistics in Medicine.* In: Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice.* Norwalk, CT: Appleton & Lange; 1993.
67. Kuzma J. *Basic Statistics for the Health Sciences.* In: Rubinson L, Neutens JJ. *Research Techniques for the Health Sciences.* New York, NY: Macmillan Publishing Company; 1987.
68. Toyoshima S, Hoshikawa T, Miyashita M, et al. Contribution of the body parts to throwing performance In: Wilk KE, Arrigo C. *Current concepts in the rehabilitation of the athletic shoulder.* *J Orthop Sports Phys Ther.* 1993;18(1):365-375.

69. Wilk KE, Arrigo C. Current concepts in the rehabilitation of the athletic shoulder. *J Orthop Sports Phys Ther.* 1993;18(1):365-375.
70. Portney LG, Watkins MP. *Foundations of Clinical Research: Applications to Practice.* Norwalk, CT: Appleton & Lange; 1993.

**APPENDIX A**  
**CONTACT LETTER**

Dear Coach \_\_\_\_\_,

We are graduate students in Grand Valley State University's Masters of Physical Therapy program and are looking for volunteers of college female softball players to participate in a research study we are conducting.

Our study is investigating if a relationship exists between the strength of the muscles surrounding the shoulder blade and throwing accuracy. The upper arm, forearm, wrist, and hand require the stable base of the shoulder blade in order to function as efficiently as possible. Should any muscle weakness be present about that stable base, optimal functional performance can be compromised.

Should a relationship be found, the results of this study would have implications for athletes' preseason strengthening programs and rehabilitation protocols.

We need volunteers to perform 25 warm-up throws with a partner, have four different muscles tested against the manual resistance of the researchers, and perform a Functional Throwing Performance Index (FTPI) which measures the accuracy of a maximal effort throw to a one foot square target. Volunteers must be infielders or outfielders currently on the roster. We are excluding players whose primary position is pitcher due to the fact that their muscle strength may differ significantly from the other players because of the repetitive underhand throwing motion.

We appreciate your teams' willingness to help us with our study. Testing will be performed on the campus of your college or university at your convenience during the preseason. We anticipate it will take approximately 30 minutes to test one player. All testing will be conducted on one day with no follow-up required. We will make our results available to all participants and coaches who request them. We will contact you soon to confirm the date to test your players. If you have any immediate questions please feel free to call Grand Valley State University's Physical Therapy Department at 616-895-3356 to leave a message for one of us.

Thank You,

Louise Logdberg, S.P.T.  
Student Physical Therapist

Karen Bos, A.T.,C., S.P.T.  
Certified Athletic Trainer  
Student Physical Therapist

Kellie Gehrs, S.P.T  
Student Physical Therapist

## APPENDIX B

### PRE-TEST QUESTIONNAIRE

**Subject's Name:** \_\_\_\_\_ **Age:** \_\_\_\_\_  
**Address:** \_\_\_\_\_ **Date of Birth:** \_\_\_\_\_  
\_\_\_\_\_ **University:** \_\_\_\_\_  
**Primary position you currently play:** \_\_\_\_\_

1. Did you pass the university physical exam for this season 1998?    Yes        No
  
2. Please circle your dominant arm:            Left            Right
  
3. Background:
  - a. How many years have you played softball? \_\_\_\_\_ yrs.
  - b. What other positions have you played besides the one you currently play?  
\_\_\_\_\_
  
4. Has your shoulder ever "slipped out of joint" or dislocated?    Yes        No
  
5. Have you injured any of the following joints in the past year? (please circle yes or no)
  - a. Shoulder            Yes            No
  - b. Elbow                Yes            No
  - c. Back                 Yes            No
  - d. Wrist                Yes            No
  - e. Hand                 Yes            No
  
6. Did your injury keep you out of practice or a game for more than one week?
  - a. Shoulder            Yes            No
  - b. Elbow                Yes            No
  - c. Back                 Yes            No
  - d. Wrist                Yes            No
  - e. Hand                 Yes            No
  
7. Do you have any health restrictions?    No            Yes –Please describe below  
\_\_\_\_\_

8. List any medications you currently take: \_\_\_\_\_

9. Check here if you want a copy of the research results: \_\_\_\_

\_\_\_\_\_  
Subject signature

\_\_\_\_\_  
Parent signature (if athlete < 18 yrs)

## **APPENDIX C**

### **ACCEPTANCE CRITERIA**

1. The subject passed her university physical for the school year 1998.
2. The subject's current primary playing position is not pitcher.
3. The subject did not have an injury to her back, shoulder, elbow, wrist or hand that kept her out of practice or game for more than one week in the past one year.
4. The subject is not currently under any health restrictions.
5. The subject does not display a static scapular asymmetry greater than 2 cm when measured bilaterally.
6. The subject has never had a glenohumeral subluxation or dislocation.



## **APPENDIX D**

### **CONSENT FORM**

I understand that I am participating in a study that will measure the strength of the upper, middle, and lower trapezius and serratus anterior using :1) a hand-held dynamometer, and 2) the examiner's hands. I understand that a functional throwing performance test will also be used to measure the accuracy of throws during three 30 second intervals. I also understand that the knowledge gained from the strength measurements is expected to help physical therapists, certified athletic trainers, coaches, athletes, and doctors better relate how weakness of the scapular muscles may impact throwing performance.

I also comprehend that:

1. I was selected because I have not had an upper extremity or back injury in the past one year that kept me out of practice or a game for more than one week.
2. It is not anticipated that this study will lead to physical risk to myself.
3. There is potential for muscle soreness following the testing procedure.
4. Information I provide will be kept strictly confidential and that the data will be coded so that identification of individual participants will not be possible.
5. A summary of the results will be made available to me upon my request.
6. I will "warm-up" with a partner using a standard softball prior to the strength and throwing testing.
7. I will be given verbal and written instructions about the testing procedure before testing.

I acknowledge that:

"I have been given an opportunity to ask questions regarding this research study and that those questions have been answered to my satisfaction"

"In giving my consent, I understand that my participation in this study is voluntary and I may discontinue the study at any time during the testing"

"I hereby authorize the investigator(s) to release information obtained in this study to scientific literature. I understand that I will not be identified by name."

"I have been given the investigators' names, Karen Bos, Kellie Gehrs, and Louise Logdberg, phone numbers, (616) 672-7144, so that I may contact them if I have further questions."

**“I acknowledge that I have read and understand the above information and that I agree to participate in the study.”**

**“I have been given the phone number of Paul Huizenga, the director of Human Subjects Review Board at Grand Valley State University, (616) 895-2472, so that I may contact him if I have any questions regarding my rights as a participant in this study.”**

---

**Date and Location**

---

**Signature of athlete**

---

**Signature of parent (if athlete <18 years old)**

---

**Signature of witness (must be 18)**

## **APPENDIX E**

### **PARENT INFORMATION LETTER**

Dear parents,

We are graduate students in Grand Valley State University's Masters of Physical Therapy program and are looking for volunteers of college female softball players to participate in a research study we are conducting.

Our study is investigating if a relationship exists between the strength of the muscles surrounding the shoulder blade and throwing accuracy. The upper arm, forearm, wrist, and hand require the stable base of the shoulder blade in order to function as efficiently as possible. Should any muscle weakness be present about that stable base, optimal functional performance can be compromised.

Should a relationship be found, the results of this study would have implications for athletes' preseason strengthening programs and rehabilitation protocols.

We need volunteers to perform 25 warm-up throws with a partner, have four different muscles tested against the manual resistance of the researchers, and perform a Functional Throwing Performance Index (FTPI) which measures the accuracy of a maximal effort throw to a one foot square target. Volunteers must be infielders or outfielders currently on the roster. We are excluding players whose primary position is pitcher due to the fact that their muscle strength may differ significantly from the other players because of the repetitive underhand throwing motion.

If you are willing to allow your daughter to participate in this study, please sign the attached consent form. She must have this form and the pre-test questionnaire with her when we are scheduled at her college/university.

Thank you,

Louise Logdberg, S.P.T.  
Student Physical Therapist

Karen Bos, A.T.,C., S.P.T.  
Certified Athletic Trainer  
Student Physical Therapist

Kellie Gehrs, S.P.T.  
Student Physical Therapist

## **APPENDIX F**

### **WARM-UP PROTOCOL**

#### **Introduction:**

The purpose of our study is to determine if there is a relationship between the strength of four scapular muscles and the throwing accuracy of female college softball players. Before we start the the tests to measure your strength, we are going to have you perform a warm-up to minimize the risk of injury. After that we will move to the strength testing and then have you do a test that measures your throwing accuracy.

For the warm-up, you will perform an overhead toss to Karen or Kellie 25 times as if warming up for a game. You will stand 20 feet apart as designated by these two lines on the floor (point to the two lines). After you've completed the 25 tosses, you should be warmed up sufficiently and we will proceed to the strength testing. Do you have any questions before we begin?

1. Set-up:
  - a. Use sports tape to make two lines on the floor spaced 25 feet apart.
2. Instruct subject:
  - a. "Please stand behind the line in your normal throwing stance."
  - b. "Throw the ball overhead to Karen/Kellie 25 times as if you were warming up for a game."
  - c. "Go ahead and begin the warm-up"

## **APPENDIX G**

### **INSTRUCTIONS FOR STRENGTH ASSESSMENT**

#### **Introduction:**

At this station Louise will be measuring the strength of four of your scapular muscles. She will be doing this in two ways. First, she will do what is called a manual muscle test. For that she will first place you in a position that requires you to use the muscle she is testing, and then she will apply resistance with her hand and ask you to maintain the position. For the manual muscle test she will be testing each muscle once, on both your dominant and nondominant arms.

The second way Louise will be measuring your strength is by using a Nicholas dynamometer, which is this instrument here (hold dynamometer up). For this test she will place you in the same position as she did for the manual muscle test, but instead of resisting with just her hand, she will place the dynamometer on your arm and apply resistance through it. This will allow us to get a more objective measure of your muscle strength. Louise will take three measurements of each muscle so an average can be obtained. She will test your dominant arm only.

Test: "Do you have any questions before we begin?"

#### **1. Set-up:**

- a. Using a ruler and washable marker, measure and mark the point 5 cm from the radial styloid process on each upper extremity.

#### **2. Positioning: "First we are going to position you for the test."**

#### **3. Upper Trapezius**

- a. "Go ahead and have a seat here." Point to the portable chair.
- b. "Shrug your right/left shoulder and stabilize with your opposite arm by hanging on to the underside of the chair."
- c. "Don't let me move you."
- d. Pressure is applied to the shoulder at the acromion process in a downward direction toward the floor."
- e. When the arm has moved through 75% of the range, say: "Good, now you can relax."

#### **4. Middle Trapezius**

- a. "Now let's have you lie down on your stomach here." Point to the portable plinth.
- b. "Scoot over toward me so you are at the edge of the table." Stand on the side of the arm which is to be tested.

- c. "Now I'm going to position your arm for the test."
- d. Position the arm in 90° abduction with scapular retraction, and the elbow extended with the thumb facing up toward the ceiling.
- e. "Hold this position and don't let me move you."
- f. Apply pressure at the mark which was made 5 cm from the radial styloid process in a downward direction pushing the arm toward the floor.
- g. If at any time during the test the arm moves out of position, the test will be terminated. The subject will get 30 seconds to rest and the test will be repeated.
- h. When the arm has been moved through 75% of the range, say: "Good, now you can relax."

#### 5. Lower Trapezius

- a. "Now let's have you lie down on your stomach here." Point to the portable plinth.
- b. "Move up toward the top of the table and toward me." Be standing on the side of the arm which is to be tested.
- c. "Now I'm going to position your arm for the test."
- d. Position the arm in approximately 160° abduction with the elbow extended and the thumb facing up toward the ceiling.
- e. "Hold this position and don't let me move you."
- f. Apply pressure at the mark which was made 5 cm from the radial styloid process in a downward direction pushing the arm toward the floor. The other hand will stabilize proximally, just superior to the scapular spine, to eliminate any substitution of the upper trapezius. If upper trapezius substitution occurs, instruct the patient to "Stop the test, and don't shrug your shoulder as you try to maintain the position."
- g. If at any time during the test the arm moves out of position, the test will be terminated. The subject will get 30 seconds to rest and the test will be repeated.
- h. When the arm has been moved through 75% of the range, say: "Good, now you can relax."

#### 6. Serratus Anterior

- a. "Now let's have you lie on your back on the mat."
- b. "Hold your arm straight up so your palm is facing up toward the ceiling. Now, I want you to raise your arm higher so your scapula is off the mat as well."
- c. "Hold this position and don't let me move you."
- d. Pressure is applied on the palm of the hand in a downward direction toward the floor.
- e. When the arm has been moved through 75% of the range, say: "Good, now you can relax."

## **APPENDIX H**

### **INSTRUCTION FOR FUNCTIONAL THROWING PERFORMANCE TEST**

#### **Introduction:**

At this final station we will measure your throwing accuracy when aiming at that 1 x 1 foot square target (point to target). All the balls that land completely or partially within the target will be considered “accurate”, whereas the balls that land outside the target will be deemed “inaccurate.” You must use normal throwing technique for this test. (One of the researchers will demonstrate the “crow-hop” technique). If your foot should cross this line (point to 15-foot line) the throw will not count. Before the actual test, you will have four submaximal and five maximal practice throws. Finally, you will get a 30 second interval to throw as many balls as you can at the target. You will have three test intervals.

Test: “Do you have any questions before we begin?” .... “Let’s begin.”

#### **Set-up:**

- a. With a measuring tape, measure 4 feet up from the floor and tape the bottom of the target at this height on the exercise mat.
  
- b. With the tape, measure and mark a line that is 15 feet from the wall where the target is placed.
  
- c. With the tape, measure and mark a line that is 5 feet behind the 15-foot line. Put 25 softballs in a bucket and place this bucket on a chair 5 feet behind the 15-foot line.

#### **Instruct Subject:**

- a. “Using the technique shown before, you will have 4 practice throws at the target. The first throw should be 25% of your maximal effort. Gradually increase your effort, so that by the fourth throw you are throwing at 100% of maximal effort.”
  
- b. “Once you have released the ball, return to the starting position to retrieve the next ball that Louise will hand you”.
  
- c. “Go ahead and begin the practice session.”

(Subject will perform 4 submaximal gradient throws. Any comments on throwing technique will be addressed and corrected to insure that all subjects use a similar throwing style.)

- d. “Next, you will have 5 practice throws using maximal effort.”

(One researcher will provide a continuous supply of balls to the subject by placing balls into the palm of the subject. This researcher will remain stationary at a point 5 feet behind the 15-foot line. This researcher will count the number of attempted throws.)

g. "Now let's begin the testing. If the target should be disturbed at any time during the test, we'll stop the test and start the 30 second interval over. You will have 30 seconds to throw softballs at the target. Ready, set, GO!"

(Another researcher will count the number of accurate throws as defined above and time the interval. The stopwatch utilized will have an alarm that sounds after 30 seconds. The data will be recorded on the data collection sheet.)

h. "You may now rest for 30 seconds, then we will start the next timed interval."

(Two researchers will collect and place the softballs in the bucket while the timer will notify the involved parties when there are 10 seconds left. This procedure will be repeated for all timed intervals.)



## APPENDIX I

### MODIFIED FUNCTIONAL THROWING PERFORMANCE TEST PROTOCOL

#### Materials:

Distance: 15 feet  
Height: 4 feet  
Target: 1 foot x 1 foot taped on an exercise mat ( ft x ft x in)  
Balls: 25 Standard softballs (12 inch model) in a bucket  
Chair to place bucket on.

#### Testing Protocol:

1. Normal throwing mechanics are encouraged. Subject should use the “crow-hop” technique when throwing and not just stand still at the 15-foot line.
2. Subject performs 4 gradient submaximal warm-up throws (25, 50, 75, 100 % of controlled volitional effort).
3. Subject performs 5 maximal controlled volitional throws. The subject will be handed a continuous supply of softballs by a researcher. This researcher will remain stationary at a mark 5 feet behind the 15-foot line.
4. The subject throws as many times as she can in 30 seconds with control and accuracy.
5. Three 30 second tests are performed with a 30 second rest between trials.
6. Data analysis:
  - a. The number of throws in 30 seconds is counted.
  - b. The number of throws that land within the target area are counted.

#### **Functional Throwing Performance Index (FTPI)**

$$\text{FTPI} = \frac{\text{Accuracy in Target Square}}{\text{Total Number of Throws}} \times 100$$

$$\text{FTPI} = \underline{\hspace{2cm}} \%$$

## APPENDIX J

### KENDALL'S MUSCLE STRENGTH GRADES

	ANTIGRAVITY POSITION	GRADE SYMBOL	
<b>T E S T  P O S I T I O N</b>	Gradual release from test position	4	3-
	Holds test position (no added pressure)	5	3
	Holds test position against slight pressure	6	3+
	Holds test position against slight to moderate pressure	7	4-
	Holds test position against moderate pressure	8	4
	Holds test position against moderate to strong pressure	9	4+
	Holds test position against strong pressure	10	5

Permission granted by Florence P. Kendall to reproduce this chart.  
(Page 189 in *Muscles: Testing and Function*, ed 4).

**APPENDIX K**

**SCREENING EVALUATION  
DATA COLLECTION SHEET**

Name: \_\_\_\_\_

ID# \_\_\_\_\_

Height: \_\_\_\_\_ inches

Weight: \_\_\_\_\_ lbs.

Age: \_\_\_\_\_

Throwing Arm: \_\_\_\_\_

**I. Upper Quarter Screen**

**A. Cervical**

ROM: \_\_\_\_\_

**B. Shoulders**

ROM: \_\_\_\_\_

**C. Elbow and Forearm**

ROM: \_\_\_\_\_

**D. Static scapular alignment**

Distance between T7 and left inferior angle of the scapula: \_\_\_\_\_ cm

Distance between T7 and right inferior angle of the scapula: \_\_\_\_\_ cm

Difference: \_\_\_\_\_

**II. Strength testing**

**A. MMT**

Upper Trap: \_\_\_\_\_

Middle Trap: \_\_\_\_\_

Lower Trap: \_\_\_\_\_

Serratus Ant: \_\_\_\_\_

**B. Hand-held dynamometer**

Upper Trap: \_\_\_\_\_

Middle Trap: \_\_\_\_\_

Lower Trap: \_\_\_\_\_

Serratus Ant: \_\_\_\_\_

III. FTPI

[Redacted]				
[Redacted]				
[Redacted]				
[Redacted]				

IV. Results of screening exam:

\_\_\_\_\_ Accepted

\_\_\_\_\_ Rejected

Reasons for rejection: