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EMG ANALYSIS OF UPPER EXTREMITY MUSCLES DURING ISOKINETIC TESTING OF THE SHOULDJOINT

SIYOUNG PARK¹, SHUMPEI MIYAKAWA², and HITOSHI SHIRAKI²

Abstract

Purpose: This study was to investigate the patterns of electromyography (EMG) amplitude responses during maximal, eccentric muscle action with shoulder adduction and diagonal movement, at 6 different positions on the dynamometer.

Methods: The participants for this investigation were 9 males and 5 females. Testing consisted of each subject performing eccentric muscle exercise of the dominant shoulder muscle at a velocity of 60°/sec and 180°/sec. Muscle activity values were recorded individually from six different muscles and peak torque values were extracted for each test from torque curves once. EMG data were normalized to the highest root mean square (RMS), and were expressed as a % maximum voluntary isometric contraction (%MVIC).

Results: The posterior parts of upper extremity muscle complex generate overall high muscle activity (>40%MVIC) during all testing for eccentric muscle activity with diagonal shoulder movement. Posterior deltoid (PD), upper trapezius (UT), and middle trapezius (MT) muscles show differences between eccentric muscle action with shoulder adduction and eccentric muscle action with diagonal shoulder movement.

Conclusion: The present results show that an improved understanding of muscle activity patterns during different movement may benefit many fields of athletic trainers, coaches, and athletes, in addition to assisting in injury prevention for throwers, and even rehabilitation after injury.


Key word: electromyography, peak torque, eccentric muscle action, diagonal movement

I. Introduction

The basic motion of throwing is routine, and injury develops due to repeated motion, and environmental and individual factors. Throwing injuries are injuries in the shoulder, elbow, and hand that occur during throwing. Consequently, throwing injuries are variously named overuse syndrome, little leaguer's shoulder, baseball elbow, baseball shoulder, etc.

Electromyographic (EMG) studies have performed to obtain sufficient data of upper extremity muscles by clinicians for particularly clinical aim¹–⁵. One of the generally recognized tools to measure muscle activity is EMG analysis. EMG has been used to quantify muscle activity patterns during various rehabilitation programs¹,⁶–⁸ and to analyze muscle activity and coordination of upper extremity muscle for sports activity⁹,¹⁰. Upper extremity muscle activities of shoulder joint are crucial for the normal performance of shoulder motion in overhead sports, injuries of shoulder joint are influenced by the types of throwing, activity levels and cooperation of muscle activity¹¹–¹⁴. The role of upper extremity muscles in shoulder joint are not only to experience concentric contractions as agonist muscle during the windup and cocking phases, but also to maintain dynamic stabilization of the shoulder joint as antagonist muscle during the deceleration and follow-through phases of overhead-throwing¹⁵–¹⁸. These results were found in estimations for the isokinetic muscular performance of the shoulder abductor muscles with adduction and diagonal patterns in overhead athletes¹⁹,²⁰. Therefore, eccentric muscle activities and strength ratio data for posterior upper

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extremity muscles are crucial for the normal performance of shoulder motion in overhead sports.

Isokinetic muscle strength testing of shoulder joint has been used to assess eccentric peak torque by researchers for particularly clinical aim\textsuperscript{18,20–22}. Although isokinetic muscle action studies include exercises that emphasize detailed sequence in muscle action for upper extremity muscles of shoulder joint by using electromyographic (EMG), most studies have only estimated eccentric muscle activity with shoulder rotation movement in their methodology\textsuperscript{12,23}. No previous studies have examined the detailed sequence of muscular activity in selected shoulder muscles during eccentric muscle action focus on deceleration phase for various patterns.

The purpose of this study was to investigate the patterns of EMG amplitude responses during maximal, eccentric muscle action with shoulder adduction and diagonal movement, at 6 different positions on the dynamometer. In addition, the investigation was to identify the muscular coordination patterns during low (60°/sec) and high testing speed (180°/sec), and to design exercise continuous of upper extremity muscle activity for progressive training or rehabilitation.

II. Methods

A. Subjects

The participants for this investigation were 9 males (mean age, 24.2 ± 1.6 years; mean height, 177.0 ± 3.0 cm; mean body mass, 69.0 ± 4.0 kg) and 5 females (mean age, 21.6 ± 1.0 years; mean height, 160.6 ± 2.1 cm; mean body mass, 53.2 ± 1.5 kg). The subjects were selected from university students who participate in overhead sports (volleyball, javelin throw, baseball and tennis) at least two days a week. Subjects were excluded for problems such as tendonitis, adhesive capsulitis, instability, or impingement. Each subject provided written informed consent before participation and signed a consent form approved by the Human Research Ethics Committee of the University of Tsukuba.

B. Testing procedures

Subjects completed eccentric muscle actions of shoulder on a calibrated Biodex System 3 isokinetic device (BIODEX System 3, USA) with movement of various positions, eccentric muscle action of shoulder abduction muscle and eccentric muscle action of shoulder with diagonal. During the testing, subjects were seated on the Biodex System 3 with 90° hip flexion, and restraining straps were placed across their waist and the chest in addition to a rigid sternal stabilizer. The tests were performed as follows.

For the eccentric muscle action with shoulder adduction movement (EA), the upper extremity with the elbow extended, 90° of forearm pronation, and 130° of shoulder abduction was performed with the starting position for 30°, 50°, and 70° of horizontal adduction, respectively. Total range of motion was maintained from 130° of shoulder abduction to 30° (Fig. 1, A).

For the eccentric muscle action with shoulder diagonal movement (ED), the upper extremity with the elbow extended, 90° of forearm pronation, and 30° of horizontal adduction was performed with the starting position for 115°, 130°, and 145° of shoulder abduction, respectively. Total range of motion was among a diagonal range of 100° (Fig. 1, B).

Prior to isokinetic testing, each subjects warmed up by using an upper-body ergometer for approximately 5-min after stretching of the major shoulder muscle groups. After a brief explanation of the testing procedures, subjects performed practice sessions for three submaximal trials to familiarize themselves on eccentric muscle action at a velocity of 60°/sec.

Eccentric tests consisted of 5 maximal-effort repetitions, and during the test, subjects were asked to exert themselves to the fullest extent possible. Passive shoulder abductions occurred after each maximal eccentric muscle action at a speed of 30°/sec, and the subject was allowed a 2-minute rest period between exercises to control for any fatigue effect. Testing consisted of each subject performing eccentric muscle exercise of the dominant shoulder muscle at a velocity of 60°/sec and 180°/sec, and the order
randomly selected for accuracy of data.

C. EMG procedure

Electrodes were connected to a WEB-5000 8-channel frequency-modulation transmitter (Nihon Kohden, Tokyo, JAPAN). Acetabuliform Ag/AgCl bipolar surface electrodes (5-mm diameter recording surface, NT-511G, Nihon Kohden, Tokyo, JAPAN) were placed along the main direction of muscle fibers with an inter-electrode center-to-center distance of 20 mm. Accuracy of the differential amplifier was measured using a Common Mode Rejection Ratio (CMRR) of 110 dB at 60 Hz, a gain of 1000, and noise <0.2 μV (EMG 100, BIOPAC System, Santa Barbara, USA). Amplitude of the raw EMG signal from the receiver was interfaced with a computer using 16 channels through a 16-bit A/D card (UIM 100; BIOPAC System). During the test, the System

FIGURE 1. Subjects executed at least 3 maximal eccentric muscle actions of shoulder on the isokinetic dynamometer at 60° and 180°/s. A. Eccentric muscle action with shoulder adduction movement (EA) at starting positions of 30°, 50°, and 70° of horizontal adduction. B. Eccentric muscle action with shoulder diagonal movement (ED) at starting positions of 115°, 130°, and 145° of shoulder abduction.

FIGURE 2. Raw EMG signals and peak torque recorded during eccentric muscle action with shoulder adduction and diagonal movement (AD, anterior deltoid; MD, middle deltoid; PD, posterior deltoid; UT, upper trapezius; MT, middle trapezius; BB, biceps brachii; ROM, range of motion).
device and Biopac system were connected to accurately determine range of motion simultaneous with EMG. All data were stored on a personal computer and Acknowledge 3.7.5 software (BIOPAC System) was used for data processing and analysis (Fig. 2). Sampling rate was set at 1000 Hz per channel. The EMG signal was band-pass filtered at 10-500Hz. EMG data was recorded individually from each muscle and peak torque values were extracted for each test from torque curves once.

D. Testing procedures

EMG activity was recorded individually from AD, MD, PD, UT, MT, and BB muscles. The AD muscle electrode was placed 1 finger-width distal and anterior to the acromion, and the MD muscle electrode was placed to a major protuberance from the acromion to the lateral epicondyle of the elbow. For PD muscle, the electrode was placed about 2 finger-widths posterior to the acromion. The UT muscle with supraspinatus electrode was placed midway between the spinous process of the seventh cervical vertebra and the posterior tip of the acromion process along the line of the trapezius muscle, and the MT muscle electrode was placed midway on a horizontal line between the root of the spine of the scapula and the third thoracic spine. The BB muscle electrode was placed on a line between the medial acromion at 1/3 at the distance from the cubital fossa. A reference electrode was placed over the seventh cervical spine process.

Prior to isokinetic testing, subjects performed a 5-s maximal voluntary isometric contraction (MVIC) for each muscle to ensure correct placement of the electrodes, and to assess for the purposes of EMG trial normalization. The positions for MVIC performance chose based on standard muscle strength testing positions. The EMG activity at the sector of motion containing the peak moment was determined visually and identified using cursors.

In order to allow comparison of the activity in subject's different muscles and the activity in specific muscles among different individuals EMG data were normalized to the highest root mean square (RMS), and were expressed as a % maximum voluntary isometric contraction (%MVIC). RMS values were calculated for consecutive segments of 50 ms, and the mean and standard deviation of %MVIC were determined for each muscle during the different tasks. Muscle activity was categorized as minimal (%MVIC, 0-20%), moderate (20-40%), high (40-60%), or very high (>60%).

During the isokinetic test, the peak moment (in Nm) for each condition was obtained from the dynamometer's dedicated software. The average peak moment of the five maximal repeated contractions in each testing condition was calculated and used for computing the dynamic control ratios namely the Ecc strength of the Add, Ext, and D2E at each angular velocity.

E. Data analysis

To determine differences within muscle activities with each different task, one-way repeated-measure analysis of variance (one-way ANOVA) was used, and to test relationship within peak torques with each different task. Two-way repeated-measure analysis of variance (two-way ANOVA) was used to test the relationship between different task and angular velocity selected for EMG activity of each muscle. Post-hoc analyses were performed using a Bonferroni procedure when significant differences were found with analysis of variance or post hoc test within different tasks. An α level of 0.05 with a confidence interval of 95% was used in determining significant differences. All statistical analyses were performed with the statistical package for the social sciences, version 11.0 (SPSS Inc., Chicago, Illinois, USA).

III. Result

A. Muscle activities for adduction vs. diagonal pattern

Mean and standard deviations of EMG for each muscle during eccentric muscle test with shoulder adduction and diagonal movement are displayed in
Table 1 and 2. One-way ANOVA revealed significant differences between AD muscle activities for each test at 60 (F = 13.49, P < 0.001) and 180/sec (F = 20.39, P < 0.001). AD muscle activity elicited greater %MVIC during all EA60s than 115ED60, and during all EA180s than each ED180. 50 and 70EA60 displayed greater muscle activity than 130ED60 (P < 0.001). One-way ANOVA revealed significant differences between PD muscle activities for each test at 60/sec (F = 17.92, P < 0.001). PD muscle activity elicited greater %MVIC during all ED 60 than each EA60. One-way ANOVA revealed significant differences between UT muscle activities for each test at 60 (F = 3.13, P < 0.05) and 180/sec (F = 5.42, P < 0.001). UT muscle activity showed significant differences between 70EA60 and 145ED60, and between 70EA180 and 115ED180. One-way ANOVA revealed significant differences between MT muscle activities for each test at 180/sec (F = 3.52, P < 0.05). MT muscle activity elicited greater %MVIC during 115ED180 than 70EA180. One-way ANOVA revealed significant differences between BB muscle activities for each test at 180/sec (F = 4.21, P < 0.05). BB muscle activity elicited greater %MVIC during 130ED180 than 30EA180.

B. Eccentric muscle action with adduction movement

Two-way ANOVA revealed significant differences between different task and angular velocity for UT muscle activity (F = 10.49, P < 0.001). Post-hoc testing revealed significant differences between 70 and 30 and 50EA at 180/sec. 70EA180 displayed greater muscle activity than 70EA60. Two-way

<table>
<thead>
<tr>
<th>Task</th>
<th>Movement (deg/sec)</th>
<th>Anterior deltoid</th>
<th>Middle deltoid</th>
<th>Posterior deltoid</th>
<th>Upper Trapezius</th>
<th>Middle Trapezius</th>
<th>Biceps brachii</th>
</tr>
</thead>
<tbody>
<tr>
<td>30° horizontal adduction with abduction 130°</td>
<td>EA60</td>
<td>59.64(18.43)***</td>
<td>76.79(44.20)**</td>
<td>33.98(14.83)**</td>
<td>80.26(30.97)**</td>
<td>158.46(64.00)**</td>
<td>62.80(40.33)**</td>
</tr>
<tr>
<td></td>
<td>EA180</td>
<td>68.23(16.32)**</td>
<td>122.15(47.10)**</td>
<td>37.51(10.12)**</td>
<td>88.00(29.68)**</td>
<td>109.27(48.27)**</td>
<td>27.60(9.17)**</td>
</tr>
<tr>
<td>50° horizontal adduction with abduction 130°</td>
<td>EA60</td>
<td>73.27(13.04)**</td>
<td>58.14(22.38)**</td>
<td>29.01(8.73)**</td>
<td>78.38(24.26)**</td>
<td>126.81(48.69)**</td>
<td>53.96(15.03)**</td>
</tr>
<tr>
<td></td>
<td>EA180</td>
<td>68.85(14.93)**</td>
<td>99.85(50.33)**</td>
<td>46.80(24.79)**</td>
<td>77.32(24.90)**</td>
<td>121.15(42.18)**</td>
<td>45.76(15.42)**</td>
</tr>
<tr>
<td>70° horizontal adduction with abduction 130°</td>
<td>EA60</td>
<td>77.11(28.73)**</td>
<td>75.95(52.22)**</td>
<td>27.20(8.66)**</td>
<td>69.10(34.90)**</td>
<td>121.28(35.17)**</td>
<td>57.45(21.71)**</td>
</tr>
<tr>
<td></td>
<td>EA180</td>
<td>68.75(44.43)**</td>
<td>75.83(25.05)**</td>
<td>59.07(37.76)**</td>
<td>133.59(33.24)**</td>
<td>101.94(42.20)**</td>
<td>55.51(10.81)**</td>
</tr>
</tbody>
</table>

Movement: EA, eccentric muscle action with shoulder adduction movement
Activity level: +, minimal; ++, moderate; ++++, high; +++, very high

<table>
<thead>
<tr>
<th>Task</th>
<th>Movement (deg/sec)</th>
<th>Anterior deltoid</th>
<th>Middle deltoid</th>
<th>Posterior deltoid</th>
<th>Upper Trapezius</th>
<th>Middle Trapezius</th>
<th>Biceps brachii</th>
</tr>
</thead>
<tbody>
<tr>
<td>115° abduction with 30° horizontal adduction</td>
<td>ED60</td>
<td>32.93(11.98)**</td>
<td>86.43(24.21)**</td>
<td>61.99(14.92)**</td>
<td>67.75(27.13)**</td>
<td>143.87(50.93)**</td>
<td>47.83(16.98)**</td>
</tr>
<tr>
<td></td>
<td>ED180</td>
<td>33.03(12.19)**</td>
<td>78.27(28.05)**</td>
<td>47.40(8.75)**</td>
<td>79.05(35.65)**</td>
<td>159.53(27.24)**</td>
<td>38.56(25.39)**</td>
</tr>
<tr>
<td>130° abduction with 30° horizontal adduction</td>
<td>ED60</td>
<td>39.90(10.09)**</td>
<td>70.31(19.46)**</td>
<td>59.20(13.97)**</td>
<td>65.43(22.89)**</td>
<td>130.23(34.78)**</td>
<td>49.23(25.34)**</td>
</tr>
<tr>
<td></td>
<td>ED180</td>
<td>41.72(12.59)**</td>
<td>87.20(80.64)**</td>
<td>47.84(8.40)**</td>
<td>105.59(47.23)**</td>
<td>139.93(37.43)**</td>
<td>53.00(27.86)**</td>
</tr>
<tr>
<td>145° abduction with 30° horizontal adduction</td>
<td>ED60</td>
<td>55.37(20.32)**</td>
<td>88.89(34.40)**</td>
<td>73.42(34.66)**</td>
<td>113.40(65.12)**</td>
<td>167.06(57.27)**</td>
<td>51.15(24.65)**</td>
</tr>
<tr>
<td></td>
<td>ED180</td>
<td>46.85(11.35)**</td>
<td>77.23(30.68)**</td>
<td>65.42(33.40)**</td>
<td>108.23(69.97)**</td>
<td>124.09(33.60)**</td>
<td>37.97(24.36)**</td>
</tr>
</tbody>
</table>

Movement: ED, eccentric muscle action with shoulder diagonal movement
Activity level: +, minimal; ++, moderate; ++++, high; +++, very high
ANOVA revealed significant differences between different task and angular velocity for MT muscle activity ($F = 3.66, P < 0.05$). Post-hoc testing revealed significant differences between 30 and 70EA at $60^\circ$/sec. 30EA60 displayed greater muscle activity than 30EA180. Two-way ANOVA revealed significant differences between different task and angular velocity for BB muscle activity ($F = 6.20, P < 0.05$). Post-hoc testing revealed significant differences between 30 and 50 and 70EA at $180^\circ$/sec.

C. Eccentric muscle action with diagonal movement

Two-way ANOVA revealed significant differences between different task and angular velocity for UT muscle activity ($F = 4.10, P < 0.05$). Post-hoc testing revealed significant differences between 145 and 115 and 130ED at $60^\circ$/sec. 130E60 displayed smaller muscle activity than 130EA180.

D. Torque

Mean peak torque during different tasks is presented in Table 3. Peak torque during each test showed a range of 43-52 and 49-55Nm at 60 and $180^\circ$/sec, respectively (Table 3). One-way ANOVA revealed significant differences between each test at 60 ($F = 7.97, P < 0.001$), and $180^\circ$/sec ($F = 5.84, P < 0.001$). Peak torque elicited greater activity during 145ED60 than all EA60s. 30EA60 showed significant differences between all ED60s. Peak torque elicited greater activity during 145ED180 than all EA180s. 130ED180 showed significant differences between 30EA180.

IV. Discussion

The present study was designed to quantify the EMG activity level of shoulder muscle during maximum-effort eccentric muscle action in various shoulder position. Our study was chosen for establishment of the hypotheses for present study, based on 60 and $180^\circ$/s may have been more appropriate to eccentric contraction by consideration of safety\textsuperscript{20}. Our goal was to specifically describe which eccentric muscle actions for upper extremity muscle complex are to affect training of the shoulder, and are thus believed to be important during the deceleration phase for the throw.

A. EMG analysis

Muscle activity pattern of present study was characterized by maximal value of muscle contraction on various shoulder positions. Jobe et al.\textsuperscript{16} described that the anterior, middle, and posterior deltoid as all displaying similar patterns with peak activity in the

<table>
<thead>
<tr>
<th>Task</th>
<th>$60^\circ$/s (standard deviation)</th>
<th>$180^\circ$/s (standard deviation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30° horizontal adduction with abduction 130°</td>
<td>43.44(12.81)$^a$</td>
<td>49.21(12.75)$^a$</td>
</tr>
<tr>
<td>50° horizontal adduction with abduction 130°</td>
<td>46.51(12.57)$^a$</td>
<td>50.11(14.45)</td>
</tr>
<tr>
<td>70° horizontal adduction with abduction 130°</td>
<td>47.24(12.19)$^a$</td>
<td>50.60(14.57)</td>
</tr>
<tr>
<td>115° abduction with 30° horizontal adduction</td>
<td>49.99(12.38)$^a$</td>
<td>51.56(11.21)</td>
</tr>
<tr>
<td>130° abduction with 30° horizontal adduction</td>
<td>50.62(12.37)$^a$</td>
<td>53.73(12.82)$^a$</td>
</tr>
<tr>
<td>145° abduction with 30° horizontal adduction</td>
<td>52.21(11.84)$^a$</td>
<td>55.37(13.57)</td>
</tr>
</tbody>
</table>

\textsuperscript{a} significant difference between 145ED and all EA tasks ($P < 0.05$); \textsuperscript{b} significant difference between 30EA and all ED tasks ($P < 0.05$); \textsuperscript{c} significant difference between 30EA and 130ED at $180^\circ$/s ($P < 0.05$)
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early cocking and follow-through stages. However, Myers et al.\textsuperscript{8} showed that AD muscle resulted in at least moderate activation (29\%MVIC) during a diagonal movement pattern similar to the deceleration phase of throwing using the tubing, connected to a standard baseball that rotates around a fixed axis of rotation. These results support the findings of Illyes et al.\textsuperscript{29} that while AD muscle elicited greatest %MVIC in javelin throwers during elevation exercise and during maximum speed for overhead throw.

In the present study, AD muscle elicited greater %MVIC during eccentric muscle action with shoulder adduction than eccentric muscle action with diagonal movement. Furthermore, while the other posterior upper extremity muscles showed large differences to MT muscle during eccentric muscle action with shoulder adduction, AD muscle showed large difference to MT muscle during eccentric muscle action with diagonal shoulder movement. In other words, these results demonstrate that eccentric muscle action with shoulder adduction may strain AD muscle as an upper extremity muscles. Although the results of this study could not prove the availability of AD muscle, we postulate that these results are explained to differing AD muscle activity due to various positions.

Ekstrom et al.\textsuperscript{26} demonstrated that the highest mean levels of EMG activity were generated in MT muscle with resistance applied when the shoulder was horizontally abducted with external rotation (94\%MVIC) and with the arm raised overhead in line with the lower trapezius muscle fibers (87\%MVIC). Anders et al.\textsuperscript{28} demonstrated that upper extremity muscles exhibited excessive activity during horizontal abduction exercises for isometric contraction, mainly assigned to stabilizing function rather than mobilizing the arm.

The present study provides evidence that the posterior parts of upper extremity muscle complex generate overall high muscle activity (> 40\%MVIC) during all testing for eccentric muscle action with diagonal shoulder movement. PD, UT and MT muscles showed significant differences within various positions and speeds during eccentric muscle action with shoulder adduction and diagonal movement. These findings support previous studies\textsuperscript{16,17,29}, in that shoulder muscle (posterior upper extremity muscle) activity has to be elicited to ensure proper stability of the shoulder joint as forces generated during follow-through. In these studies, we supported the hypothesis that the posterior parts of shoulder muscle elicit greater muscle activity during eccentric muscle action with diagonal shoulder movement, and show greater significant differences due to changing for various positions and speeds.

Jobe et al.\textsuperscript{17} demonstrated that the follow-through phase also involves an active event with the shoulder moving across the body and the elbow into extension with forearm pronation, and showed that while BB muscle elicits lower muscle activity than other upper extremity muscles during the acceleration phase, higher muscle activity is elicited in the follow-through phase for throwing than in the acceleration phase. However, a previous study\textsuperscript{6} found that BB muscle elicits lower than moderate activation during throwing deceleration exercises for throwers. BB muscle in the present study showed large difference across posterior upper extremity muscles during eccentric muscle action with diagonal shoulder movement. These results demonstrated that BB muscle motor control correlates with various training as eccentric muscle action with shoulder adduction movement.

B. Torque

Previous studies\textsuperscript{20} demonstrated deceleration pattern, offering numerous implications regarding shoulder injuries, including preventive strengthening and evaluation.

The present study showed that peak torque is generated during eccentric muscle activity with diagonal shoulder movement rather than eccentric muscle action with shoulder adduction. These findings correlated with the results\textsuperscript{20} that the thrower produced greater force during eccentric muscle action of shoulder in the deceleration phase for throw-
ing, and indicated that the eccentric muscle action with diagonal shoulder movement is more important for shoulder strengthening.

V. Conclusion

The present study provides evidence that posterior parts of the upper extremity muscle complex elicit overall muscle activity during eccentric muscle action with diagonal shoulder movement, and show greater significant differences due to changing for various positions and speeds. Furthermore, the present results only suggest that there are muscle-specific motor controls during maximal eccentric muscle action with various positions, shoulder adduction and diagonal movement.

Although these results can be used to substantiate some effective deceleration activation of shoulder muscles is important for throwing motion, we must note that greater strain on specific muscles is elicited by greater muscle activity on the changes for various positions and speeds. The present results show that an improved understanding of muscle activity patterns during different movement may benefit many fields of athletic trainers, coaches, and athletes, in addition to assisting in injury prevention for throwers, and even rehabilitation after injury.

VI. Acknowledgments

We wish to thank the Sport and Performance Clinic Lab (SPEC) for support of this study. We are also grateful to the Sports Medicine Lab researchers for their invaluable assistance.

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VII. References


