Jpn. J. Phys. Fitness Sports Med. 2009, **58** : 143～154

UPPER EXTREMITY MUSCLE ACTIVITIES AND STRENGTHS IN OVERHEAD THROWER DURING ECCENTRIC MUSCLE ACTION

SIYOUNG PARK[1)], SHUMPEI MIYAKAWA[2)], HITOSHI SHIRAKI[2)], NAOKI MUKAI[2)] and HYUNMIN CHOI[3)]

Abstract

PURPOSE : To determine the patterns of electromyographic (EMG) responses and torques of upper extremity muscles in overhead throwers during maximal, eccentric muscle action for shoulder flexion ($Flex_{Ecc}$), abduction (Abd_{Ecc}) and diagonal activities (Dia_{Ecc}) with full glenohumeral internal rotation, at 60, 120, and 180°/s on the dynamometer.

METHODS : Seven asymptomatic subjects (7 men, 4 women) who participate in overhead sports at least three days a week volunteered to participate in this study. Subjects were randomly performed with the test procedure which consisted of at least 5 grade maximal-effort repetitions on the three different testing conditions, at 60, 120, and 180°/s on the dynamometer, while we assessed muscle activation of the anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and biceps brachii (BB) muscles by surface electromyography. EMG data was expressed as a percentage of maximum voluntary isometric contraction (%MVIC) that was obtained from the highest root mean square (RMS, 50 ms) of each muscle and was normalized and averaged.

RESULT : AD muscle elicited lower muscle activity during Dia_{Ecc} than $Flex_{Ecc}$ and Abd_{Ecc} ($P<0.05$) while the MD, PD, UT, MT, and LT muscles elicited overall greater muscle activities during Dia_{Ecc}. MD and MT muscle activities were significantly greater for the faster speed than for the slower speed as 60°/s during Abd_{Ecc} ($P<0.05$). Peak torque generated greater muscle strength for Dia_{Ecc} than $Flex_{Ecc}$ and Abd_{Ecc}, and it was significantly greater for the faster speed than slower speed during Dia_{Ecc} ($P<0.05$).

CONCLUSION : Posterior upper extremity muscle activities and peak torque values were found to be dependent on eccentric muscle action for diagonal shoulder activity at the faster speed. This study provided evidence that isokinetic eccentric muscle strength testing of the posterior upper extremity muscle was effective to develop of a proper program for overhead sports athletes require forceful stability during deceleration phase.

(Jpn. J. Phys. Fitness Sports Med. 2009, **58** : 143～154)

key word : electromyography, diagonal activity, peak torque

I. Introduction

Injuries to the shoulder joint and muscles are common in overhead sports that require overhand arm motions[1)]. The dynamic action in overhead sports generates a forceful activity of eccentric load on posterior upper extremity muscles located from scapula and may lose the ability to maintain balanced relation with posterior rotator cuff muscles namely agonists, such as a decelerator from forceful repetitive movement[2)]. Previous studies agree that many of the throwing injuries occur during the follow-through phase in which muscles of the shoulder are contracting eccentrically to decelerate the limb after the ball has been released[3,4)]. Furthermore, Fleisig et al.[5)] noted that the shoulder joint to generate forceful activity for horizontal adduction, internal rotation, and superior translation

[1)] 筑波大学大学院人間総合科学研究科スポーツ医学専攻 〒305-8574 茨城県つくば市天王台1-1-1
Doctoral Program in Sports Medicine, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8574, JAPAN

[2)] 筑波大学大学院人間総合科学研究科 〒305-8574 茨城県つくば市天王台1-1-1
Graduate School of Comprehensive Human Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8577, JAPAN

[3)] 韓国　慶熙大学校　スポーツ医学専攻 〒446-701 韓国　京畿道龍仁市器興區書川洞1
Department of Sports Medicine, Kyung Hee University, 1 Seocheon, Ghieung, Yongin, Gyeonggi 446-701, KOREA

of the abducted humerus may cause compulsory subacromial impingement after ball release.

Although, in overhead sports, rotator cuff muscles with the flexion, abduction and external rotation movements of the shoulder joint during the wind-up and cocking phases are required dynamic mobilization to maintain humeral head congruency[5~7], posterior upper extremity muscles which require repetitive bouts of high-velocity arm movement have not only to decelerate the arm, but also to mobilize dynamic stabilization of the shoulder joint during a sudden change as deceleration phase[4,8,9]. Previous studies noted that the shoulder joint continued internal rotation and horizontal adduction during follow-through phases in throwing while the deltoid, trapezius and biceps brachii muscles act eccentrically to decelerate the arm[6,8].

Consequently, many authors[10~17] have advocated emphasis on coordination of shoulder muscle during rehabilitation or athletic conditioning programs to enhance muscular strength and endurance in overhead athletes by using electromyography (EMG) to obtain sufficient data. Cools et al.[16] demonstrated the stabilizing role of upper extremity muscles by using muscle latency times for the temporal recruitment pattern. Anders et al.[17] reported activation characteristics of shoulder muscles during isometric exercises at four different angular positions in frontal, sagittal, and horizontal planes. Furthermore, a number of studies have estimated the relationship between EMG and isokinetic muscle strength tests to analyze the function of shoulder muscles[18~20].

Isokinetic muscle strength testing has been used by researchers to assess concentric and eccentric peak torque as to the injury ratio of shoulder muscles in overhead athletes[9,21~25]. Furthermore, Milesky et al.[23] suggested that eccentric strength required for posterior upper extremity muscles during the follow-through phase might be the most critical to injury. Accurate muscular activity like this would have provided the efficient information to athletic trainers, coaches, and athletes, in addition to providing a valid approach to assist in rehabilitation after injury and injury prevention for throwers. In the overhead athlete, an accurate data of eccentric antagonist muscle strength is critical for dynamic stability and optimal function. Park et al.[20] demonstrated the role of eccentric upper extremity muscle action throughout maximal eccentric muscle action for shoulder joint activity with various positions and two speeds in neutral rotation of glenohumeral.

Although several studies have investigated the muscle strength of the shoulder and arm muscles in overhead throwers as to analyze eccentric muscle strength of the shoulder muscle in an abduction and diagonal patterns[20,22,26,27], investigations in this area have lacked statistical analysis among eccentric shoulder muscle action with various shoulder position and velocities, such as the flexion, abduction and diagonal patterns with particularly glenohumeral internal rotation. Therefore, our study would have selected testing in various shoulder position and velocities for choosing appropriate rehabilitation or athletic conditioning programs, as emphasis on coordination of shoulder muscle. These results may be contribute to athletes engaged in sports like overhead throwing, as an efficient data of the muscle strength and activity for posterior upper extremity muscles during eccentric muscle strength testing.

The purpose of this study was to examine the pattern of EMG responses and torque during maximal, eccentric muscle action for shoulder flexion, abduction and diagonal activities with full glenohumeral internal rotation, at 60, 120, and 180°/s on the dynamometer. In this paper, we hypothesized the following : 1) upper extremity muscles will show different muscle activity patterns for eccentric muscle action ; 2) EMG values will change due to different position and velocities ; 3) peak torques will show different patterns due to specific position and velocities.

II. Methods

A. Subjects

Seven men (mean age, 24.6 ± 1.8 years ; mean height, 177.1 ± 2.2 cm ; mean body mass, 70.6 ± 4.4 kg) and four women (mean age, 21.3 ± 0.8 years ;

TABLE 1. Characteristics of subjects.

Height (cm)	Weight (kg)	Age (years)	Field	Experience (years)	Dominant shoulder	Sex
178.2	75.5	23	Javelin throw	7	Right	Male
175.1	75.5	27	Javelin throw	10	Right	Male
174	68.2	22	Javelin throw	6	Right	Male
179.7	74.1	26	Handball	10	Right	Male
175	71.2	25	Handball	9	Right	Male
178.2	65.5	23	Volleyball	8	Right	Male
179.7	64.1	26	Volleyball	11	Right	Male
158	56	22	Handball	7	Right	Female
158.2	52.4	21	Handball	9	Right	Female
162.4	55	22	Javelin throw	6	Right	Female
163.1	54.5	20	Javelin throw	6	Right	Female

mean height, 160.4±2.3 cm ; mean body mass, 54.5 ± 1.3 kg) subjects who participate in overhead sports at least three days a week volunteered to participate in this study (Table 1). All subjects were tested to a dominant arm being defined as the arm used to throw or spike. Subjects gave informed consent prior to participating in the study. The study protocol was approved by the Human Research Ethics Committee of the University of Tsukuba.

All subjects were asymptomatic and free from musculoskeletal shoulder injuries at the time of testing. None of the subjects included had shoulder pain, discomfort, or any prior shoulder surgery.

B. Isokinetic testing

Isokinetic eccentric measures on the shoulder joint were performed on a System 3 isokinetic device (Biodex, New York, USA) with the upper body exercise and testing table. Prior to isokinetic testing, each subject underwent warm-up using an upper-body ergometer for approximately 5-min after stretching the major shoulder muscle groups. After a brief explanation of the testing procedures, subjects performed practice sessions for 3 submaximal trials to familiarize themselves with eccentric muscle action at a velocity of 60, 120, and 180°/s, respectively. Passive shoulder movement occurred after each eccentric muscle action at a speed of 30°/s. During testing, subjects were seated on System 3 device with 90° hip flexion, and restraining straps were placed across the waist and chest in addition to a rigid sternal stabilizer. Subject was allowed a 2-minute rest period between exercises to control for any fatigue effect, and were asked to exert themselves to the fullest extent possible.

Isokinetic eccentric muscle action for shoulder flexion activity ($Flex_{Ecc}$) was performed eccentrically at 130° of shoulder flexion and 70° of horizontal adduction with full glenohumeral internal rotation, and the ending position was placed at 30° of shoulder flexion (Fig. 1). Isokinetic eccentric muscle ac-

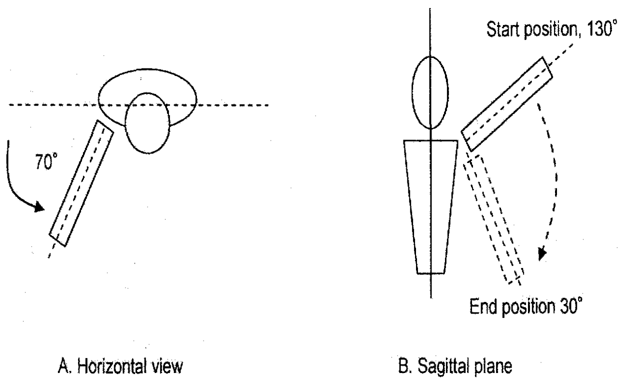

FIGURE 1. Eccentric muscle action with shoulder flexion activity ($Flex_{Ecc}$). A. Horizontal plan, starting position with full glenohumeral internal rotation in 70° of horizontal adduction ; B. Sagittal plan, starting position at 130° of shoulder flexion. Data were collected for specific muscle during eccentric muscle action at a velocity of 60, 120, and 180°/s, respectively.

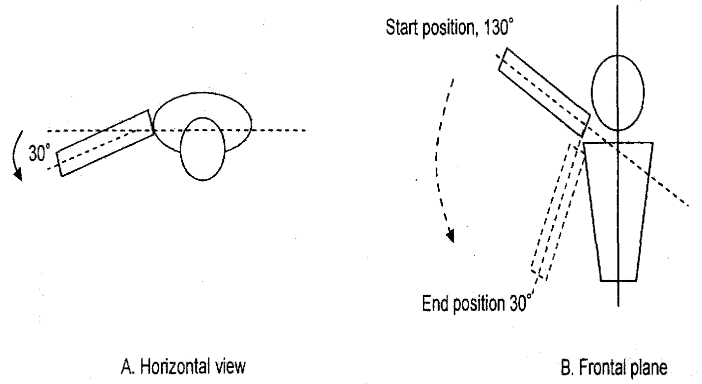

FIGURE 2. Eccentric muscle action with shoulder abduction activity (Abd_{Ecc}). A. Horizontal plan, starting position with full glenohumeral internal rotation in 30° of horizontal adduction ; B. Frontal plan, starting position at 130° of shoulder abduction. Data were collected for specific muscle during eccentric muscle action at a velocity of 60, 120, and 180°/s, respectively.

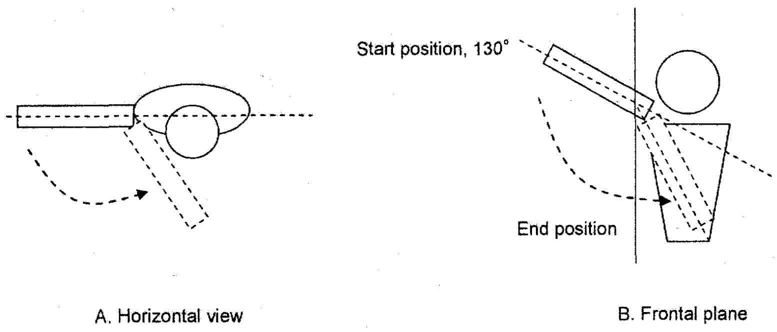

FIGURE 3. Eccentric muscle action with diagonal shoulder activity (flexion/abduction/external rotation, Dia_{Ecc}). A. Horizontal view, starting position in 0° of horizontal adduction ; B. Frontal plan, 130° of shoulder abduction (with a light elbow flexion) in a total range of motion of 100° with full glenohumeral internal rotation. Data were collected for specific muscle during eccentric muscle action at 60, 120, and 180°/s.

tion for shoulder abduction activity (Abd_{Ecc}) was performed eccentrically in a range from 130° to 30° of shoulder abduction and 30° of horizontal adduction (scapula plane) with full glenohumeral internal rotation (Fig. 2). Isokinetic eccentric muscle action for diagonal shoulder activity (flexion/abduction/external rotation, Dia_{Ecc}) were performed from 130° of shoulder abduction (with a light elbow flexion) in a total range of motion of 100° with full glenohumeral internal rotation (Fig. 3). Subjects were familiarized with the test procedure which consisted of at least 5 grade maximal-effort repetitions at each of the three different testing conditions : 1) $Flex_{Ecc}$, 2) Abd_{Ecc}, and 3) Dia_{Ecc} at a velocity of 60, 120, and 180°/s, with the order randomly selected for accuracy of data.

Each eccentric muscle action was followed by a passive shoulder movement. During the isokinetic test, the peak torque (in Nm) for each condition was obtained from the dynamometer's dedicated software. The average peak torque of the five maximal repeated contractions in each testing condition was calculated and used for computing the dynamic muscle activity namely the eccentric strength of the flexion, abduction, and diagonal at each angular velocity.

C. EMG procedures

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[15,19,28]. The positions for MVIC performance were chosen based on standard muscle strength testing positions[29]. EMG activity at the sector of motion containing the peak torque was simultaneously determined visually and identified using cursors.

EMG activity was recorded individually from the anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and biceps brachii (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. LT muscle electrode was placed at 2/3 on the line from the trigonum spinea to the 8^{th} thoracic vertebra. The BB muscle electrode was placed on a line between the medial acromion at 1/3 at the distance from the cubital fossa[30,31]. A reference electrode was placed over the seventh cervical spine process.

D. Signal processing

Electrodes were connected to a WEB-5000 8-channel frequency-modulation transmitter (Nihon Kohden, Tokyo, JAPAN). 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 $< 0.2\ \mu V$ (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 3 device and Biopac system were connected to accurately determine range of motion simultaneous with EMG. 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. All data were stored on a personal computer and Acknowledge 3.7.3 software (BIOPAC System) was used for data processing and analysis. Sampling rate was set at 1000 Hz per channel. The EMG signal was band-pass filtered at 10～500 Hz. EMG data was recorded individually from each muscle, and peak torque values were extracted for each test from torque curves once.

Root mean square (RMS) values were calculated for consecutive segments of 50 ms[15,16,32]. In order to allow comparison of the activity in subject's different muscles and the activity in specific muscles among different individual RMS data were normalized to the highest recorded value, and were expressed as a percentage of maximum voluntary contraction (%MVIC) produced by the muscle activity, and the mean and standard deviation of %MVIC were determined for each muscle during the different tasks.

E. Data analysis

To determine differences for normalized value between different tasks within each testing speed, one-way repeated-measure analysis of variance (one-way ANOVA) was used, and to test the relationship between different speeds within each task selected for eccentric muscle action. An α level of 0.05 with a confidence interval of 95% was used in determining significant differences ($P < 0.05$). Post hoc analyses were performed using a Bonferroni procedure when significant differences were found with analysis of variance. Bonferroni corrections were applied to t test to maintain type I error rate at $<5\%$ ($P<0.05$). Threshold for significance was set at $P < 0.017$ for post hoc testing. All statistical analyses were performed using the statistical package for the social sciences, version 11.0 (SPSS, Chicago, Illinois, USA).

Ⅲ. Result

Mean and standard deviations of EMG activity for each muscle during eccentric muscle action with shoulder flexion, abduction, and diagonal activity were displayed in Table 2.

A. Specific muscle activity by different speeds

EMG activity for specific muscle during the $Flex_{Ecc}$ and Dia_{Ecc} was not statistically significant between different speeds, but for the MD, MT, and BB muscles, EMG activities during the Abd_{Ecc} were statistically significant between different speeds (MD, $F=8.24$, $P<0.05$; MT, $F=5.96$, $P<0.05$; BB, $F=13.82$, $P<0.001$). Post hoc analyses for the MD, and MT muscles data revealed that muscle activities were significantly greater for the 180°/s than for 120°/s (both, $P<0.05$), but BB muscle activity was significantly greater for the 60°/s than for 120°/s and 180°/s ($P<0.001$, and $P<0.05$, respec-

TABLE 2. Means (standard deviation) expressed of as %MVIC for electromyography activity of eccentric muscle action with various shoulder tasks.

Task	Speeds (°/s)	Anterior Deltoid	Middle Detoid	Posterior Deltoid	Upper Trapezius	Middle Trapezius	Lower Trapezius	Biceps Brachii
	60	88.5(22.9)	59.4(13.7)	51.7(15.6)	60.2(15.5)	130.5(41.2)	42.9(6.2)	34.3(15.8)
$Flex_{Ecc}$	120	85.9(28.1)	82.5(27.0)	57.0(26.7)	105.8(65.8)	106.3(46.0)	69.4(33.6)	35.7(15.0)
	180	73.0(16.2)	76.5(24.8)	75.7(34.0)	100.1(42.6)	93.1(33.8)	58.9(37.0)	45.3(15.0)
	60	64.3(11.0)	97.1(32.9)[a]	43.5(17.3)	107.5(47.9)	67.1(23.8)[a]	36.1(11.0)	37.3(10.8)[a,b]
Abd_{Ecc}	120	79.7(17.4)	112.9(31.7)	35.4(8.7)	122.1(60.3)	78.8(18.8)	56.6(23.5)	22.3(6.6)[a]
	180	75.0(16.9)	143.7(34.3)[a]	45.9(5.3)	102.4(32.4)	98.7(22.1)[a]	56.2(22.0)	25.4(10.1)[b]
	60	52.0(22.9)	99.7(16.2)	98.6(23.7)	130.6(63.0)	181.8(63.5)	52.2(18.1)	46.7(27.1)
Dia_{Ecc}	120	73.1(35.7)	103.3(26.8)	84.9(22.4)	125.5(74.5)	150.8(47.8)	65.5(21.8)	22.8(11.4)
	180	47.7(17.1)	94.1(30.3)	83.0(27.0)	142.6(43.4)	123.3(47.4)	44.0(20.1)	33.4(19.7)

Task : Flex, Flexion ; Adb, Abduction ; Dia, Diagonal ; Ecc, Eccentric ;
[a,b]$P<0.05$, significant difference between different speeds within task for each muscle activity (*by* Bonferroni post-hoc analysis).

tively).

B. Muscle activity by individual task

AD muscle activity was statistically significant between different tasks at 60°/s and 180°/s ($F=11.98$, $P<0.001$, and $F=8.37$, $P<0.05$, respectively). Post hoc analyses for AD muscle data revealed that in the 60°/s, the muscle activity was significantly greater for the $Flex_{Ecc}$ than for Abd_{Ecc} and Dia_{Ecc} ($P<0.05$, and $P<0.001$, respectively), and in the 180°/s, the muscle activity was significantly greater for the $Flex_{Ecc}$ and Abd_{Ecc} than for Dia_{Ecc} (both, $P<0.05$) (Fig. 4).

MD muscle activity was statistically significant between different tasks at 60°/s and 180°/s ($F=1.11$, $P<0.05$, and $F=17.69$, $P<0.001$, respectively). Post hoc analyses for MD muscle data revealed that in the 60°/s, the muscle activity was significantly greater for the Abd_{Ecc} and Dia_{Ecc} than for $Flex_{Ecc}$ (both, $P<0.05$), and in the 180°/s, the muscle activity was significantly greater for the Abd_{Ecc} than for $Flex_{Ecc}$ and Dia_{Ecc} ($P<0.001$, and $P<0.05$, respectively) (Fig. 5).

PD muscle activity was statistically significant between different tasks at 60°/s and 120°/s ($F=26.64$, $P<0.001$, and $F=16.00$, $P<0.001$, respectively). Post hoc analyses for PD muscle data revealed that in the 60°/s, the muscle activity was significantly greater for the Dia_{Ecc} than for $Flex_{Ecc}$ and Abd_{Ecc} (both, $P<0.001$), and in the 120°/s, the muscle activity was significantly greater for the Dia_{Ecc} than for $Flex_{Ecc}$ and Abd_{Ecc} ($P<0.05$, and $P<0.001$, respectively) (Fig. 6).

UT muscle activity was statistically significant

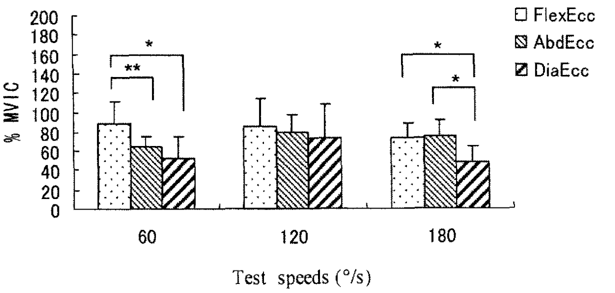

FIGURE 4. EMG activity of anterior deltoid muscle during eccentric muscle action with various shoulder activities at 60, 120, and 180°/s. $^{*}P<0.05$, $^{**}P<0.001$, significant differences by Bonferroni post hoc analysis.

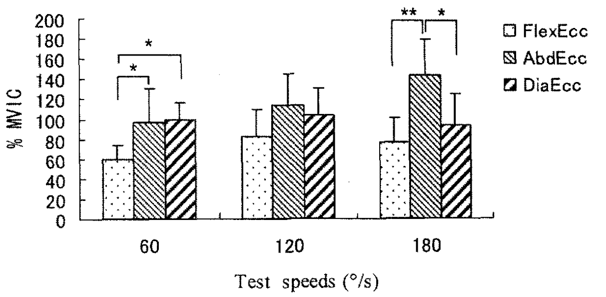

FIGURE 5. EMG activity of middle deltoid muscle during eccentric muscle action with various shoulder activities at 60, 120, and 180°/s. $^{*}P<0.05$, $^{**}P<0.001$, significant differences by Bonferroni post hoc analysis.

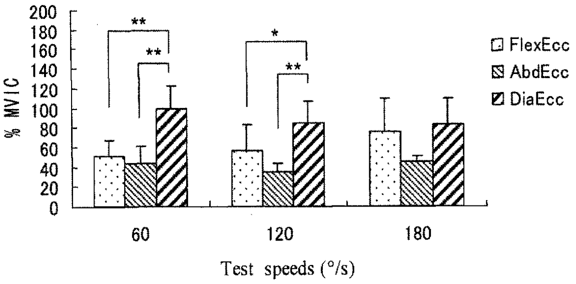

FIGURE 6. EMG activity of posterior deltoid muscle during eccentric muscle action with various shoulder activities at 60, 120, and 180°/s. $^{*}P<0.05$, $^{**}P<0.001$, significant differences by Bonferroni post hoc analysis.

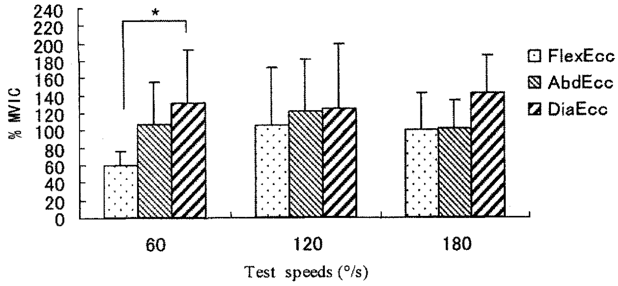

FIGURE 7. EMG activity of upper trapezius muscle during eccentric muscle action with various shoulder activities at 60, 120, and 180°/s. $^{*}P<0.05$, significant differences by Bonferroni post hoc analysis.

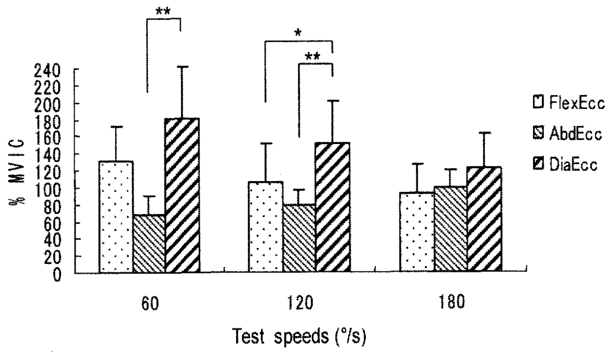

FIGURE 8. EMG activity of middle trapezius muscle during eccentric muscle action with various shoulder activities at 60, 120, and 180°/s. $^{*}P<0.05$, $^{**}P<0.001$, significant differences by Bonferroni post hoc analysis.

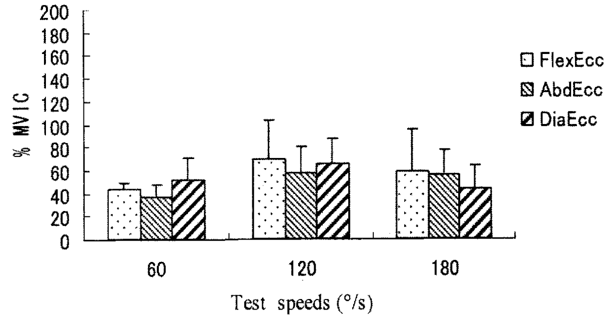

FIGURE 9. EMG activity of lower trapezius muscle during eccentric muscle action with various shoulder activities at 60, 120, and 180°/s.

between different tasks at 60°/s ($F=5.34$, $P<0.05$). Post hoc analysis for UT muscle data revealed that the muscle activity was significantly greater for the Dia_{Ecc} than for $Flex_{Ecc}$ ($P<0.05$) (Fig. 7).

MT muscle activity was statistically significant between different tasks at 60°/s and 120°/s ($F=13.38$, $P<0.001$, and $F=12.91$, $P<0.001$, respectively). Post hoc analyses for MT muscle data revealed that in the 60°/s, the muscle activity was significantly greater for the Dia_{Ecc} than for Abd_{Ecc} ($P<0.001$), and in the 120°/s, the muscle activity was significantly greater for the Dia_{Ecc} than for $Flex_{Ecc}$ and Abd_{Ecc} ($P<0.05$, and $P<0.001$, respectively) (Fig. 8).

LT muscle activity among 3 speeds was not statistically significant between different tasks (Fig. 9).

BB muscle activity was statistically significant between different tasks at 120°/s ($F=6.41$, $P<0.05$). Post hoc analysis for BB muscle data revealed that the muscle activity was significantly greater for the

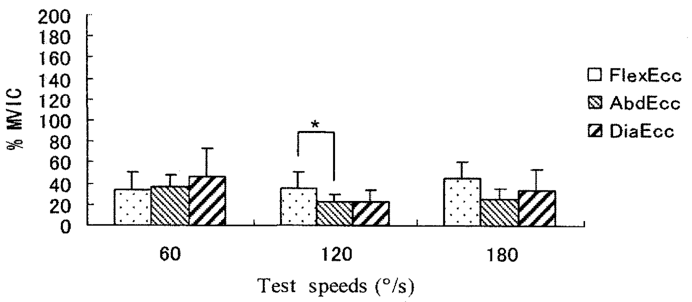

FIGURE 10. EMG activity of biceps brachii muscle during eccentric muscle action with various shoulder activities at 60, 120, and 180°/s. $^{*}P<0.05$, significant differences by Bonferroni post hoc analysis.

$Flex_{Ecc}$ than for Abd_{Ecc} ($P<0.05$) (Fig. 10).

C. Muscle strength by different speeds

Peak torque value for muscle strength during the $Flex_{Ecc}$ and Abd_{Ecc} was not statistically significant between different speeds, but for muscle strength, peak torque value during the Dia_{Ecc} was statistically significant between different speeds ($F=6.25$, $P<0.05$). Post hoc analysis of the muscle strength data revealed that peak torque value was statistically greater for the 180°/s than for 120°/s ($P<0.05$) (Table 3).

D. Muscle strength by individual task

Peak torque value was statistically significant between different tasks at 60°/s, 120°/s, and 180°/s ($F=16.79$, $P<0.001$, $F=13.26$, $P<0.001$, and $F=20.51$, $P<0.001$, respectively). Post hoc analyses for peak torque data revealed that the muscle strength was significantly greater for the $Flex_{Ecc}$ and Dia_{Ecc} than for Abd_{Ecc} in the 60°/s ($P<0.05$, and $P<0.001$, respectively) and 120°/s ($P<0.001$, and $P<0.05$, respectively), and in the 180°/s, the muscle strength was significantly greater for the Dia_{Ecc} than for $Flex_{Ecc}$ and Abd_{Ecc} ($P<0.05$, and $P<0.001$, respectively), for the $Flex_{Ecc}$ than for Abd_{Ecc} ($P<0.05$) (Fig. 11).

TABLE 3. Peak torque value during eccentric muscle action with various shoulder tasks.

Speeds (° /s)	$Flex_{Ecc}$	Abd_{Ecc}	Dia_{Ecc}
60	52.3(8.2)	47.8(10.4)	54.9(10.4)
120	52.5(13.2)	45.4(11.8)	50.1(12.1)[a]
180	51.5(11.5)	46.7(15.1)	60.4(17.6)[a]

[a]$P<0.05$, significant difference between different speeds within each task (*by* Bonferroni post-hoc analysis).

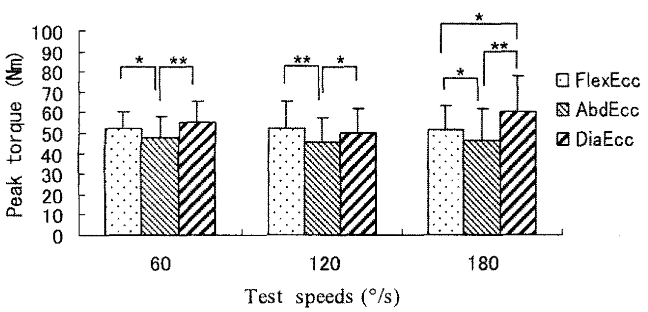

FIGURE 11. Peak torque values of muscle strength during eccentric muscle action with various shoulder activities at 60, 120, and 180°/s. $^{*}P<0.05$, $^{**}P<0.001$, significant differences by Bonferroni post hoc analysis.

Ⅳ. Discussion

Eccentric muscle action for overhead thrower is crucially act that uses upper extremity muscles of shoulder joint during the deceleration phase of the throw. Our study was to specifically describe whether EMG activity of upper extremity muscles were affected with the various testing velocities among the maximum-effort eccentric muscle actions in three different shoulder positions with glenohumeral internal rotation, including a functional pattern performing in the rehabilitation or training of shoulder. The results of the present study indicate that upper extremity muscle strength is differently generated to decelerate the arm during eccentric muscle action with various position and velocities. The goal of our study was to examine how specific muscles are being activated among eccentric muscle action in isokinetic device, and which tasks are most effective in facilitating activation to depend on the quality of upper extremity muscles believed to be important among the deceleration phase for throwers.

A. Muscle activities for various speeds and positions

Our study for accurate data, normalization of the EMG variable with respect to a reference value obtained in the individual shoulder muscle which estimated the manual muscle testing, and processing data, used the %MVIC of each muscle to compare various muscle activities of different subjects during several activities. Our results for the EMG variable indicate that the RMS is for normalization of muscle voluntary contraction data for dynamic muscle activity such as to provide a better understanding of specific muscle firing patterns. Results of data processing for the RMS in the present study have resembled patterns from previous studies by Myers et al.[15] and Illyes et al.[32].

Jobe et al.[6] described that three part of deltoid muscle (anterior, middle, and posterior) displayed similar patterns with peak activity in the early cocking and follow-through stages. Illyes et al.[32] reported that both of the anterior and middle deltoid muscles elicited maximal muscle activity by the javelin thrower group during fast overhead throw and elevation movement. Myers et al.[15] showed that the anterior deltoid muscle resulted in at least moderate activation (29%MVIC) during a diagonal activity pattern believed to be important to the deceleration phase of throwing using the tubing, while other posterior upper extremity muscles elicited greater muscle activities by then. Although, their studies revealed each other result, these indicate that three part of deltoid muscle activity plays a significant role as forces generated during fast speed motion, as to overhead throw for a muscle activation with shoulder flexion/abduction/external rotation.

In the present study, the anterior deltoid muscle activity was not statistically significant between different speeds for each eccentric muscle action with full glenohumeral internal rotation on isokinetic device. However, the anterior deltoid muscle activity was statistically significant between different positions within each speed. Despite the various speeds, the anterior deltoid muscle activity showed overall greater muscle activity for shoulder flexion than for abduction and diagonal activity. These results indicate that coordination in the anterior deltoid muscle contraction plays a significant role in overhead athletes during eccentric muscle action for shoulder flexion than abduction and diagonal activity at full glenohumeral internal rotation.

Ekstrom et al.[28] examined the evidence that the highest mean levels of EMG activity were generated in middle trapezius muscle fivers with resistance applied while 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). In the present study, the middle trapezius muscle was overall greater muscle activity for shoulder diagonal activity than for flexion and abduction activity, while middle deltoid muscle activity was overall greater muscle activity for shoulder abduction than for flexion and diagonal activity. However, two studies are what they tested in different speeds each other.

In the present study, the middle deltoid and trapezius, and biceps brachii muscle activities was statistically significant between different speeds during eccentric muscle action for shoulder abduction activity. However, both of the middle deltoid and trapezius muscle activities were significantly greater for the faster speed than for the slower speed, while the biceps brachii muscle activity was significantly greater for the slower speed than for the faster speed. On the basis of the results, the middle deltoid and trapezius muscles could be determined the peak muscle activity is significantly greater during the faster speed as above 180°/s.

Illyes et al.[32] reported that in the javelin throw group the posterior deltoid muscle elicited the greatest muscle activity during fast overhead throwing, but it elicited the moderate muscle activity (40 ~74.9%MVIC) during elevation phase. Park et al.[20] reported that the posterior deltoid muscle activity during eccentric muscle action was greater muscle activity for diagonal activity than for shoulder abduction activity with various positions. In the present study, the posterior deltoid muscle activity was not statistically significant between different speeds for each eccentric muscle action with full glenohumeral internal rotation on isokinetic device. However, this muscle showed overall greater muscle activity for shoulder diagonal activity within each speed, while the anterior and middle deltoid muscles showed greater muscle activity for shoulder flexion and abduction than for diagonal activity. Furthermore, the posterior deltoid muscle in the slower speed showed the greatest muscle activity during eccentric muscle action for shoulder diagonal activity.

On the basis of above results, the posterior deltoid muscle may not to be significant role during deceleration phase like the decelerator muscles generate forceful eccentric muscle activity for shoulder stability. Because the posterior deltoid muscle has a little muscle volume and activity compared with the other decelerator muscles, it may have fatigued the other decelerator muscles to the point of not providing a significant contraction at the fast speed.

In the present study, the upper and lower trapezius muscle activities were not statistically significant between different speeds for eccentric muscle action with full glenohumeral internal rotation on isokinetic device. The lower trapezius muscle showed no significant difference at all the tasks, while the upper trapezius muscle was overall greater muscle activity during eccentric muscle action for shoulder diagonal activity. However, as is typical with EMG data, substantial inter-subject variation was seen in EMG activity of the lower trapezius muscle selected during eccentric muscle testing. Furthermore, in the slower speed the upper trapezius muscle were significantly greater for shoulder diagonal activity than for flexion and abduction activity.

Although, our results could not prove the availability of posterior upper extremity muscles, we postulate that these results are explained by differing upper extremity muscle activity due to various exercise patterns with full glenohumeral internal rotation. Therefore, the EMG results of our study suggested the muscle activity by using the full glenohumeral internal rotation exercise for greater muscle activity of posterior upper extremity muscle because it produced minimal muscle activity by using the neutral rotation exercise by previous studies[20,22,26,27].

B. Shoulder muscle strength

Page et al.[22] mentioned that below 60°/s in isokinetic muscle action is still much slower than actual angular velocity of the pitching arm, but above 180°/s is much faster than would be comfortable for subjects in the diagonal pattern. Therefore, our study was displayed angular velocities for present study, based on 60, 120, and 180°/s may have been more appropriate to eccentric contraction by consideration of safety.

Previous studies[24,26] have determined isokinetic muscle strength testing with various positions and velocities, offering numerous implications regarding shoulder injuries, including preventive strengthening and evaluation for overhead athletes. Previous studies have branched different sports athletes to evaluate isokinetic strength in throwers at different arm positions[33,34] and compare strength to pitching velocity[11]. On the basis of this definition our study could be only use for eccentric muscle action of upper extremity muscles with shoulder flexion, abduction and diagonal activity, and determined accurate muscle activities, when maximal voluntary contraction (MVC) occurred during eccentric muscle action with full glenohumeral internal rotation. The present study demonstrated that peak torque overall generated greater muscle strength during diagonal than eccentric muscle action with shoulder flexion activity. The muscle strength only generated greater muscle strength due to the fast speed at diagonal activity while unchanged by different speeds during eccentric muscle action with flexion and abduction activities. These findings have showed that eccentric muscle strength overall generated greater muscle strength by the faster speed which is similar to findings of earlier study[22].

V. Conclusion

This study provided evidence that isokinetic eccentric muscle strength testing of the posterior upper extremity muscle was effective to develop of a proper program for overhead sports athletes require forceful stability during deceleration phase. Furthermore, the present results demonstrated that posterior upper extremity muscle activities and peak torque values were found to be dependent on eccentric muscle action for diagonal shoulder activity at the faster speed. In other words, these results demonstrate that eccentric muscle action for full glenohumeral internal rotation may strain posterior upper extremity muscles by the faster speed. However, these findings can be used to substantiate some claims of strength gains by using isokinetic device for posterior upper extremity muscles adapt to the faster speeds, as the decelerator muscles generate forceful eccentric muscle activity for shoulder stability during deceleration phase. These results reveal that there are muscle-specific motor controls as well as specifically muscle strength patterns during eccentric muscle action for various positions and speeds.

Acknowledgments

This work was supported in part by the Sport and Performance Clinic Lab (SPEC) by Sports Medicine Laboratory. We are also grateful to research group for their invaluable assistance.

(Accepted Nov. 20, 2008)

References

1) Meister, K. Injuries to the shoulder in the throwing athlete. Part one : Biomechanics/pathophysiology/classification of injury. Am. J. Sports Med. (2000), **28**, 265-275.
2) Hutchinson, M. R., Laprade, R. F., Burnett, Q. M II., Moss, R., and Terpstra, J. Injury surveillance at the USTA Boys' Tennis Championships : a 6-yr study. Med. Sci. Sports Exerc. (1995), **27**, 826-830.
3) Duda, M. Prevention and treatment of throwing-arm injuries. Physician Sportmed. (1985), **13**, 181-186.
4) Matsuoka, T., Tachibana, T., Nishikawa, H., Nojima, A., and Hisamune, J. Analysis of cocking to acceleration phase during pitching [in papanese]. Clin. Sports Med. (1994), **11**, 601-606.
5) Fleisig, G. S., Andrews, J. R., Dillman, C. J., and Escamilla, R. F. Kinetics of baseball pitching with implications about injury mechanism. Am. J. Sports Med. (1995), **23**, 233-239.
6) Jobe, F. W., Tibone, J. E., Perry, J., and Moynes, D. R. An EMG analysis of the shoulder in throwing and pitching. A preliminary report. Am. J. Sports Med. (1983), **11**, 3-5.
7) Wuelker, N., Schmotzer, H., Thren, K., and Korell, M. Translation of the glenohumeral joint with stimulated active elevation. Clin. Orthop. (1994), **309**, 193-200.
8) Jobe, F. W., Moynes, D. R., Tibone, J. E., and Perry, J. An EMG analysis of the shoulder in pitching. A second report. Am. J. Sports Med. (1984), **12**, 218-220.
9) Noffal, G. J. Isokinetic eccentric-to-concentric strength ratios of the shoulder rotator muscles in throwers and nonthrowers. Am. J. Sports Med. (2003), **31**, 537-41.
10) Bradley, J. P., and Tibone, J. E. Electromyographic analysis of muscle action about the shoulder. Clin. Sports Med. (1991), **10**, 789-805.
11) Fleisig, G. S., Barrentine, S. W., Zheng, N., Escamilla, R. F., and Andrews, J. R. Kinematic and kinetic comparison of baseball pitching among various levels of development. J. Biomecha. (1999), **32**, 1371-1375.
12) Kelly, B. T., Backus, S. I., Warren, R. D., and Williems, R. J. Electromyographic analysis and phase definition of the overhead football throw. Am. J. Sports Med. (2002), **30**, 837-847.
13) Moseley, J. B. Jr., Jobe, F. W., Pink, M., Perry, J., and Tibone, J. EMG analyis of the scapular muscles during a shoulder rehabilitation program. Am. J. Sports Med. (1992), **20**, 128-134.
14) Mullaney, M. J., McHugh, M. P., Donofrio, T. M., and Nicholas, S. T. Upper and lower extremity muscle fatigue after a baseball pitching performance. Am. J. Sports Med. (2005), **33**, 108-113.
15) Myers, J. B., Pasquale, M. R., Laudner, K. G., Sell, T. C., Bradley, J. P., and Lephart, S. M. On-the field resistance-tubing exercises for throwers : An electromyographic analysis. J. Athl. Train. (2005), **40**, 15-22.
16) Cools, A. M., Witvrouw, E. E., Declercq, G. A., Danneels, L. A., and Cambier, D. C. Scapular muscle recruitment patterns : trapezius muscle latency with and without impingement symptoms. Am. J. Sports Med. (2003), **31**, 542-549.
17) Anders, C., Bretschneider, S., Bernsdorf, A., and Schneider, W. Activation characteristics of shoulder muscles during maximal and submaximal efforts. Eur. J. Appl. Physiol. (2005), **93**, 540-546.
18) David, G., Magarey, M. E., Jones, M. A., Dvir, Z., Turker, K. S., and Sharpe, M. EMG and strength correlates of selected shoulder muscles during rotations of the glenohumeral joint. Clin. Biomecha. (2000), **15**, 95-102.
19) Kronberg, M., Brostrom, L. A., and Nemeth, G. Differences in shoulder muscle activity between patients with generalized joint laxity and normal controls. Clin. Orthop. Relat. Res. (1991), **269**, 181-192.
20) Park, S., Miyakawa, S., and Shiraki, H. EMG analysis of upper extremity muscles during isokinetic testing of the shoulder joint. Jpn. J. Phys. Fitness Sports Med. (2008), **57**, 101-110.
21) Greenfield, B. H., Donatelli, R., Wooden, M. J., and Wilkes, J. Isokinetic evaluation of shoulder rotational strength between the plane of scapula and the frontal plane. Am. J. Sports Med. (1990), **18**, 124-128.

22) Page, P. A., Lamberth, J., Abadie, B., Boling, R., Collins, R., and Linton, R. Posterior rotator cuff strengthening using theraband in a functional diagonal pattern in collegiate baseball pitchers. J. Athl. Train. (1993), **28**, 346-354.
23) Mikesky, A. E., Edwards, J. E., Wigglesworth, J. K., and Kunkel, S. Eccentric and concentric strength of the shoulder and arm musculature in collegiate baseball pitchers. Am. J. Sports Med. (1995), **23**, 638-642.
24) Wilk, K. E., Andrews, J. R., and Arrigo, C. A. The abductor and adductor strength characteristics of professional baseball pitchers. Am. J. Sports Med. (1995), **23**, 307-311.
25) Malanga, G. A., Jenp, Y. N., Growney, E. S., and An, K. N. EMG analysis of shoulder positioning in testing and strengthening the supraspinatus. Med. Sci. Sports Exerc. (1996), **23**, 307-311.
26) Baltaci, G., and Tunay, V. B. isokinetic performance at diagonal pattern and shoulder mobility in elite overhead athletes. Scand. J. Med. Sci. sports. (2004), **14**, 231-238.
27) Wilk, K. E., Meister, K., and Andrews, J. R. Current concepts in the rehabilitation of the overhead throwing athlete. Am. J. Sports Med. (2002), **30**, 136-151.
28) Ekstrom, R. A., Soderberg, G. L., and Donatelli, R. A. Normalization procedures using maximum voluntary isometric contractions for the serratus anterior and trapezeus muscles during surface EMG analysis. J. Electormyogr. Kinesiol. (2005), **15**, 418-428.
29) Kendall FP, McCreary EK, Provance PG. Muscles : Testing and Function. 4th ed. Baltimore, MD : Williams & Wilkins. (1993).
30) Freriks, B., and Hermens, H. J. SENIAM 9 : European recommendations for surface electromyography. Roessingh Research and Development. (1999).
31) Hermens, H. J., Freriks, B., Disselhorst-Klug, C., and Rau, G. Development of recommendations for SEMG sensors and sensor placement procedures. J. Electromyogr. Kinesiol. (1999), **10**, 361-374.
32) Illyes, A., and Kiss, R. M. Shoulder muscle activity during pushing, pulling, elevation and overhead throw. J. Electromyogr. Kinesiol. (2005), **15**, 282-289.
33) Cook, E. E., Gray, V. L., Savinar-Nogue, E., and Medeiros, J. Shoulder antagonistic strength ratios : a comparison between college-level baseball pitchers and nonpitchers. J. Orthop. Sports Phys. Ther. (1987), **8**, 451-461.
34) Donatelli, R., Ellenbecker, T. S., Ekedahl, S. R., Wilkes, J. S., Kocker, K., and Adam, J. Assessment of shoulder strenght in professional baseball pitchers. J. Orthop. Sports Phys. Ther. (2000), **30**, 544-551.