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COMPARATIVE EMG ANALYSIS OF THE SHOULDER BETWEEN RECREATIONAL ATHLETES AND JAVELIN THROWERS DURING ELEMENTARY ARM MOTIONS AND DURING PITCHING

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Abstract. *Shoulder problems are common in throwing sports. Although there is still much to learn, knowledge of sequential muscle activation about the shoulder is expanding. Further elucidation of muscle activity involved in pitching a ball permits more specific conditioning to help improve performance, reduce injury, and assist rehabilitation in the event of injury. The aim of this study is to compare the muscle activity of recreational athletes and javelin throwers during the elementary motion of upper extremities and during pitching. Nine javelin throwers and sixteen recreational athletes without shoulder problems were studied in the Biomechanical Laboratory at the Budapest University of Technology and Economics. Signals were recorded by surface electromyography from eight different muscles. The results obtained from the muscles of upper extremities of throwers were compared with those of recreational athletes. The better neuromuscular control of throwers caused a more profitable muscle activity. Differences during the learned motion are more significant. Muscles of the deltoideus of recreational athletes show stronger activity then those of throwers. Muscles of the rotator cuff of throwers show stronger activity. These data may provide a basis for understanding improved performance and an adjunct for sports-specific rehabilitation programs.*

Key words: *shoulder, electromyography, biomechanics, pitching.*

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1. Introduction

Electromyography as a tool for the study of muscle function has been in use since the mid1900s. Since then, both normal and pathological muscle functions have been examined by this method. Electromyography has been used to quantify muscle activity patterns during shoulder rehabilitation protocols (Decker, Tokish, Ellis, Torry, & Hawkins, 2003) as well as to analyze shoulder muscle activity and coordination during sports activity (Heise, 1995; Kelly, Backus, Warren, & Williems, 2002) and all-day work (Schuldt, Ekholm, Harms-Ringdahl, Arborelius, & Nemeth, 1987). In a number of studies, researchers have used dynamic EMG to examine shoulder muscle activity during overhead sports activities, predominantly overhead baseball pitching (David, Magarey, Jones, Dvir, Turker, & Sharpe, 2000; Gowan, Jobe, Tibone, Perry, & Moynes; Heise, 1995).

There are no reports on the muscle activity patterns of the rotator cuff muscles and the shoulder synergist during overhead throw at javelin throwers. The injury patterns observed clinically are unique to this population of athletes and include disorders of the biceps tendon and injuries to the pectoralis major muscles as well as the more common injuries of the rotator cuff.

Earlier EMG studies indicated that the subscapularis muscle is important for anterior stability and the infraspinatus for posterior stability (Hovelius, 1982; Ovensen & Nielsen, 1985; Ovensen & Nielsen, 1986). The subscapularis muscle also plays a main stabilizing role in abduction, rotation and flexion, while the infraspinatus muscle is active in abduction and flexion, and the supraspinatus muscle in extension (Kronberg, Nemetg, & Brostrom, 1990; Saha, 1971).

The purposes of this study were to define the sequence of muscular activity patterns in selected shoulder girdle muscles during elementary motion and during overhead throw and to analyze the learned characteristics of overhead throw. A more detailed understanding of the muscle activity patterns that occur during overhead throw will help analyze the neuromuscular control developing during special trainings. An improved understanding of muscle activity patterns during overhead throw will benefit many aspects of athletic training, injury prevention, and rehabilitation after injury. This information can be used to develop muscle-specific training and treatment protocols which will ultimately minimize the incidence of injury and enhance the performance and longevity of the participation of athletes involved in this sport.

2. Material and methods

Subjects

The study was carried out with a group of nine javelin throwers and a control group of 16 healthy subjects. The professional athletes' group consisted of seven male (age 21.2±3.1 years, height 185.3±12.1 cm, weight 79.1±4.1 kg) and two female (age 19.9±2.38 years, height 176.9±12.4 cm, weight 62.3±7.3 kg) javelin throwers. The control group consisted of 12 males (age 22.1±1.1 years, height 182.9±23.9 cm, weight 72.1±3.4 kg) and four females (age 22.6±2.12 years, height 164.1,±33.3 cm, weight 61.1±4.5 kg).

All subjects were screened for musculoskeletal pain or disorders of the upper limbs by an experienced physical therapist. The Constant score was 100/100 in all cases (Constant

& Murley, 1987; Constant, 1997). Subjects were excluded if they reported any type of previous disorders or symptoms within the past year.

Each subject provided informed consent before participation and signed a consent form approved by the Hungarian Human Subjects Compliance Committee.

Procedures and instrumentation

The following movements were investigated: (Fig. 1) (1) pull against resistance in the saggital plane; (2) push against resistance in the saggital plane; (3) elevation in the coronal plane; (4) slow overhead throw; and (5) maximal speed overhead throw. Elementary movements were performed under the same circumstances against minimal resistance by all subjects. A tennis ball was used for overhead pitching, whereas performing slow overhead pitching muscles were investigated during target throw and performing maximal speed overhead throw.

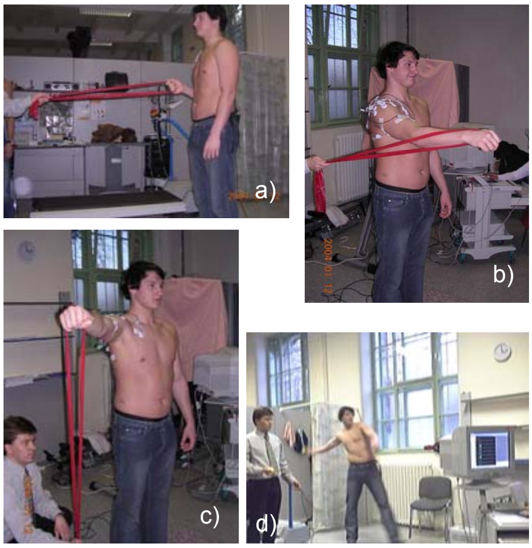

Fig. 1. Type of movements a) pull b) push c) elevation d) overhead throwing

Activity from (1) m. pectrolalis major, (2) m. infraspinatus, (3-5) m. deltoideus anterior, middle and posterior parts, (6) m. supraspinatus with m. trapesius, (7) m. biceps brachii, and (8) m. triceps brachii were recorded in parallel. Ag-AgCl mono-polar surface electrodes (blue sensor P-00-S, Germany) were attached to the skin over the muscle belly, in the main direction of muscle fibers with an interelectrode center-to-center distance of 30 mm. The reference electrode was taped to the seventh cervical spine process and to the acromion. Electrodes were placed using the recommendations of SENIAM (Hermes, Freriks, Merletti, Stegemann, Blok, Rau, Disselhorst-Klug, & Hagg, 1999). The locations of electrodes are shown in Figure 2. EMG investigation was performed on the dominant side. The electrodes were connected to an eight-channel EMG amplifier (Zebris CMS-HS motion analyzing system, Germany). The sampling rate was 1000 Hz.

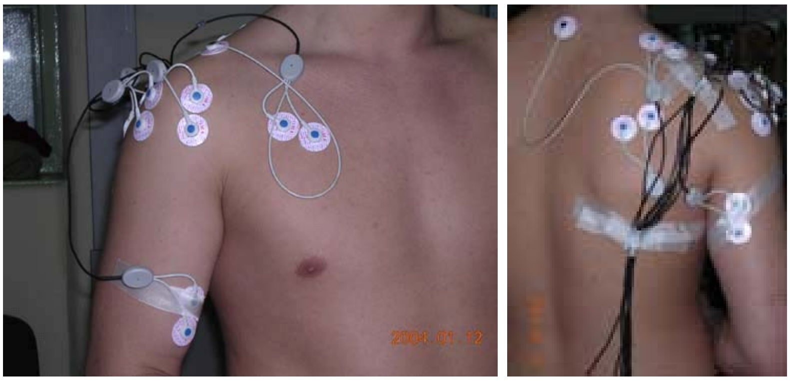

Fig. 2. Arrangement of measurements

The amplitude of the raw EMG signal is quasi stochastic (random) and can be represented by a Gaussian distribution function: the amplitude ranges from -2000 to +2000 mV and the usable energy of the signal is limited to the frequency spectrum of 10-500 Hz. The accuracy of the differential amplifier is measured by the Common Mode Rejection Ratio (CMRR > 80, dB-noise < 20V).

The root mean square (RMS) values of EMG signals were calculated for consecutive segments of 50ms. In order to allow comparison of the activity in specific muscles and the activity in specific muscles among different individuals the EMG was normalized. The activity recorded during the investigated movement was divided by the maximum voluntary contraction (MVC) achieved during all the five movements instead of reference voluntary contraction (RVC) (Kronberg et al., 1990; Schuldt et al., 1987; Soderberg & Cook, 1983). Disadvantages of the RVC method are that reference voluntary contraction should be determined during specified, isometric movements in static conditions.

The MVC range of 0% - to 10% represented inactivity, 10% to 40% minimal activity, 40% to 75% moderate activity and 75% to 100% maximum activity.

The analysis was made for movement type, whereas the activity pattern of different muscles could be compared by muscles whereas the participation of different muscles in each movement type could be compared.

Statistical analysis

Statistical analysis was carried out using the MS Excel Analysis Tool Pack. The mean and standard deviation of MVC% were determined for each muscle during the different movement types. The time difference between the maximal contractions of the muscles was calculated separately at each subject. Mean and standard deviation of time differences were determined by groups. Comparisons of MVC% and the time difference between the maximal contraction of the muscle between the two groups were made by paired t-test with p set at 0.05.

3. RESULTS

The mean values of MVC%, standard deviation (SD) and grading of activity of each muscle group are summarized in Table 1. Significance levels between the two groups are summarized in Table 2.

Table 1. Average MVC% (standard deviation) of the muscles examined in the control group and grading of activity level a) pulling b) pushing c) elevation d) slow overhead pitching e) maximal speed overhead pitching. Legend for signs used: Activity level: + minimal, ++ moderate, +++ maximal

		m. pectoralis maior	m. deltoideus anterior part	m. deltoideus middle part	m. deltoideus posterior part	m. supra-spinatus	m. infra-spinatus	m. biceps brachii	m. triceps brachii
Pulling	Controll group n=16	30.47 (22.86) +	37.67 (24.16) +	65.47 (27.81) ++	95.60 (7.23) +++	52.07 (25.71) ++	59.60 (28.03) ++	45.60 (25.00) ++	49.80 (27.82) ++
	Javelin throwers n=9	19.20 (6.12) +	24.30 (14.20) +	32.60 (26.67) +	50.90 (23.97) ++	22.00 (10.42) +	39.60 (16.26) +	28.40 (20.63) +	44.30 (30.31) ++
Pushing	Controll group n=16	58.67 (30.85) ++	75.13 (19.35) +++	53.87 (27.36) ++	27.53 (17.28) +	34.13 (16.57) +	50.27 (23.21) ++	55.53 (29.95) ++	50.67 (28.70) ++
	Javelin throwers n=9	47.60 (33.44) ++	65.50 (26.06) ++	40.30 (27.09) ++	14.70 (11.11) +	19.30 (16.09) +	44.80 (20.51) ++	53.20 (23.40) ++	32.30 (28.53) +
Elevation	Controll group n=16	31.93 (26.68) +	90.00 (14.64) +++	89.67 (21.22) +++	80.13 (19.44) +++	80.73 (28.50) +++	68.60 (26.08) ++	58.47 (23.43) ++	47.33 (26.94) ++
	Javelin throwers n=9	28.20 (24.36) +	95.90 (6.17) +++	83. 90 (19.95) +++	52.9 (26.77) ++	79.60 (24.67) +++	71.70 (30.78) ++	71.10 (35.30) ++	29.10 (19.24) +
Slow overhead pitching	Controll group n=16	46.00 (25.97) ++	68.27 (21.40) ++	52.93 (24.82) ++	40.67 (27.30) ++	51.60 (21.79) ++	54.20 (24.10) ++	33.20 (21.65) +	53.07 (15.72) ++
	Javelin throwers n=9	51.20 (25.10) ++	69.20 (20.36) ++	66.60 (18.89) ++	41.20 (22.88) +	65.00 (21.66) ++	57.20 (18.55) ++	43.20 (19.84) ++	53.40 (18.15) ++
Fast overhead pitching	Controll group n=16	87.07 (23.34) +++	76.93 (19.40) +++	82.80 (15.73) +++	81.27 (17.23) +++	89.33 (16.68) +++	87.27 (17.89) +++	87.73 (22.51) +++	96.87 (10.36) +++
	Javelin throwers n=9	92.50 (15.30) +++	84.10 (17.30) +++	93.50 (15.17) +++	100.00 (0.00) +++	93.40 (9.86) +++	94.7 (8.81) +++	86.6 (21.45) +++	99.80 (0.63) +++

Table 2. Significance level comparing MVC% of the control group and overhead throwers during different types of motion. The significant differences were marked in italics.

	m. pectoralis maior	deltoideus anterior part	deltoideus middle part	deltoideus posterior part	m. supra-spinatus	m. infra-spinatus	m. biceps brachii	m. triceps brachii
Pulling	0.162	0.095	*0.007*	*0.00019*	*0.011*	*0.034*	0.136	0.652
Pushing	0.414	0.333	0.236	*0.034*	*0.037*	0.542	0.829	0.131
Elevation	0.721	0.181	0.498	*0.014*	0.917	0.797	0.337	0.061
Slow overhead pitching	0.622	0.913	0.133	0.958	0.146	0.729	0.237	0.963
Maximum speed overhead pitching	0.489	0.345	0.104	*0.00087*	0.452	0.116	0.900	0.292

Pulling

In the control group, mainly the posterior deltoid takes part in the motion: it demonstrated maximal activity. Activity of the middle deltoid, the m. supraspinatus, the m. infraspinatus, the m. biceps brachii, and the m. triceps brachii is moderate. In javelin throwers, approximately all investigated muscles take part in the same ratio in generating the movement, the activity level of each muscle is minimal, except for the posterior deltoid and the m. triceps brachii, which were moderately active.

In the control group, the middle and posterior part of the m. deltoideus, the m. supraspinatus, m. infraspinatus, m. biceps brachii and m. triceps brachii take part in generating the pulling phase, while the anterior deltoid is active solely in the deference phase, rarely cooperating with the m. pectoralis maior. In javelin throwers, the posterior deltoid, the m. supraspinatus, the m. infraspinatus, and the m. biceps brachii – and rarely the middle deltoid - are active in the pulling phase. In the deference phase, the m. pectoralis maior, the anterior deltoid, and the m. triceps brachii are mainly active.

Significant differences can be observed between the two groups in the MVC% of the middle and posterior deltoid, the m. supraspinatus and m. infraspinatus as well as between their ratio to each other (Table 1 and Table 2).

Pushing

During pushing, the anterior deltoid is maximally active while m. pectoralis major, m. infraspinatus, and m. biceps brachii are moderately active in the control group.

On the other hand, the anterior and middle deltoid, the m. pectoralis major, and the m. biceps brachii demonstrated moderate activity, all other muscles are minimally active in javelin throwers.

In the control group, the m. pectoralis major, the anterior and middle deltoid, the m. infraspinatus, and the m. triceps brachii are achieving their maximal activity level in the pushing phase, whereas the posterior part of the m. deltoideus, the m. supraspinatus, and the m. biceps brachii are active in the deference phase.

In the pushing phase at the javelin throwers, the m. pectoralis maior, the anterior and middle deltoid, the m. infraspinatus, and biceps brachii are taking part, while in the deference phase the m. supraspinatus and the m. biceps brachii achieve maximum level of activity.

Significant difference can be observed between the two groups in the MVC% of the posterior deltoid and m. supraspinatus (Table 1 and Table 2)

Elevation

In the control group, all three heads of the m. deltoideus, the m. supraspinatus, and the m. pectoralis maior demonstrated maximum activation while all other muscles were moderately active. In javelin throwers, the anterior and middle m. deltoid and the m. supraspinatus were maximally active and the posterior head of m. deltoideus, the m. infraspinatus and m. biceps bachii demonstrated moderate activation.

All muscles achieve the maximum level of their activity in the elevation phase.

Significant differences between the two groups can only be observed in the MVC% of the posterior head of m. deltoideus in the control group, where the activity level of the muscle is maximum while in javelin throwers it is moderate (Table 1 and Table 2).

Slow overhead pitching (as goal oriented movement)

All muscles of subjects of both groups were moderately active except for the m. biceps brachii, which was minimally active.

No significant differences were observed between the group of subjects (Tables 1 and 2).

The mean maximum time difference of maximum activity of the muscles is 24.53% in the control group, while it is 21.87% at javelin throwers if we consider the total time of a pitching to be 100%. No significant differences were observed between the group of subjects (p=0.73) (Tables 1 and 2).

Maximal speed overhead pitching

All muscles of the subjects of both groups were maximally active. Significant differences can be observed in the activity of the posterior deltoid (Tables 1 and 2).

In the control group, a time dislocation can be observed between the maximum activity of the different muscles in the same phase of movements comparing to the javelin throwers. (Fig. 3). In javelin throwers the difference is minimal (Fig. 3b). The mean maximum time difference of the maximum activity of the muscles is 13.12% in the controls and 10.63% in javelin throwers if we consider the total time of a pitching to be 100%. The difference is not significant (p=0.44)

4. Discussion

Professional thrower-athletes are at risk of shoulder injury caused by javelin throwing motion. In our experience with professional throwers and recreational athletes are examined and compared to each other. The rationale for using EMG to study muscle activation during elementary motion and during the throwing movement is to provide a better understanding of muscle firing patterns during these specific shoulder movements. Ultimately, this improved understanding will lead to the development of more effective and sport-specific rehabilitation and conditioning protocols.

In our investigation surface EMG electrodes were used. Neither of the electrodes caused pain and they did not restrict subjects' movements. A disadvantage of this method is that the m. supraspinatus could only be examined together with the m. trapezius.

Processing the data, we used the MVC achieved by each muscle to compare different muscles of different subjects. The advantage of this type of normalizing method is that it belongs to a dynamic condition and a second set is not needed for determining the RVC.

By analyzing EMG curves of all movements we can determine that muscle activity occurred simultaneously in muscles producing the movement and in antagonistic muscles stabilizing the joints with nearly equal amplitude. This indicates that coordination due to muscle contraction plays a significant role in stabilizing the shoulder joint. In the control group the m. biceps brachii, the m. triceps brachii, and the m. deltoideus also play an important role, while in javelin throwers the role of the rotator cuff muscles are more intensive in ensuring the proper stability. The difference between ensuring stability is best visible during elevation, as in the control group the activity of all three parts of m. deltoideus and the m. supraspinatus is maximum while in javelin throwers the anterior and middle deltoid and the m. supraspinatus demonstrate maximal activation.

In javelin throwers the time difference between the activity maximum of the agonist and antagonist muscles are minimal, while in the control subjects the time difference is broader; however the difference between the groups is not significant. This can be well observed during maximum speed pitching (Fig. 3). This agrees with David et al. (2000) who reported delayed muscle activation during rotation. This suggests that the different neuromuscular control and proprioception of the javelin throwers caused different muscle coordination during throwing.

The low level of activity for all muscles of javelin throwers during the pulling and pushing phases may be due to the different neuromuscular control and proprioception in javelin throwers. In the control group, the activity level of one of the muscles – mostly one head of m. deltoideus – is much higher than the activity level of other muscles, and all muscles demonstrated moderate or maximum activation.

During overhead pitching, the activity level of all muscles are moderate or maximum. In the control group, the activity level of one head of m. deltoideus is much higher than that of the other muscles while in javelin throwers besides the m. deltoideus the activity level of one of the muscles of the rotator cuff is higher than the others'. During slow overhead pitching, there was no significant difference in the maximum contraction of the muscles between the two groups (Table 2) or in the time difference of the maximum contraction of the muscles. We suppose that this type of motion was equally unknown for both groups and this is the reason why the supposedly more developed neuromuscular control of the athletes was not obvious.

During maximum speed overhead pitching, there was significant difference between the two groups in the activity of the posterior deltoid (Table 2). No significant differences were shown in the time difference among the maximum contraction of the muscles between the two groups. Another important observation is that in the control group, 3-4 muscles achieve nearly 100% MVC value, while in javelin throwers 5-8 muscles achieve nearly 100% MVC value. In javelin throwers, the standard deviation of the maximum voluntary contraction values of the muscles is significantly smaller than that of the control group ($p=0.007$). The observations above may result from different motion patterns in the two groups that may refer to the learned character of overhead pitching (Decker et al., 2003; Gowan et al., 1987; Heise, 1995; Kelly, 2002).Evaluating this needs further kinetic and kinematic investigation.

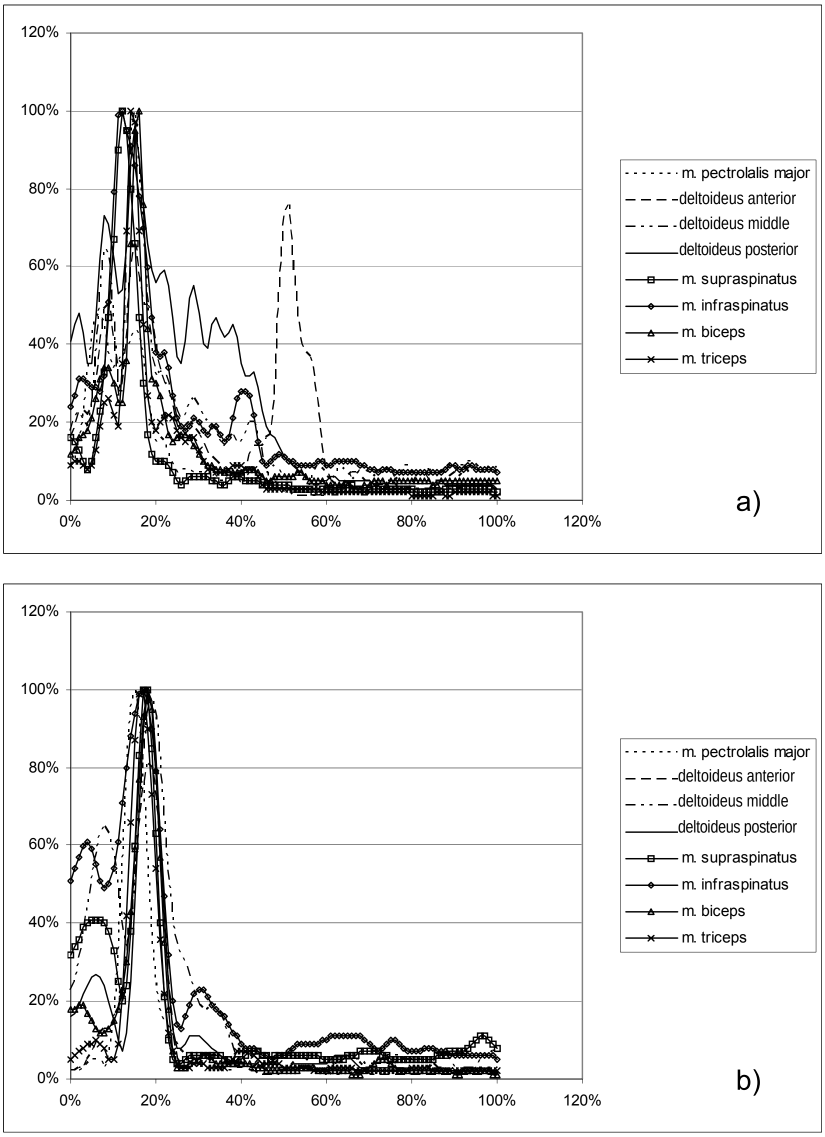

Fig. 3. Normalized EMG curve of the muscles examined, during maximal speed overhead pitching a) healthy individual b) overhead athlete

In order to better understand the difference of the motion pattern, we must examine the role of different muscles in generating different types of movements. Those muscles producing the moment that creates the movement are referred to as movers, called agonist muscles. If activation occurs in muscles located at the opposite side of the motion axis, an opposite moment will be produced. This muscle activity is referred to as antagonistic activity and those muscles that stabilize the joint during the movement are referred to as stabilizers. While generating basic movements, some of the muscles are agonists while others are antagonists stabilizing the joint with simultaneous activity. This indicates that coordination due to muscle contractions plays a significant role in stabilizing the shoulder joint. During complex movements of the shoulder the role of rotator cuff muscles increases, because force in rotator cuff muscles press the humeral head into the glenoid fossa and centralize the humeral head and add stability to the joint. These findings are supported by the increased activity level of m. supra and infraspinatus during fast overhead pitching.

According to the literature (Kronberg et al., 1990; Saha, 1971) and our results in abduction, the movers are the anterior and middle deltoid and the m. supraspinatus, the stabilizers are a m. infraspinatus with the posterior deltoid. In external rotation the agonist muscles are the m. infraspinatus and m. supraspinatus, in internal rotation the agonist muscle is the m. pectoralis maior. In extension, the movers are the middle and posterior deltoid whereas the stabilizer is the m. supraspinatus.

As a consequence of the above, we may suppose that elementary movements are generated from one or two basic type of motions. During pulling or pushing, shoulder motions are combined of flexion and extension, elevation is combined of ab- and adduction, and flexion-extension. In the control group, elementary movements are combined of several motion types, and they add considerable rotation to all movements. This may explain the difference in the activity of muscles between the two investigated groups in generating elementary movements (Table 1) and may also support why different motion patterns can be observed at some subjects.

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KOMPARATIVNA EMG ANALIZA RAMENA IZMEĐU SPORTISTA REKREATIVACA I BACAČA KOPLJA TOKOM OSNOVNIH KRETANJA RUKE I TOKOM BACANJA

Árpád Illyés, Rita M. Kiss

Problemi sa ramenima su časti kod bacačkih sportova. Iako postoji još toga što se može naučiti, znanje o uzastopnoj mišićnoj akciji ramena se širi. Dalje tumačenje mišićne aktivnosti vezane za ubacivanje lopte dozvoljava specifičnije uslove da se poboljša izvođenje, smanje povrede, doprinese rehabilitaciji u slučaju povrede. Cilj ove studije je da se uporedi mišićna aktivnost sportista rekreativaca i bacača koplja tokom osnovnih kretanja gornjih ekstremiteta i tokom bacanja. Devet bacača koplja i šesnaest sportista rekreativaca bez problema sa ramenima bili su testirani u Biohemijskoj laboratoriji Budimpeštanskog univerziteta Tehnologije i Ekonomije. Signali su beleženi na površini elektromiograma od osam različitih mišića. Rezultati dobijeni sa mišića gornjih ekstremiteta bacača upoređeni su sa sportistima rekreativcima. Bolja neuromišićna kontrola bacača proizvela je korisniju mišićnu aktivnost. Razlike tokom naučenih okvira kretanja su više značajne. Mišić deltoideus sportista rekreativaca pokazuje veću aktivnost nego kod bacača. Mišić rotator cuff kod bacača pokazuje jaču aktivnost. Ovi podaci mogu omogućiti osnovu za razumevanje poboljšavanja izvođenja i dodatak sportskim specifičnim rehabilitacionim programima.

Ključne reči: *ramena, elektromiografija, biomehanika, bacanje.*