Title: Shoulder muscle activity during pushing, pulling, elevation and overhead throw at professional athletes
Authors: Árpád ILLYÉS
Rita M. KISS
Country: Hungary

The original research project is published as an original article in Journal of Electromyography and Kinesiology (Illyés Á., Kiss R.M.: Shoulder muscle activity during pushing, pulling, elevation and overhead throw. Journal of Electromyography and Kinesiology 15(3) pp. 282-289. 2005. (IF=2.102)). Now, we summarized the most important details of research and highlight the results which are useable in coaching practice.

Introduction

The motion analysis of different sport motion is a widespread and interesting field of biomechanical research. Several studies summarized the kinematical parameters of different athletics motion for example running, jumping and throwing. The researchers generally used video-based motion analyzer systems. However there have few reports been published about the muscle activity during different motions. The functions of shoulder muscles during different elementary motions such as ab- and adduction, flexion-extension and rotation have been widely studied by surface EMG and these provide a basis for designing rehabilitation protocols as well as for following up the rehabilitation program of glenohumeral and scapulothoracal muscles [1, 9-11]. Few researchers have used dynamic EMG to examine shoulder muscle activity during overhead sports activities, predominantly overhead baseball pitching [2-4].

Among overhead athletes the risk of shoulder injury may be increased with the level of athlete, the style of throwing, the length of the throw and the level of associated muscle fatigue that occurs throughout practices. Developmental instability may appear after several years of heavy trainings that leads to different shoulder problems developing during the career of overhead throwers. Injuries of the rotator cuff are the most common ones while disorders (rupture, tendinitis etc) of biceps tendon and pectoralis major can
also be observed [8]. Increasing the strength of muscles responsible for shoulder joint stability can lead to injury prevention by maintaining the humeral head in the glenoid. Detailed defining activation patterns of various muscles may help in planning the rehabilitation process as the accurate simulation and training program of the injured and/or affected muscles can properly be planned and regularly and accurately followed up with EMG measurements. The purposes of this study were i) to define a detailed sequence of muscular activity patterns in selected shoulder girdle muscles during pull, push, and elevation and during overhead throw and ii) to analyze the characteristics of overhead throw in professional javelin throwers. An improved understanding of muscle activity patterns during different movements may benefit many aspects of athletic training, injury prevention, and even rehabilitation after injury.

Method
Out of 15 professional javelin throwers 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) athletes were selected for the measurement. The professional athletes were all trained by the same trainer of the national team, which ensured the same training protocol for all the athletes. The comparison group was selected from among university students, so as the age, body height and weight, BMI were comparable to those of professional athletes. Out of 20 of the comparison group 12 males (age 22.1±1.1 years, height 182.9±23.9 cm, weight 72.1±3.4 kg) and 4 females (age 22.6±2.12 years, height 164.1±33.3 cm, weight 61.1±4.5 kg) remained in the study. All subjects were screened for musculoskeletal pain or disorders of the upper limbs by an experienced medical doctor. 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.
The following movements were investigated: (Fig. 1.) (a) pull; (b) push; (c) elevation; (d) slow and (e) fast overhead throw. Subjects were standing during the measurement. Each movement was repeated at least three times one after the other, the movement series was continuous. Before the measurement the end points of the movements and the movement itself were taught to the subjects so as they could repeat the movement in the same manner. Each phase of the pull, push and elevation exercises was performed at 40 beats per minute, standardized with the aid of a metronome. Exercises involving the use of elastic resistance were performed at a distance away from the point of fixation, where the subject could perform at least three repetitions while maintaining consistent metronome speed.

![Figure 1. Type of movements a) pull b) push c) elevation d) overhead throw](image)

Activity from (1) pectoralis major, (2) infraspinatus, (3-5) anterior, middle and posterior deltoid, (6) supraspinatus with trapesius (upper trapesius), (7) biceps brachii, and (8) 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 [5]. 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.

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.
Maximum EMG reference values were calculated for each muscle by using the maximum
of five peaks EMG signals to represent 100%MVC. [10]. Muscle activity was categorized
as minimal (0% to 39.9%), moderate (40% to 74.9%) or marked (75% to 100%) [8].

The mean and standard deviation of MVC% were determined for each muscle during the
different movement types. The time broadness among peak muscle activities in percent of
total time of a movement cycle was calculated separately at each subject. The mean and
standard deviation of time broadness were determined by groups. Comparisons of
MVC% and the time broadness among peak muscle activities between the two groups
were made by unpaired t-test with α set at 0.05.

Results

The mean values of MVC%, standard deviation (SD), grading of activity of each muscle
group and significant differences between the two groups are summarized in Table 1.
Longer time broadness among peak muscle activities could be observed in the
comparison group comparing to the javelin throwers. (Fig. 2.). In javelin throwers the
difference was minimal (Fig. 2.b.). The mean of time broadness among peak muscle
activities was 13.1% in the comparisons and 10.6% in javelin throwers if we considered
the total time of a throw to be 100%. The difference was not significant (p=0.44).
Figure 2. Normalized EMG curve of the muscles examined, during maximal speed overhead throw a) comparison group b) javelin throwers
Discussion

Gowan et al. [3] and Kelly et al. [8] have defined two groups of muscles. Infraspinatus, supraspinatus, three part of deltoid defined as stabilizers. Subscapularis, pectoralis major, latissimus dorsi and triceps brachii defined as accelerators. On the basis of our study this definition could be use not only for throw, but it could be used for pull, push and elevation as well. During pull and push, the activity of all muscles of recreational athletes is higher than that of professional athletes’ (Table 1). Significant differences could be observed between the two groups of the middle and posterior deltoid, supra- and infraspinatus (Table 1). The difference is best visible during elevation, as in the comparison group the activity of all three parts of the deltoid and the supraspinatus is maximum while in javelin throwers the anterior and middle deltoid and the supraspinatus demonstrate maximal activity (Table 1). This indicates that coordination in muscle contraction plays a significant role in stabilizing the shoulder joint, and the role of the muscles mentioned above is higher in recreational athletes during pull, push and elevation than in qualifier throwers.

During overhead throw in the comparison group, the activity level of one head of the deltoid is much higher than that of the other muscles while in javelin throwers besides the deltoid the activity level of one of the rotator cuff muscles is higher than the others’ (Table 1). During slow overhead throw, there was no significant difference in the maximum contraction of the muscles between the two groups (Table 1.) We suppose that this type of motion was equally unknown for both groups and this is the reason why the supposedly more developed neuromuscular comparison of the athletes was not obvious. During maximum speed overhead throw, there was significant difference between the two groups in the activity of the posterior deltoid (Table 1). This indicates that during overhead throw of professional athletes an additional muscle (posterior deltoid) has to be involved to ensure proper stability of the shoulder joint as forces generated during fast speed throw requires this.

On basis of the results it could be determined the peak muscle activity is significantly higher during the dynamic motion, as the overhead throw than during the isokinetic motion. Peak muscle activity depends on force, on speed and on proprioception level of muscles. In the comparison 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 MVC values of the muscles is significantly higher than that of the comparison group (p=0.007) (Table 1). These findings are correlated by results of Hintermeister et al. [6].

The other parameter for the characteristics of muscle activity pattern is the time broadness in the percent of the movement cycle. In javelin throwers that of the agonist and antagonist muscles are minimal, while in the comparison subjects the time broadness is wider; however, the difference between the groups is not significant (Table 1). This can be well observed during fast overhead throw (Fig. 2.). This suggests that different neuromuscular control and proprioception of javelin throwers cause different muscle coordination during throwing.

The comparison of results of MVC% and time broadness in the percent of the movement cycle may strengthen our belief that the different motion patterns could be characterized by MVC and by time broadness in the percent of the movement cycle. The observations above resulted from different motion patterns in the two groups that may refer to the learned character of overhead throw, which is correlated by findings of earlier studies [2-4, 7, 8].

**Conclusion**

The different neuromuscular control of professional throwers cause a more profitable muscle activity. Differences during the overhead throw are more significant. The deltoid muscle and rotator cuff of recreational athletes show stronger activity than those of throwers during pull, push and elevation. The deltoid muscle and the rotator cuff of professional throwers show stronger activity during overhead throw. Studying the detailed characteristics of muscle activity pattern (differences in length of activity periods, MVC% of muscles and time broadness among peak muscle activities in percent of total time of a movement cycle) may provide a basis for better understanding improved performance and help in planning proper training and rehabilitation protocol.
**Recommendations**

Muscle activity patterns have clinical implications for both the training and rehabilitation protocol.

1. By knowing the manner in which different muscles fire during various motions (pull, push, elevation and throw), muscle-specified conditioning protocols could be provided. The demonstration of distinct patterns of muscle activation may have further implications for changes in training and rehabilitation protocols.

2. The maximal activation documented during the different movement in all muscles tested suggests the mechanism of muscle injury. Movements execute with low peak amplitudes may minimize the risk of damage for initial muscular training. This is useful in the first part of rehabilitation and for strengthening stabilizer muscles (muscles infraspinatus, supraspinatus and all three parts of deltoid). Large peak amplitudes may exceed the maximal load that repaired and injured muscles can withstand. Exercises with large peak amplitudes can be used in the last period of rehabilitation and the strengthening of accelerator muscles (muscles pectoralis maior, triceps brachii and biceps brachii).

**Bibliography**


Table 1. Average MVC% (standard deviation) of the muscles examined of the comparison group and javelin throwers; grading of activity level of muscles during a) pull b) push c) elevation d) slow overhead throw e) maximal speed overhead throw.

<table>
<thead>
<tr>
<th></th>
<th>Pectoralis major</th>
<th>Anterior deltoid</th>
<th>Middle deltoid</th>
<th>Posterior deltoid</th>
<th>Supraspinatus</th>
<th>Infra-spinatus</th>
<th>Biceps brachii</th>
<th>Triceps brachii</th>
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<tbody>
<tr>
<td><strong>Pull</strong></td>
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<tr>
<td>Comparison group n=16</td>
<td>30.47 (22.86)</td>
<td>37.67 (24.16)</td>
<td><strong>65.47 (27.81)</strong></td>
<td><strong>95.60 (7.23)</strong></td>
<td><strong>52.07 (25.71)</strong></td>
<td><strong>59.60 (28.03)</strong></td>
<td>45.60 (25.00)</td>
<td>49.80 (27.82)</td>
</tr>
<tr>
<td>Javelin throwers n=9</td>
<td>19.20 (6.12)</td>
<td>24.30 (14.20)</td>
<td><strong>32.60 (26.67)</strong></td>
<td><strong>50.90 (23.97)</strong></td>
<td><strong>22.00 (10.42)</strong></td>
<td><strong>39.60 (16.26)</strong></td>
<td>28.40 (20.63)</td>
<td>44.30 (30.31)</td>
</tr>
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| **Push** |                  |                  |                |                   |               |               |                |                |
| Comparison 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** |                  |                  |                |                   |               |               |                |                |
| Comparison 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) | **52.90 (26.77)** | 79.60 (24.67) | 71.70 (30.78) | 71.10 (35.30) | 29.10 (19.24) |

| **Slow overhead throw** |                  |                  |                |                   |               |               |                |                |
| Comparison 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 throw** |                  |                  |                |                   |               |               |                |                |
| Comparison 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) |

Legend: Activity level: + minimal, ++ moderate, +++ maximal
The significant differences (p<0.05) in muscle activity were marked in bold.