Semmelweis University
PhD School Clinical Medical Sciences

Determining biomechanical parameters of stabile and instabile shoulders with a new dynamic motion analyzer system

Summary of PhD dissertation

Árpád Illyés MD

Head of PhD school of branch of science:	Prof. Zsolt Tulassay MD, CSc, DSc
Head of programm:	Prof. Miklós Szendroi MD, CSc, DSc
Supervisor:	Rita M. Kiss PhD, CSc

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Introduction

Motion analysis during motion; qualitative and quantitative examination of the translation and rotation of the body segments involved in motion (e.g. lower arm, upper arm, leg, thigh, etc.), as compared to each other and to fixed spatial axes in the function of time. Shoulder joint motion analysis is a special field of motion analysis.

Various diseases of the shoulder (injury of n. thoracicus longus, recurrent/habitual shoulder dislocation, frozen shoulder syndrome, rotator cuff tear, etc.) cause substantial changes in the rhythm of scapulothoracal movements, therefore the 3D kinematic model of the shoulder and the diagnostic method developed therewith may provide opportunities for better understanding the pathogenesis of diseases. The kinematic analysis of movements can be useful for not only diagnostics but for the accurate (numerical) follow-up of rehabilitation as well. It is essential to know the spatial position of shoulder bones (scapula, humerus, clavicle) to describe the inverted dynamics of the shoulder and to determine the forces generated in the shoulder joint. Familiarity with this latter plays an essential role, among other things, in the accurate design and selection of shoulder prostheses, as well as in the development and verification of finite element and numerical methods used for biomechanical analysis of the shoulder.

And initially, radiological and MRI tests were performed for describing the motion of the scapula and the humerus. During tests, the upper arm was positioned in a variety of ways to model motion. Recorded images were used for measuring the angles included by the humerus and the thorax (humerus elevation), the humerus and the scapula (glenohumeral angle), as well as the scapula and the thorax (scapulothoracal angle). An advantage of this method is that tests are easy to perform. Disadvantages include the X-ray radiation patients are exposed to, the insufficient accuracy of the method, and the static character of the method. The radiological method can be used for determining the angles and the planar projections of their changes.

The first breakthrough in motion tests was brought about by the appearance of video-based systems. An advantage of this method is that natural movement can be recorded and displayed as well as replayed later on. Disadvantages are that processing is difficult and its accuracy depends on the experience of the person performing the processing work; processing accuracy is within the range is 1 to 3 cm. With the appearance of electromagnetic systems (Flock of Birds), motion of the thorax, the humerus, and the clavicle could be recorded continuously by the measurement triplets placed on them; however, the position of the scapula can only be determined after stopping the motion, meaning that motion dynamics cannot be recorded. Such measurements are termed quasi-dynamic measurements. The method made it possible to determine the helical axis and rotation center of the glenohumeral joint, used for characterizing motion dynamics, on a cadaver shoulder joint; as well as to examine scapulothoracal rhythm in the case of various motions and loads. The method is also suitable for comparing the scapulothoracal rhythm of athletes at different levels. The method provides opportunities for detecting kinematic changes caused by various shoulder diseases.

A major deficiency of the motion analysis systems described in the literature is that they study shoulder joint kinematics under static or quasi-dynamic conditions. The methods known are not suitable for the analysis of motion dynamics. In my opinion, the most accurate picture of shoulder joint motion can be received, both in terms of healthy subjects and patients with shoulder problems, by conducting kinematic tests in vivo, under dynamic conditions, supplemented by electromyographic tests.

Electromyographic tests can be used for monitoring muscular motion pattern changes and analysing muscle coordination in the course of sports activities, everyday work, and as a result of various shoulder diseases. EMG tests to analyse shoulder muscle functions provide a basis for designing rehabilitation protocols, comparing different shoulder joint rehabilitation protocols, or for monitoring the rehabilitation process of glenohumeral and scapulothoracal muscles.

Based on the literature described, it can be stated that the results of electromyographic tests conducted under simple and complex dynamic conditions produce substantial differences when comparing healthy subjects, thrower athletes, and patients suffering from various shoulder disorders. It can be established that the functions and motion patterns of muscles are considerably affected by the level of fitness and the type of shoulder injury. Accurate information on the activity features of different muscles may assist in rehabilitation process design and the numerical follow-up of rehabilitation protocols, provided that EMG tests are conducted under standardized conditions.

Objectives

The *first objective* of the research is to develop and verify a measurement method for an ultrasound-based motion analysis system which is suitable for the quantitative determination of shoulder joint motion without stopping the motion.

The *second objective* is to specify, analyze, and compare the kinematic characteristics of stable and unstable shoulder joints and the on-off pattern of certain muscles in the course of elevation.

The *third objective* of the research is to study the impact of multidirectional shoulder joint instability on the motion patterns of shoulder joint muscles in case of simple and complex dynamic motion.

The *fourth objective* is to study the impact of intensive motion-specific sports activities (javelin throwing) on the motion patters of shoulder joint muscles in case of simple and complex dynamic motion.

Research method

In the course of the research, the shoulder motion of a total of 58 healthy subjects and 15 patients with multidirectional shoulder joint instability were analyzed; approximately 588 measurements were performed.

The group of healthy subjects consists of two parts: the control group and the group of professional javelin throwers. The motion of 74 shoulder joints of 50 people (18 females and 32 males) was analyzed by kinematic and electromyographic methods during elevation. 15 people (8 males and 7 females) were chosen randomly from the control group to participate in the verification of the test method as well; and 25 persons (14 males and 11 females) to participate in the electromyographic tests during simple and complex dynamic motion as well. The other group of healthy subjects includes 8 professional javelin throwers (6 males and 2 females), who took part only in the electromyographic tests during simple and complex dynamic motion.

The group of patients examined is made up of the 15 patients (5 males and 10 females) whose multidirectional shoulder joint instability was demonstrated by a physical examination, some sort of imaging procedure or diagnostic arthroscopy performed earlier. 18 shoulders of the patients with multidirectional shoulder joint instability were examined by kinematic and electromyographic methods in the course of elevation. The electromyographic characteristics of muscles around the shoulder joint were measured at each subject during simple and complex dynamic motion as well.

Displacements of the shoulder joint can be recorded without stopping the movement using the ZEBRIS CMS-HS (ZEBRIS, Medizintechnik GmbH, Germany) computer-controlled ultrasound-based movement analysis system located at the Biomechanical

Laboratory of the Department of Applied Mechanics of Budapest University of Technology and Economics. The movements of scapula can be recorded by triplets own developed that can be fastened by vacuum to the acromion. In order to record shoulder joint motion, further triplets were placed onto the sternum, the upper arm, and the lower arm; furthermore, three individual sensors were fastened to the clavicle. The measurement control software enables us to determine the spatial coordinates of specific anatomical points of the sensors and the segments examined (thorax, clavicle, upper arm, lower arm, scapula) from the dispersion time of the ultrasound recorded by the measurement system using the triangulation method. This is subject to the fact that the position vectors of the anatomical points to be examined should be determined by an ultrasound-based pointer in the local system of coordinates defined by the measurement triplets before starting the measurement. Using the 16-point biomechanical model developed, involving the following anatomical points into the examination: incisura jugularis, processus xyphoideus, processus spinosus of spondyle Th1, processus spinosus of spondyle Th6, 3 points of the clavicle, angulus acromialis scapulae, trigonum spina scapulae, angulus inferior scapulae, insertion point of m. deltoideus at the humerus, epicondylus ulnaris humeri, epicondylus radialis humeri, olecranon ulnae, processus styloideus radii, and processus styloideus ulnae – shoulder joint motion can be described in a reproducible manner.

The structure of the ZEBRIS CMS-HS movement analysis system and of the measurement control software enables us to measure changes of electric potential generated in muscles in the course of movement simultaneously with recording the kinematic characteristics of movements, without any subsequent synchronization, by surface electromyography.

The following muscle groups were included in the investigation: (1) m. pectoralis maior, (2) m. infraspinatus, (3-5) anterior, central, and posterior part of m. deltoideus, (6) m. supraspinatus with m. trapesius, (7) m. biceps brachii, (8) m. triceps brachii, (9) inferior part of m. trapesius, (10) m. serratus anterior, (11) m. latissimus dorsi, (12) m. sternocleidomastoideus.

In the course of a movement test, the measurement system records the changes through time of the spatial coordinates of designated anatomical points. The following kinematic parameters (13) were calculated from spatial coordinate data: (1) humerus elevation (HE) defined as an angle of spatial vectors; scapulothoracal (ST), glenohumeral angles (GH), (2) range of humerus elevation, scapulothoracal, glenohumeral angle, (3) scapulothoracal and glenohumeral rhythm, (4) minimum and maximum distance between the rotation centers of the scapula and the humerus as well as their absolute and relative displacement.

In the case of kinesiological electromyographic analysis, time-based processing should be applied and the purpose is to generate a linear cover curve in order to be able to determine the on-off pattern of each muscle group in the course of movement.

Surface electromyography was used for the examination of the behaviors of major shoulder joint muscles during simple (pulling, pushing, elevation), and complex (slow and rapid overhead throwing) dynamic motion as well. The following muscle groups were included in the investigation: (1) m. pectoralis maior, (2) m. infraspinatus, (3-5) anterior, central, and posterior part of m deltoideus, (6) m. supraspinatus with m. trapesius, (7) m. biceps brachii, (8) m. triceps brachii. The linear cover curves of different muscles are normalized by modified maximum voluntary contraction. The following muscle activity characteristics were analyzed: (1) the on-off pattern of muscle activity (2) maximum of normalized voluntary contraction, (3) maximum time range.

Data processing and statistical analyses were performed using MS Excel based software of own development. In case of each subject examined, we calculated the average and the standard deviation of the biomechanical parameters, and these data were further processed.

The biomechanical properties of individuals pertaining to a given group and those of various groups were statistically analyzed using the MS Excel Analysis ToolPak software. The average and standard deviation of biomechanical parameters of individuals pertaining to a given group were calculated. The uniformity of standard deviations was checked by an F-test; significance levels of the difference between the average values of identical parameters were determined by a t-test applying a symmetrical critical range. A two-sample t-test was applied when comparing the results for stable and unstable shoulder joints and healthy people and professional athletes. It is assumed that the muscle activity parameters of stable and unstable shoulder joints and healthy and professional athletes should be different, and results present statistically significant differences if $p < 0.05$.

Results of the research completed

1. The ZEBRIS CMS-HS ultrasound-based spatial motion analysis system – with the triplet developed, to be fastened on the acromion (Figure 1) – is suitable for recording the movements of the shoulder joint including the scapula without stopping the motion. The 16-point biomechanical model, analyzing a minimum of three anatomical points on the bones constituting the shoulder joint and on the lower arm, can describe shoulder joint motion.
    1.1. In the course of verification, it was established that measurement results can be reproduced because intraobserver errors range between 1 and 3 mm and the maximum value of interobserver error is 4 mm. There is a 1 to 3 mm difference between the spatial coordinates specified using the commercially available ZEBRIS 3DCAD software and by the measurement method developed by us.
    1.2. Verification results show that the spatial coordinates specified by the measurement system are independent of the direction of the coordinate and the degree of elevation, but they greatly depend on the experience of the person performing the measurement.

Figure 1. Triplet of own development to record scapular motion

2. For the biomechanical analysis of the shoulder joint, the characteristics known by the literature were modified and new biomechanical characteristics were introduced:
    2.1. Definitions of the angles used for describing shoulder joint motion in orthopedic and biomechanics – humerus elevation, scapulothoracal, and glenohumeral angles – were modified. By using the 16-point model, angles can be defined as angles of spatial vectors. An advantage of this calculation method is that there are no errors arising from projection – which represents mapping not retaining angles. In order to eliminate the anthropometrical characteristics of subjects, the range of angle was introduced, representing the difference between the actual angle value and the angle value to be specified in the initial position. In order to define the role of the scapulothoracal and the glenohumeral joints, scapulothoracal and glenohumeral

  rhythm – the scapulothoracal and glenohumeral angles in the function of humerus elevation – was examined during the entire range of motion.
  - 2.2. The angular velocity of the bones – as rigid bodies – constituting the shoulder joint as well as the position vectors of their rotation centers can be calculated by a closed formula. In our tests, rotation centers of the scapula and the humerus were analyzed during motion. The measurement method introduced made it possible to determine the relative displacement of the two rotation centers. Following displacement normalization, parameter values will not depend on the anthropometrical characteristics of subjects. The new parameter was termed as relative displacement of the rotation centers. This parameter enabled the numerical display of the relative motion of the scapula and the humerus, which can be used for a more accurate modeling of shoulder joint motion.
  - 2.3. The linear cover curves produced from electromyographic records were normalized by the largest voluntary contraction achieved in the course of simple and complex dynamic motion. This normalization was termed ‘modified maximum voluntary contraction’. As opposed to normalization known so far, its advantage lies in the fact that no special measurement is required for determining reference voluntary contraction; it is specified at each subject with the maximum voluntary contraction characteristic of the person concerned; normalized voluntary contraction does not exceed 100% in the case of the types of motion studied.
3. The following statements can be made as a result of the analysis of modified and new parameter values and their characteristics on control.
  - 3.1. Based on our measurements, it can be stated that the regression line characterizing scapulothoracal and glenohumeral rhythm is bilinear (Figure 2a). Rhythm significantly changes at about 60 degrees. As regards motion generation, the role of the scapula increases to the detriment of the role of the glenohumeral joint. Scapulothoracal and glenohumeral rhythm are independent from sex and lateral dominance. This is probably due to the fact that the role of the scapulothoracal and glenohumeral joints in motion generation is independent from these parameters. This is also supported by the fact that angle values characterizing motion are also independent from these parameters.
  - 3.2. Test results show that that the relative displacement parameter of the newly defined rotation centers, characterizing the motion of the humerus and the scapula relative to each other is independent from sex and lateral dominance (Table 1). This is probably due to the fact that the relative motion of the humerus and the scapula is independent from these parameters, depending only on the condition of static and dynamic stabilizers. This is also supported by the fact that the other features describing motion– glenohumeral, scapulothoracal, and humerus elevation angle values, range of angle, as well as scapulothoracal and glenohumeral rhythm – are also independent from these parameters.
4. Test results show that members of the control group can be classified into three subgroups based on the on-off pattern of muscle activity of simple and complex dynamic motions. For 56% of the subjects, the proportion of the elementary movements of flexion-extension, rotation, and abduction / adduction is identical. In case of 24% of the subjects, it can be assumed that rotation is more emphatic than the elementary motion of abduction / adduction, which is caused by the increased role of m. pectoralis maior. For 20% of the control group, it can be assumed that the dominant type of motion is abduction / adduction, caused by the increased role of m. deltoideus and m. infraspinatus.

5. Based on the results of motion tests performed on patients with multidirectional shoulder joint instability, it can be established in summary that there are substantial changes in shoulder joint biomechanics as a result of instability.
   5.1. We proved that the proportions of range of the scapulothoracal and the humerus elevation angle and of range of the humerus elevation – glenohumeral angle are reduced; as well as that the proportions of range of the humerus elevation – scapulothoracal and the range of glenohumeral – scapulothoracal angle are increased.
   5.2. In case of multidirectional shoulder joint instability, the regression line characterizing scapulothoracal and glenohumeral rhythm is linear. The decreased role of the scapula as opposed to a stable shoulder joint can be caused by the development of neuromuscular protection – sparing the shoulder joint. This is supported by the fact that.

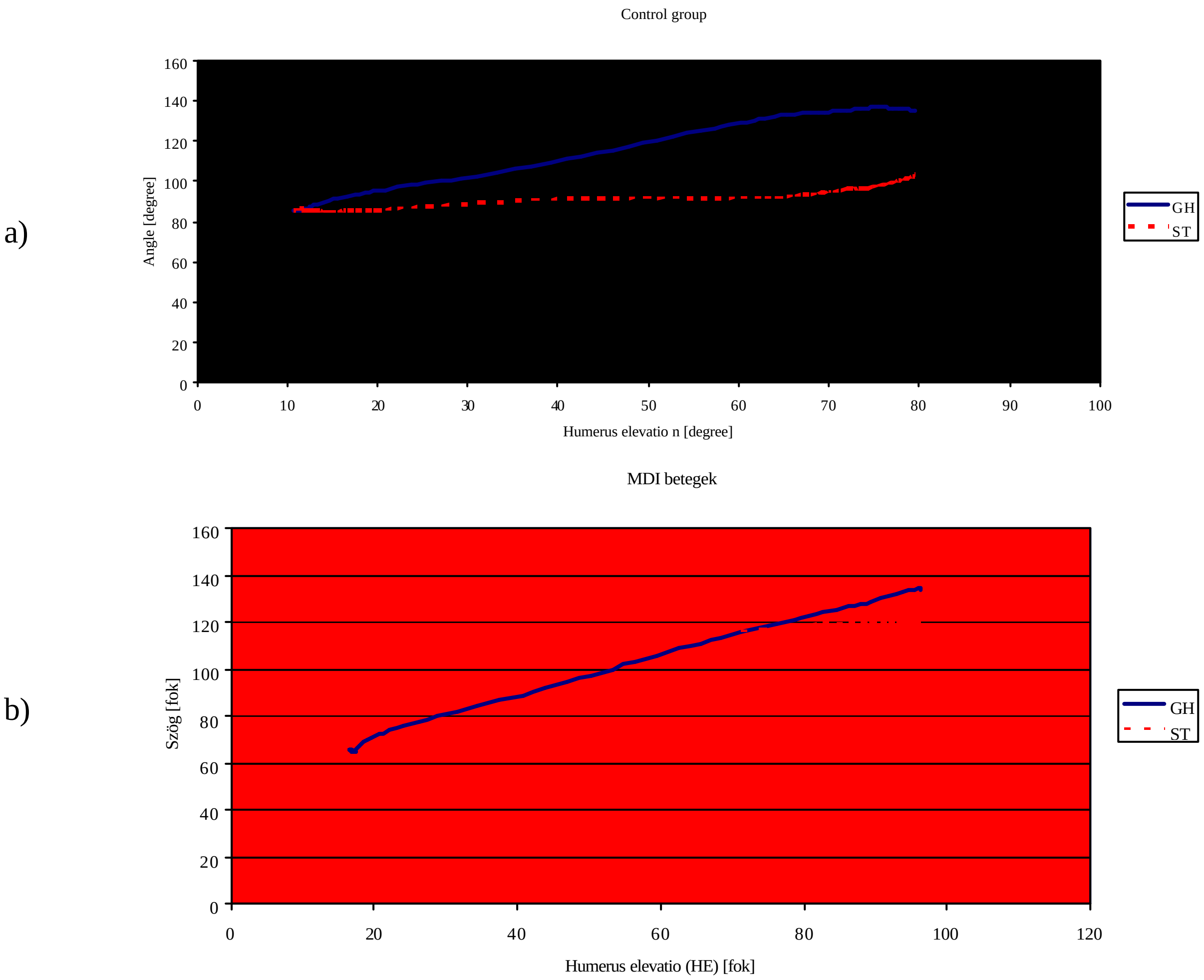


Figure 2 Scapulothoracal and glenohumeral rhythm for a) the control group b) patients with multidirectional shoulder joint instability

   5.3. Average values of the rotation center relative displacement parameter are considerably higher than those of healthy subjects (Table 1). The largest increase is produced by antero-posterior (direction x) and inferior (direction z) displacements, which corresponds to the direction of instability (Table 2). The relative displacement parameter of rotation centers models the displacement of the humerus and the scapula relative to each other; elongated ligaments do not prevent excessive motion.

Table 1: Relative ($?_{SH}$) displacement of the rotation center of the scapula and the humerus

	Dominant side	**Opposite side**
	$?_{SH}$	$?_{SH}$
Control group	0.065	0.079
MDI patient	0.223	0.23

Table 2 Components in directions x, y, and z of the relative ($?_{SH}$) displacement of the rotation center of the scapula and the humerus

	Dominant side			**Opposite side**		
	$?_{SH,x}$	$?_{SH,y}$	$?_{SH,z}$	$?_{SH,x}$	$?_{SH,y}$	$?_{SH,z}$
Control group	0.039	0.021	0.047	0.042	0.019	0.064
MDI patient	0.113	0.039	0.174	0.116	0.037	0.195

5.4. Our investigations show that multidirectional shoulder joint instability substantially changes the activity of muscles around the shoulder. The increased role of m. supraspinatus, m. infraspinatus, m. biceps brachii, and m. triceps brachii compensate for the reduced functions of m. pectoralis maior, and all three parts of m. deltoideus. The decreased scapulothoracal movement range is compensated by the increased role of the glenohumeral joint. Reduced muscle functions may be interrelated with an increase of the scope of motion of reflex origin or compensating the elongation of passive structures and with an increase in muscle strength as required for the proper centralization of the glenohumeral joint.

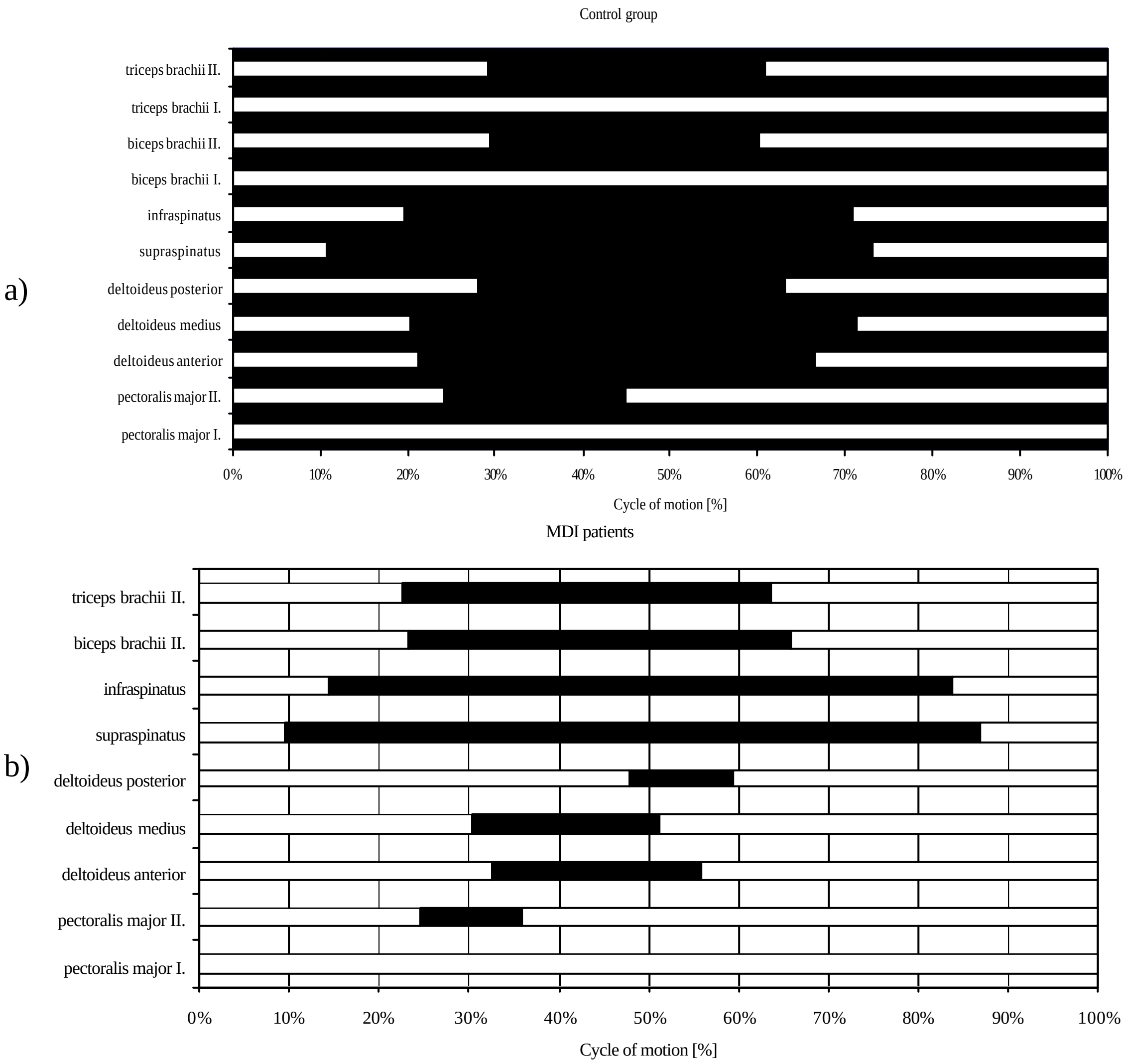


Figure 3 On-off pattern of muscle activity generated by normalization with modified muscle contraction in the course of elevation for a) the control group b) patients with multidirectional shoulder joint instability.

6. Our investigations show that multidirectional instability greatly affects the motion patterns of muscles identified in the course of simple and complex dynamic motions
    6.1. Through the analysis of the on-off pattern of muscle activity (Figure 6) and normalized maximum voluntary contraction values (Table 3), it can be assumed that the centralization of the glenohumeral joint is attempted to be ensured by increasing the role of the rotator cuff muscles and reducing the role of m. deltoideus, m. biceps brachii, and m. pectoralis maior. M. triceps brachii is involved in the centralization of the glenohumeral joint by longer muscle activity but not with increased normalized voluntary contraction. The fact that the normalized maximum voluntary contraction values of the anterior part of m. deltoideus, m. pectoralis maior, and m. biceps brachii – playing a role in launching the motion – are decreased, is also intended to decrease instability.
    6.2. For shoulder joints with multidirectional instability, the time lag between the maximum values of normalized voluntary contraction is significantly larger than in the case of the control group. A possible reason for this discrepancy may lie in the

different neuromuscular control and proprioception of shoulder joints with multidirectional instability, which is produced as a secondary effect due to the looseness of joints.

6.3. In case of multidirectional shoulder joint instability, two subgroups are produced. The role of loosened ligaments must be taken over by muscles; therefore there is no difference between the two subgroups as regards m. supraspinatus, m. infraspinatus, m. biceps brachii, and m. triceps brachii. The only difference is represented by the function of m. deltoideus. 27% of the subjects pertain to the subgroup lacking abduction / adduction, where rotation is the dominant elementary motion; however, the role of rotation is much smaller in producing pulling and forward punch because m. pectoralis maior does not take part in the motion. The reduced elementary motion of rotation may be attributed to the fact that shoulder joint instability would be increased by the elementary motion of rotation, which would be painful. The operation of m. pectoralis maior, primarily functioning as a rotator cuff muscle, is already required for producing complex motion types – elevation and throw. In case of 73% of the subjects, motions of abduction and adduction will be dominant over rotation. This may also prove the fact that rotation may increase instability. Dominant abduction and adduction is caused by the intensified functions of the anterior and central parts of m. deltoideus.

7. My measurements show that the type and intensity of sports activity substantially affects the motion patterns of muscles specified during simple and complex dynamic motion.

7.1. In case of m. deltoideus, there is a discrepancy between the reference motions of the control group and the javelin throwers. This discrepancy is likely to be caused by the fact that in the case of javelin throwers, the shoulder joint is increasingly stressed as a result of quicker motion; bigger forces are produced at the time of launching and decelerating the motion, forcing the humerus head towards a larger antero-posterior displacement in the glenoidal cavity. This means that the anterior and posterior parts of m. deltoideus also reach maximum voluntary contraction during rapid overhead throw. Probably due to their fitness level, javelin throwers can perform elevation by compiling less elementary motions and operating the central part of m. deltoideus, which achieves maximum voluntary contraction at this instance. In the case of the control group – in accordance with physiological function –, the anterior and central parts of m. deltoideus reach maximum voluntary contraction during elevation and the posterior part of m. deltoideus in the course of pulling.

7.2. Based on the analysis of on-off pattern of muscle activity (Figures 4 and 5) and of normalized maximum voluntary contraction values (Table 3), it was established that in the case of javelin throwers, some muscles of the rotator mantle play a greater role during various types of motion as not only their activity periods are extended but their normalized maximum voluntary contractions are also increased. In order to ensure the centralization of the glenohumeral joint, greater muscle contraction is required besides the prolonged function of the posterior parts, and less frequently of the central and anterior parts of m. deltoideus.

7.3. For the javelin throwers, the time difference between the normalized maximum voluntary contractions of agonist and antagonist muscles is smaller during rapid throw than in the control group. This discrepancy can be attributed, most likely, to the different neuromuscular control and proprioception of javelin throwers.

7.4. As regards the javelin throwers, two subgroups can be distinguished. In case of 37.5% of the javelin throwers, rotation is presumed to be dominant as opposed to abduction and adduction as elementary motions, which is caused by the increased activity of m.

pectoralis major. In case of 62.5 % of the javelin throwers, abduction and adduction are the dominant elementary motions, supported by the increased function of the anterior and central parts of m. deltoideus.

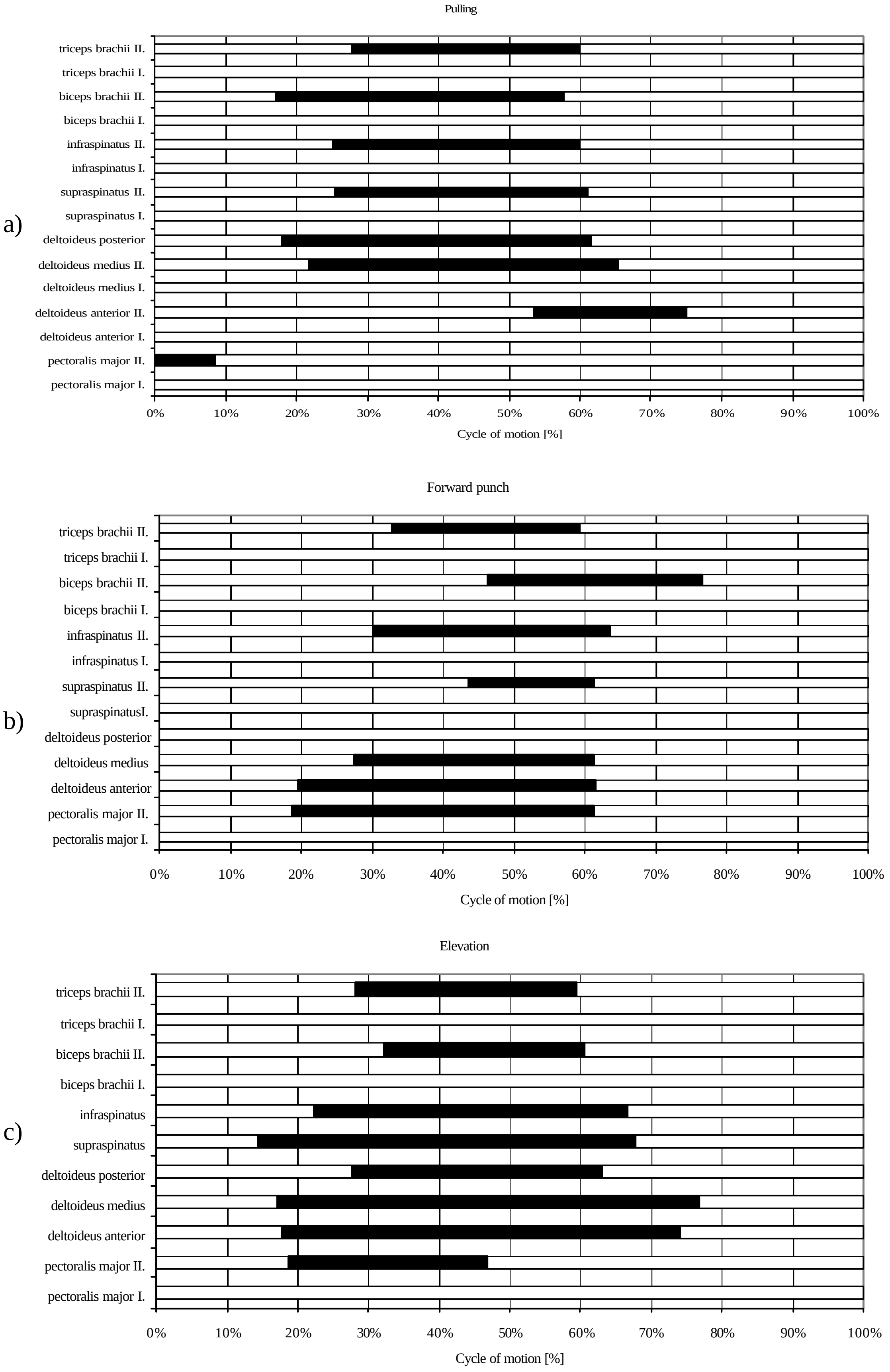


Figure 4 On-off patterns of the muscles examined of the control group during a) pulling b) forward punch c) elevation

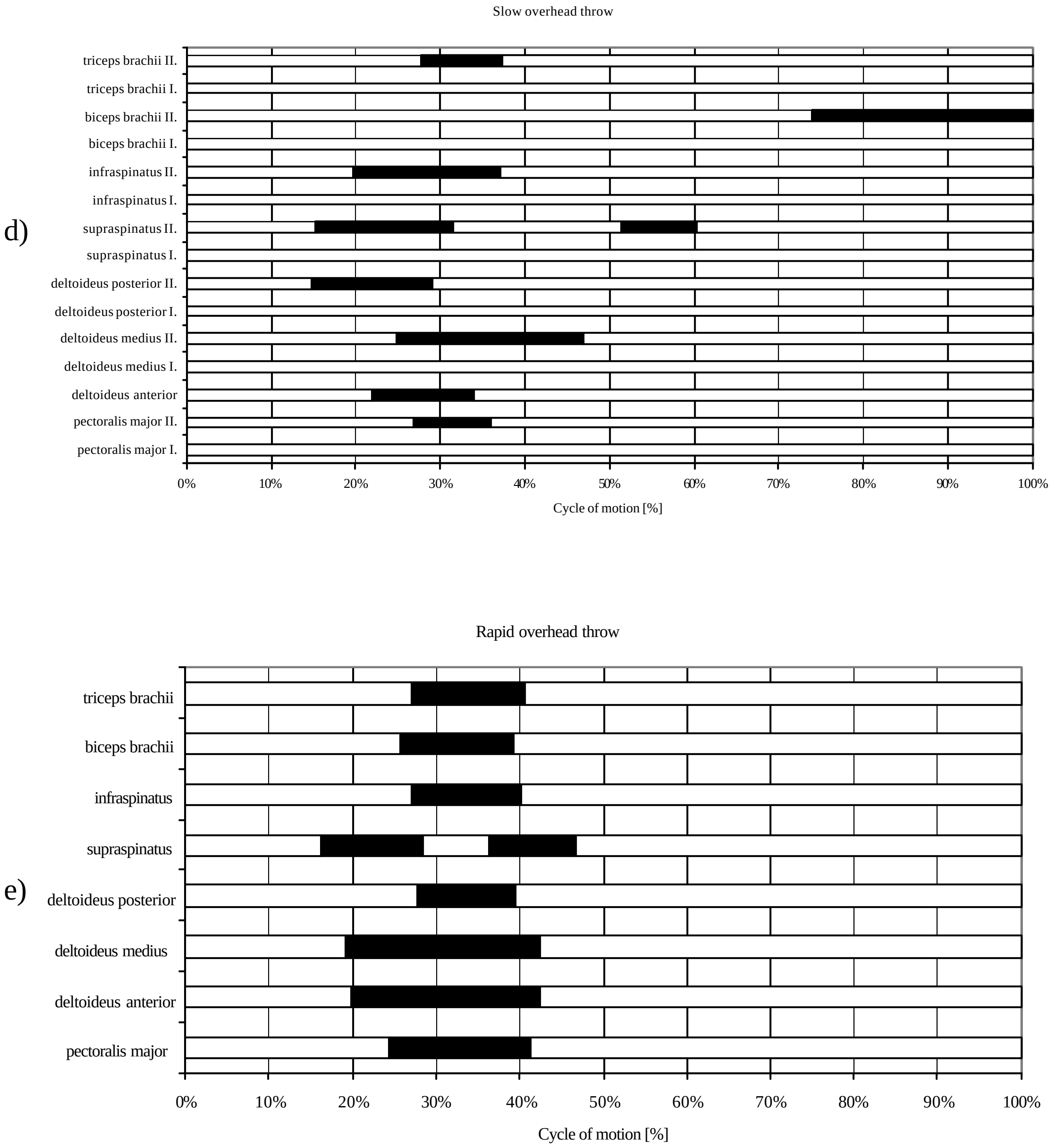


Figure 4 On-off pattern of the muscles examined of the control group during d) slow overhead throw e) rapid overhead throw

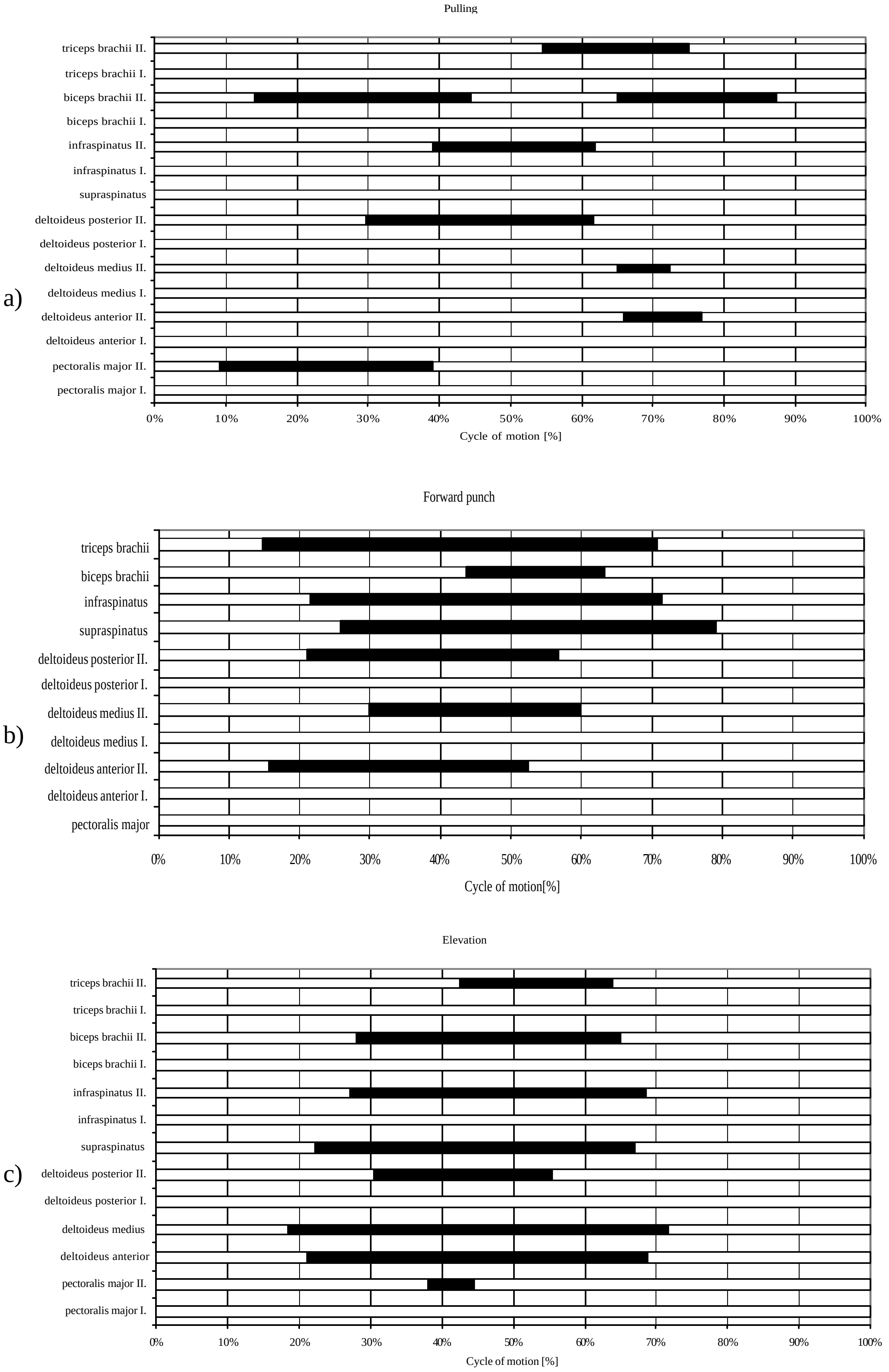
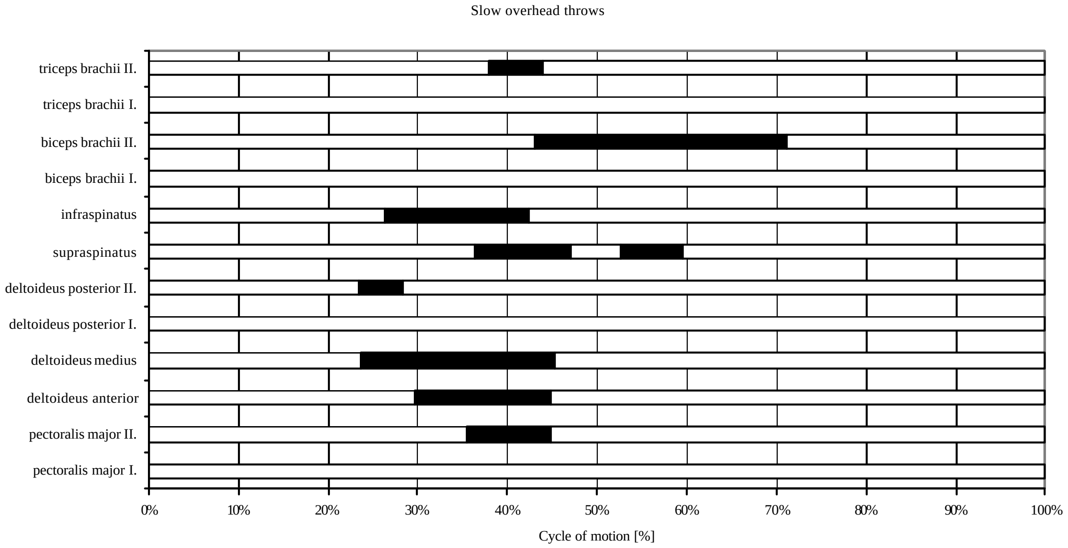


Figure 5 On-off patterns of the muscles examined of javelin throwers during a) pulling b) forward punch c) elevation

d)



e)

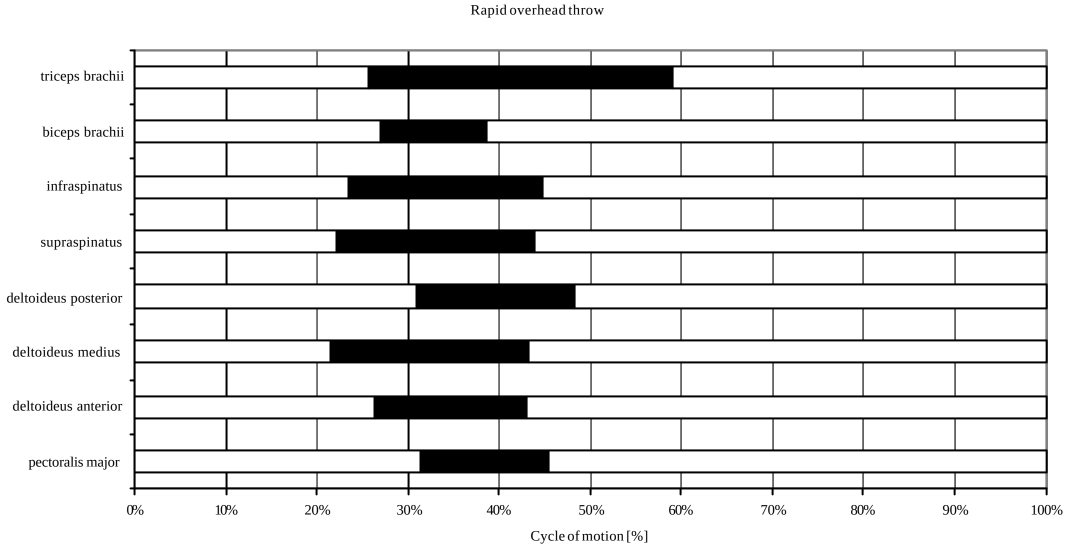


Figure 5 On-off pattern of the muscles examined of javelin throwers during d) slow overhead throw e) rapid overhead throw

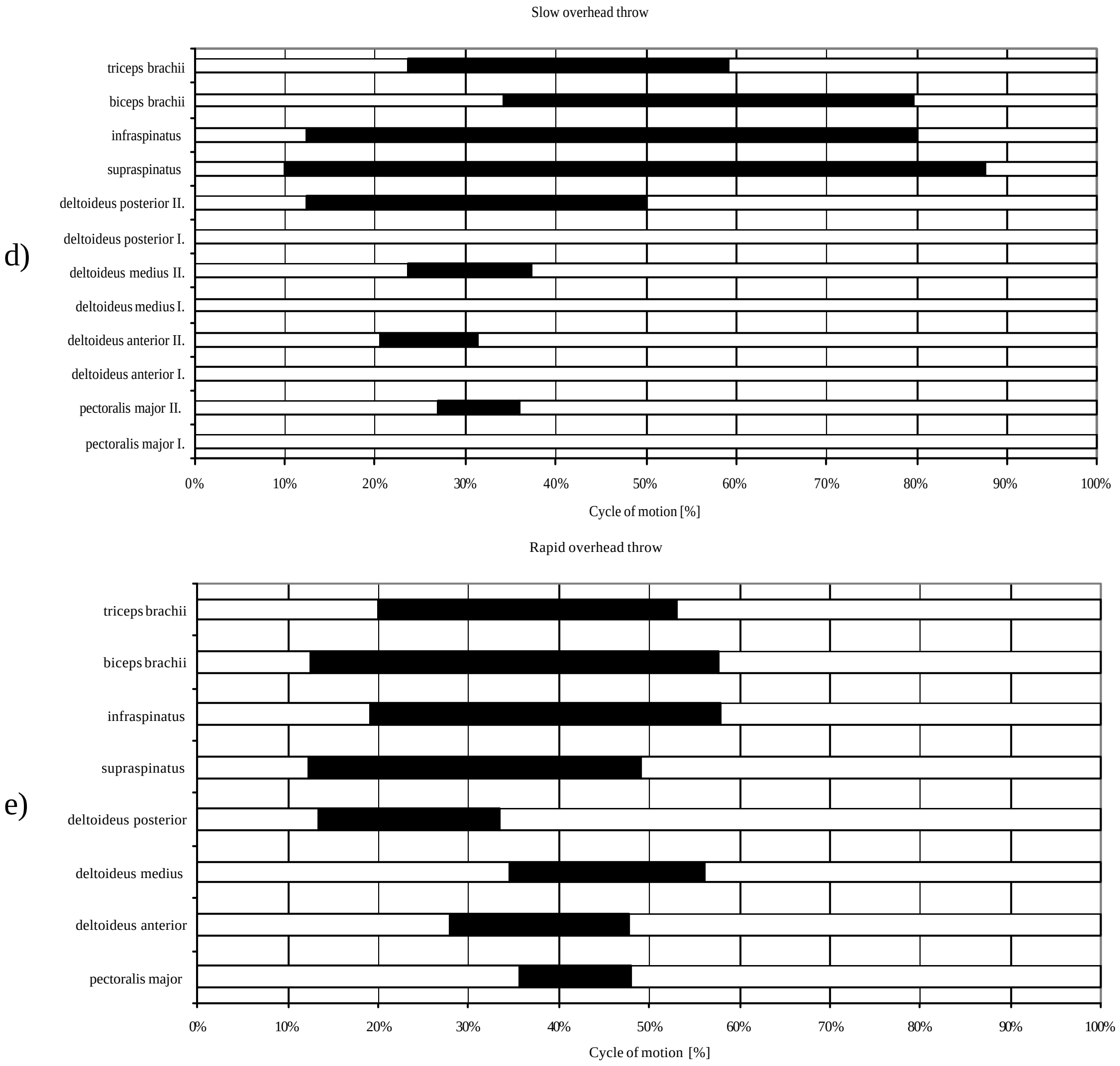


Figure 6 On-off pattern of the muscles examined of patients with multidirectional shoulder joint instability during a d) slow overhead throw e) rapid overhead throw

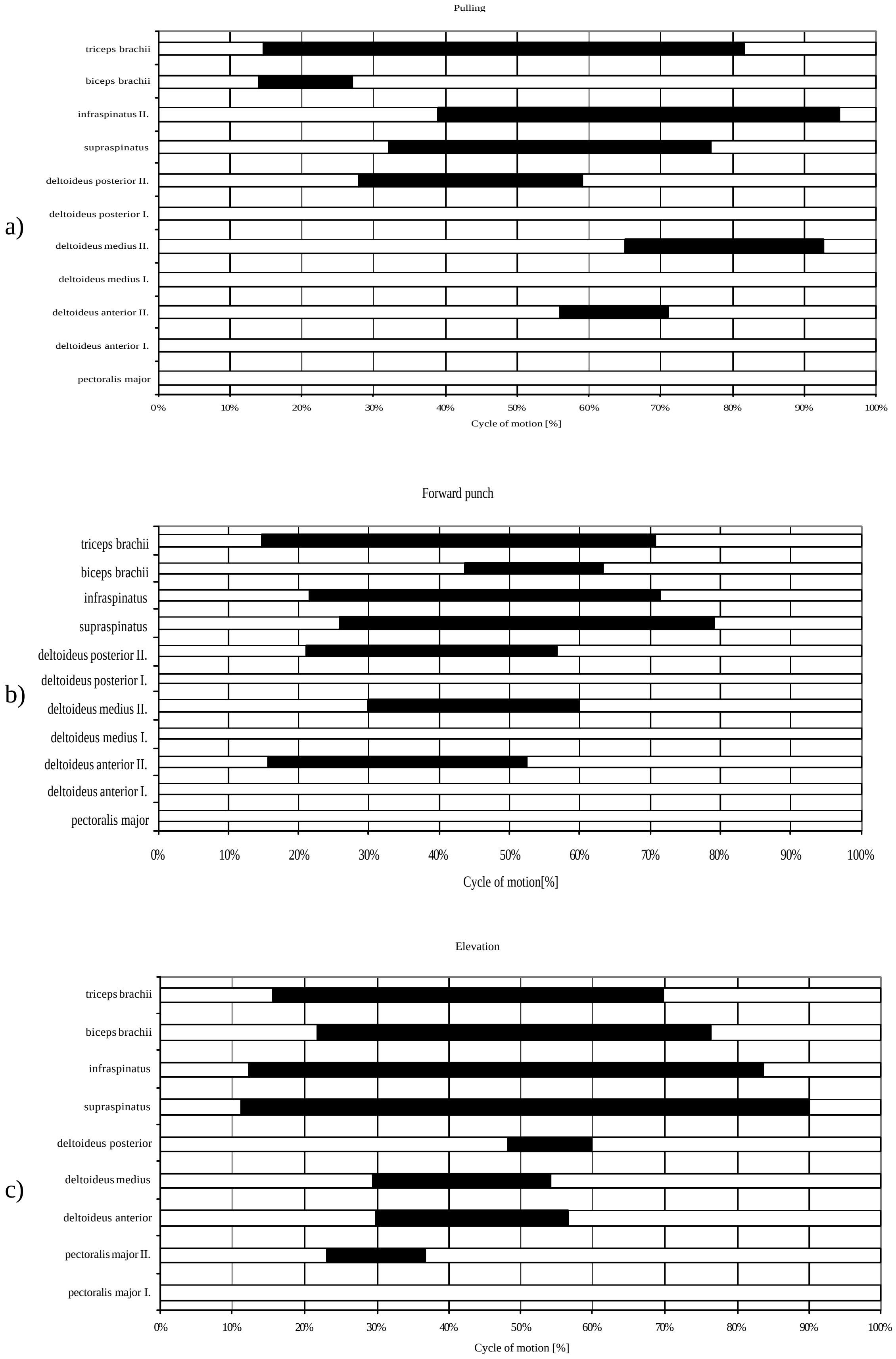


Figure 6 On-off patterns of the muscles examined of patients with multidirectional shoulder joint instability during a) pulling b) forward punch c) elevation

Table 3. Average (standard deviation) and classification of normalized maximum voluntary contraction for the control group, the javelin throwers, and patients with multidirectional shoulder joint instability

		m. pectoralis major	**anterior part of m. deltoideus**	**central part of m. deltoideus**	**posterior part of m. deltoideus**	**m. supra-spinatus**	**m. infra-spinatus**	**m. biceps brachii**	**m. triceps brachii**
Pulling	*Control group*	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)
	n=25	+	+	++	+++	++	++	++	++
	Javelin throwers	29.20 (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)
	n=8	+	+	**+**	**++**	**+**	**+**	**+**	++
	MDI patients	**9.23 (7.23)**	29.15 (31.45)	**39.67 (34.12)**	97.12 (11.78)	67.67 (30.91)	69.17 (45.67)	**21.21 (2.63)**	42.45 (34.12)
	n=15	**0**	+	**+**	+++	++	++	**+**	++
Pushing	*Control group*	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)
	n=25	++	+++	++	+	+	++	++	++
	Javelin throwers	47.60 (33.44)	**65.50 (26.06)**	40.30 (27.09)	24.70 (11.11)	29.30 (16.09)	44.80 (20.51)	53.20 (23.40)	**32.30 (28.53)**
	n=8	++	**++**	++	+	+	++	++	**+**
	MDI patients	**7.60 (2.15)**	**59.15 (26.06)**	**39.23 (35.67)**	**46.78 (11.56)**	**59.89 (17.78)**	54.13 (19.98)	**23.67 (9.34)**	**32.00(26.78)**
	n=15	**0**	**++**	**++**	**++**	**++**	++	**+**	**+**
Elevation	*Control group*	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)
	n=25	+	+++	+++	+++	+++	++	++	++
	Javelin throwers	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)**
	n=8	+	+++	+++	**++**	+++	++	++	**+**
	MDI patients	21.67 (6.78)	**27.12 (23.67)**	83. 90 (19.95)	84.56 (34.98)	91.89 (16.87)	**81.80 (34.56)**	**28.98 (14.67)**	36.34 (6.78)
	n=15	+	**+**	+++	+++	+++	**+++**	**++**	+
Slow throw	*Control group*	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)
	n=25	++	++	++	++	++	++	+	++
	Javelin throwers	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)
	n=8	++	++	++	++	++	++	++	++
	MDI patients	63.20 (25.10)	59.78 (35.14)	58.78 (23.78)	**76.17 (23.78)**	**75.67 (24.89)**	**67.12 (23.55)**	26.34 (23.34)	48.56 (22.98)
	n=15	++	++	++	**+++**	**+++**	**++**	++	++
Rapid throw	*Control group*	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)
	n=25	+++	+++	+++	+++	+++	+++	+++	+++
	Javelin throwers	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)
	n=8	+++	+++	+++	**+++**	+++	+++	+++	+++
	MDI patients	100	75.67 (17.30)	82.34 (17.00)	88.13 (16.78)	**93.99 (9.00)**	**97.36 (8.81)**	**98.14 (5.14)**	100
	n=15	+++	+++	+++	+++	**+++**	**+++**	**+++**	+++

Legend (muscle): 0 inactive + minimum activity ++ medium activity +++ maximum activity. Significant deviations are indicated in bold.