Isokinetic Evaluation of the Elbow Joint at 45° and 80° of Shoulder Abduction

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INTRODUCTION

Since Hislop[1] and Thistle[2] published the first reports on isokinetic exercise, a lot of progress has been made towards the use of isokinetic exercise and isokinetic evaluation of muscle and joint performance in sports and orthopedic physical therapy[3].

Cybex II^{+} with the Cybex Data Reduction Computer is one of the most widely used isokinetic systems for research and rehabilitation purposes. There are more than 500 published works describing the use of Cybex in various applications. Many investigations have used the Cybex isokinetic system to develop normative data on torque and work measurements of various muscle groups. Normative data are valuable to clinicians in the evaluation of the severity of an injury in terms of muscle performance deficits. In addition, such data provide physical therapists with objective data in setting rehabilitation goals, and enabl'ng sports medicine experts to identify functional deficiencies during screening of athletes.

There is a limited number of published works that have devaloped normative data for elbow flexor and extensor muscle groups[4-9]. While there is some information about peak torque and agonist-antagonist ratios, minimal information is available about torque acceleration energy, work endurance ratios, average power and flexion-extension total work ratios.

The purpose of this study was to examine the effects of 45° and 80° of shoulder abduction on torque and work measurements of the elbow joint.

In addition, normative data for elbow flexion and extension at both arm positions (testing positions suggested by Cybex) were developed.

METHODS

SUBJECTS

For the purpose of this study, elbow flexion and extension in forty volunteers was isokinetically evaluated. The subjects, ranging in age from 20 to 27 years old, were male students in the Physical Therapy Department of Athens Educational Institute of Technology. The subjects were randomly selected from a larger sample of male students that satisfied certain criteria for participation in the study, such as right dominant upper limb, no history of dominant upper extremity injury or surgery, no history of cardiovascular or metabolic disease, good health status and no participation in any training program requiring exercise of the upper limbs. All subjects had normal body weight according to their age and height, and they were requested to wear comfortable clothes during testing. The basic personal data of the subjects are presented in Table 1.

INSTRUMENTATION

Isokinetic evaluation was carried out in the ergometry lab of the Physical Therapy Dept. of T.E.I. in Athens using the Cybex II^+ Isokinetic Dynamometer and Instrumentation System with the Cybex Data Reduction Computer. The device was set to measure all values in the metric system (newton meters for torque, joules for TAE and work measurements and Watts for average power). The Cybex II^+ with the C.D.R.C. were calibrated before and mid-way during the study using certified calibration weights and Cybex instructions.

EXPERIMENTAL DESIGN

The subjects were informed of the purpose, methods, possibte risks and benefits from their participation in the study. All subjects were evaluated for upper extremity dominance, and, after a detailed description of the testing procedure was given, they signed a written consent form.

Positioning and stabilization of the subjects was done according to Cybex guidelines[10].

The subjects were instructed to avoid raising the shoulder and the upper arm off the U.B.X.T., the table extension pad or the forearm stabilization V-pad during testing. To ensure a suitable elbow flexion and extension, manual stabilization over the anterior shoulder was given. A great effort was made to maintain the alignment of the elbow joint axis with the axis of rotation of the device, during the testing procedure. However, body movement and change of elbow rotation axis was found difficult to minimize during testing at 80° of shoulder abduction. All positioning, adjustments and manual stabilization were done by one investigator to ensure consistency. Anatomical zero was taken at full extension, and the gravity effect was calculated by the C.D.R.C. at 50° from anatomical zero.

All subjects were asked to perform three submaximal and one maximal trials for adequate warm up and familiarization with the device before the torque and work tests. A 30 second rest period followed, during which shoulder abduction and axis of movement were checked and readjusted if necessary. Each subject was instructed to perform four maximal reciprocal contractions for the torque test and 25 for the work test, as forcefully and as fast as possible, starting the tests from full flexion. The subjects were sufficiently motivated to make a maximal effort by verbal encouragement, given always by the same investigator. A rest period of one minute and thirty seconds was given between the torque test and work trial repetitions.

Half of the subjects tested first with the shoulder at 45° of abduction, while the remaining half tested with the arm at 80° of abduction. After seven days, the first half tested at 80° of abd., while the remaining at 45°. During the seven days rest period between the two isokinetic evaluations, all subjects were instructed to avoid training of their upper extremities.

TABLE 1
Description of Subjects Basic Personal Data

Subjects n=40	Age	Height	Weight	Gravity effect	
				45° abd.	80° abd.
x̄	22 yrs	1.79 m	74.2 Kg	7.1 Nm	7.05 Nm
σ	±2.4	±0.05	±8.3	±0.7	±0.9
range	20-25	1.71-1.86	64-85	6-8	6-8

TABLE 2
Peak torque (PT), peak torque to body weight ratio (PT/BW) and extensors to flexors peak torque ratio (Ext/Flx) during 60°/sec torque test at 45° and 80° of shoulder abduction

Shoulder Abduction	Torque 60°/sec				
	Peak Torque		PT/BW		Ext/Flx
	Flexors	Extensors	Flexors	Extensors	
45°	50.8 Nm ±8.62	49.85 Nm ±8.6	68.45% ±9.48	67.45% ±10.14	98.55% ±11.9
80°	46.18 Nm ±10.09	47.18 Nm ±9.36	62.53% ±11.05	64.68% ±11.43	105.45% ±18.08
Difference P	4.62 Nm P<0.05	2.12 Nm NS	5.92% P<0.01	2.77% NS	−6.9% P<0.05

TABLE 3

Peak torque (PT), peak torque to body weight ratio (PT/BW) and extensors to flexors peak torque ratio (Ext/Flx) during 180°/sec torque test at 45° and 80° of shoulder abduction

Shoulder Abduction	Torque 180°/sec				
	Peak Torque		PT/BW		Ext/Flx
	Flexors	Extensors	Flexors	Extensors	
45°	36.18 Nm ±5.97	34.9 Nm ±6.4	49.7% ±7.19	47.58% ±8.35	96.73% ±12.6
80°	34.10 Nm ±7.89	35.45 Nm ±7.07	46.73% ±7.32	48.1% ±7.39	107.33% ±18.53
Difference P	2.08 Nm NS	−0.55 Nm NS	2.97% $p<0.05$	0.52% NS	−10.6% $p<0.005$

Data analysis

Extensive descriptive statistics were carried out. The range, the mean and the standard deviation of all values printed by the C.D.R.C. were calculated. Therefore, analysis of torque and work measurements for elbow flexion and extension in torque 60°/sec, torque 180°/sec, and work 180°/sec at 45° and 80° of shoulder abduction were made. The differences among the means of torque and work measurements at the two positions of shoulder abduction, as well as the differences between flexors and extensors values in all torques and work tests at both shoulder positions were tested for significance using the student t-tailed test for equal size samples. The level of significance was set at $P<0.05$.

RESULTS

Effects of 45° and 80° of shoulder abduction on elbow flexor and extensor muscle performance

Altering the positioning of the shoulder during testing of the elbow joint, from 45° to 80° of abduction, resulted in several changes on peak torque, peak torque to body weight ratio and extensors to flexors peak torque ratio, all presented in Tables 2 and 3.

Positioning the shoulder at 80° abduction decreased the peak torque of elbow flexors at 60°/sec ($PT_{45°} = 50.8$ Nm > $PT_{80°} = 46.18$ Nm at $P<0.05$), the peak torque to body weight ratio of elbow flexors at 60°/sec ($PT/BW_{45°} = 68.45\%$ > $PT/BW_{80°} = 62.53\%$ at $P<0.01$) and the peak torque to body weight ratio of the same muscle group at 180°/sec ($PT/BW_{45°} = 49.70\%$ > $PT/BW_{80°} = 46.73\%$ at $P<0.05$).

On the other hand, changing shoulder abduction from 45° to 80° was not found to produce statistically significant changes in the peak torque and peak torque to body weight ratio of elbow extensors, at both slow (60°/sec) and fast (180°/sec) angular velocities.

Testing of the elbow joint at 45° of arm abduction was found to decrease peak torque and peak torque to body weight ratio values with higher rates, when going from 60°/sec to 180°/sec test speed, comparing with 80° of abduction testing position.

TABLE 4

Peak torque acceleration energy (TAE), endurance ratio, average power and extensors to flexors total work ratio (Ext/Flx) during 180°/sec work test at 45° and 80° of shoulder abduction

Shoulder abduction	Work 180°/sec						
	TAE		Endurance Rt.		Avg. Power		Ext/Flx
	Flx.	Ext.	Flx.	Ext.	Flx.	Ext.	
45°	8.22Jl ±1.69	10.03Jl ±1.48	47.35% ±9.27	55.55% ±10.36	51.0W ±10.47	56.78W ±10.85	112.4% ±15.95
80°	7.89Jl ±1.67	10.03Jl ±1.89	46.73% ±9.11	54.03% ±9.75	49.27W ±12.45	57.08W ±13.01	119.55% ±26.18
Difference P	0.24Jl NS	— NS	0.62% NS	1.52% NS	1.73W NS	−0.3W NS	−7.15% (NS) P<0.1

TABLE 5

Differences between elbow flexors and extensors on the peak torque and peak torque to body weight ratio during the 60°/sec torque test at 45° and 80° of shoulder abduction

Muscle group	Torque 60°/sec			
	Peak Torque		Peak Torque/Body Weight	
	45°	80°	45°	80°
Flexors	50.8 Nm ±8.62	46.18 Nm ±10.09	68.45% ±9.48	62.53% ±11.05
Extensors	49.85 Nm ±8.6	47.73 Nm ±9.36	67.45% ±10.14	64.68% ±11.43
Difference P<0.05	0.95 Nm NS	−1.55 Nm NS	1.0% NS	−2.15% NS

While positioning the shoulder at 45° of abduction gave a slight (but not significant) advantage to elbow flexors, 80° of shoulder abduction seemed to favor elbow extensors. Therefore, the extensors to flexors peak torque ratio was significantly increased, when arm abduction was changed from 45° to 80°. The latter occured both at 60°/sec ($Ext/Flx_{45°} = 98.55\% < Ext/Flx_{80°} = 105.45\%$ at $P<0.05$) and at 180°/sec ($Ext/Flx_{45°} = 96.73\% < Ext/Flx_{80°} = 107.33\%$ at $P<0.005$), indicating a relative increase of extensors peak torque, compared to flexors, at 80° abduction.

Table 4 presents the effects of altering the degrees of shoulder abduction on selected work measurements of elbow flexors and extensors. Changing arm position from 45° to 80° of abduction did not alter significantly the torque acceleration energy, endurance ratio and average power of elbow flexors and extensors. Positioning the shoulder at 80° of abduction seemed to increase the extensors to flexors total work ratio. However, this difference was not significant at an acceptable level ($Ext/Flx_{45°} = 112.4\% < Ext/Flx_{80°} = 119.55\%$ at $P<0.1$).

Differences between elbow flexors and extensors

In Tables 5 and 6, the torque measurements of elbow flexors and extensors, at both testing positions and angular velocities, are presented and compared. Statistical analysis showed that no significant differences existed between the two muscle groups under all circumstances, as the peak torque and the peak torque to body weight ratio values are concerned.

Extensor muscles were found to have greater work values than flexors, as is indicated in Table 7. Torque acceleration energy was significantly higher for elbow extensors at both testing positions (P<0.005). Extensors' endurance ratio was 55.55% at 45° and 54.03% at 80° of shoulder abduction, while flexors had significantly lower values, 47.35% and 46.73% respectively (P<0.005). Average power of the extensors was significantly greater than flexors, both at 45° (P<0.01) and at 80° of arm abduction (P<0.005).

TABLE 6

Differences between elbow extensors and flexors on the peak torque and peak torque to body weight ratio during the 180°/sec torque test at 45° and 80° of shoulder abduction

Muscle group	Torque 180°/sec			
	Peak Torque		PT/BW	
	45°	80°	45°	80°
Flexors	36.98 Nm ±5.97	34.1 Nm ±7.89	49.70% ±7.19	46.73% ±7.32
Extensors	34.9 Nm ±6.40	35.45 Nm ±7.07	47.58% ±8.35	48.1% ±7.39
Difference P<0.05	1.28 Nm NS	−1.35 Nm NS	2.12% NS	−1.37% NS

TABLE 7

Differences between elbow extensors and flexors on peak torque acceleration energy (TAE), endurance ratio and average power during the 180°/sec work test at 45° and 80° of shoulder abduction

Muscle group	Work 180°/sec					
	PK TAE		Endurance Ratio		Average Power	
	45°	80°	45°	80°	45°	80°
Extensors	10.83Jl ±1.48	10.03Jl ±1.89	55.55% ±10.36	54.03% ±9.75	56.78W ±10.85	57.08W ±13.01
Flexors	8.22Jl ±1.69	7.98Jl ±1.67	47.35% ±9.27	46.73% ±9.11	51.0W ±10.47	49.27W ±12.46
Difference P	1.81Jl P<0.005	2.05Jl P<0.005	8.2% P<0.005	7.3% P<0.005	5.78W P<0.01	7.81W P<0.005

Range of motion and angle position measurements

Tables 8 and 9 show the angles when the elbow flexors and extensors had their peak torque. At 60°/sec, elbow flexors peak torque angle was 95.8° (80° of abd.) and 90.6° (45° abd.). Increasing the speed to 180°/sec did not alter significantly the above values, now being 93.1° for 80° of abduction and 89.0° for 45° abduction but testing at 45° of abduction resulted in lower measurements at both speeds.

The situation was rather complicated for elbow extensors. The angle of peak torque in three fourths of the sample averaged at 63°, ranging from 37° to 92° with no statistical differences between the mean values taken at all testing positions and speeds. However, the remaining one fourth of the sample had the angle of peak torque near the full flexion position (128.5° to 144.9°). It must be noted that no values were found in the 92° to 111° range. Further statistical analysis showed that the mean peak torque of the subjects having the peak torque angle near 63° was not significantly different from those having the same measurement near full flexion, except during the 60°/sec torque test at 45° of abduction.

In figure 1, the torque changes through the R.O.M. of elbow flexors and extensors, during testing at 45° of shoulder abduction and 60°/sec angular velocity (paper speed at 25 mm/sec), are graphically represented.

The time rate of tension development to peak torque was 1.5 seconds for elbow flexors and 1.3 seconds for elbow extensors. The mean total contraction time was about 2.5 seconds with no significant differences between the two muscle groups. The shape of the torque curves confirm the results that indicated a higher T.A.E. value for elbow extensors as calculated by the C.D.R.C. (Table 7). While the left graph represents the flexors' torque changes of all 40 subjects, the right represents the extensors' torque changes of the 31 subjects whose peak torque angle averaged at 62.9° (Table 9). For the remaining 9 subjects (peak torque angle at 134.4°), the curve of their extensors torque changes showed two peaks, one near 135° and the other near 58° from full extension.

TABLE 8

Angle of elbow flexors peak torque at 60°/sec and 180°/sec at 45° and 80° of shoulder abduction

Shoulder Position	Torque 60%/sec	Torque 180°/sec
80°	95.8° ±8.77	93.1° ±11.99
45°	90.6° ±10.52	89.0° ±12.33
Difference P	$P<0.05$	$P<0.05$

TABLE 9

Angle of elbow extensors peak torque at 60°/sec and 180°/sec at 45° and 80° of shoulder abduction

Shoulder Position	Torque 60°/sec		Torque 180°/sec	
	n-32	n-8	n-28	n-12
	63.3°	136.1°	62.9°	134.4°
45°	±12.7	±17.1	±15.7	±12.5
	40°-86°	112°-155°	40°-92°	112°-154°
	n-31	n-9	n-30	n-10
	63.6°	144.9°	62.4°	128.5°
80°	±13.1	±5.5	±14.2	±10.7
	37°-86°	136°-152°	41°-88°	111°-135°
Difference P	NS	P<0.005	NS	P<0.05

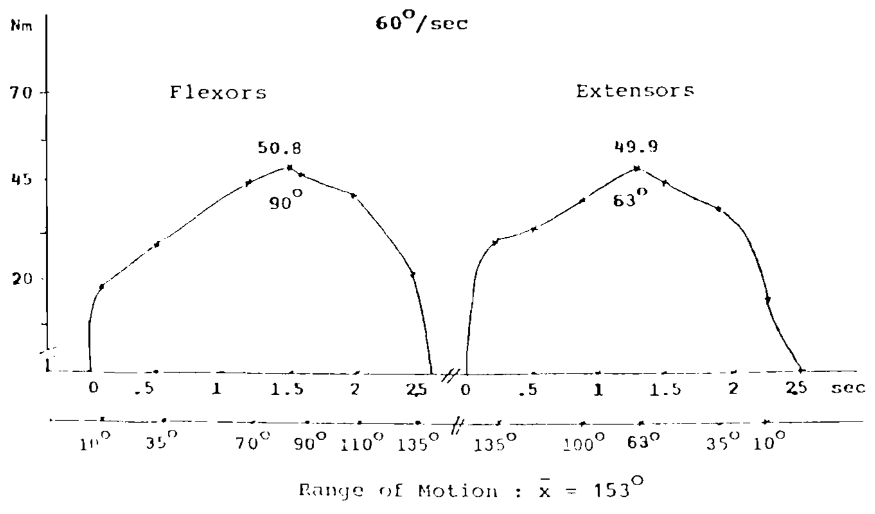

Fig. 1. Graphical representation of the peak torque changes during isokinetic evaluation of elbow flexors and extensors.

DISCUSSION

As it was stated in the introduction, few isokinetic studies have examined thoroughly the elbow flexor and extensor muscles. A review of the literature, did not reveal any study that presented extensive data on torque and work measurements of both muscle groups on young males.

According to Cybex guidelines, elbow flexion and extension was examined with the wrist and the forearm in the mid-position. Positioning the forearm midway between pronation and supination was found by Larson[11] to produce more isometric force than in pronation, while no significant differences were found between mid-position and supination. In addition, electromyographic studies by Basmajian[12] indicated that the midposition of the forearm gave an advantage to all elbow flexors.

Effects of shoulder abduction on torque and work measurements of elbow flexion and extension

The results of the present study showed that flexor torque values decreased with increasing abduction from 45° to 80°, while extensor values remained unaffected.

The prime mover in elbow extension is the medial head of triceps, with the lateral head and angoneus following.[13] All three are one-joint muscles, and since their origin arises from the humerus, shoulder position can not affect their force development.[13] The only extensor that is a two-joint muscle is the long head of triceps. As stated in the literature, the long head of triceps is the weaker muscle among all extensors, and its contribution to elbow extension is very poor.[12] Therefore, it is expected that altering shoulder abduction will not change significantly the extensors torque values.

Among the prime movers in elbow flexion with the forearm at midposition is the biceps, along with the brachiallis and brachioradialis muscles. The biceps is a two-joint muscle, arising from the supraglenoid tubercle of the scapula (long head) and from the coracoid process (short head), thus being affected by shoulder position.[14] Changes in the length-tension relationship and the biomechanical leverage of the biceps may explain the significant differences on elbow flexion torque measurements between the 45° and 80° of shoulder abduction. The results indicated that elbow flexors (and especially the biceps muscle) were in a relatively advantaged position at the 45° of shoulder abduction, compared with the 80° of abduction.

On the other hand, the work measurements of a muscle group are dependent mostly on the histological structure of the muscles and the kind of previous training; parameters that are not affected by limb or body position. Actually, as is shown in table 5, altering shoulder abduction did not change significantly the torque acceleration energy, the work endurance ratio and the average power of both muscle groups.

Finally, altering shoulder abduction did not seem to change significantly the maximum and average range of motion tested. The peak torque angle of elbow flexors was greater at 80° of abduction, while the decrease of torque values of both muscle groups (when increasing the speed from 60°/sec to 180°/sec) was significantly higher at 45° of abduction.

Differences between elbow flexors and extensors

Our results indicated that no statistically significant differences existed among the torque values of elbow flexors and extensors, at both shoulder positions and testing speeds (Tables 5 and 6).

Knapik and Ramos[6] reported similar results after they tested 352 young ($\bar{x}$ = 23.2 yrs) males, whose upper limbs had not been systematically trained. As is shown on the torque-velocity curve that the authors provide, near 60°/sec the peak torque of the two muscle groups did not differ notably. While at 30°/sec elbow flexors seem to be stronger than extensors (≈6.5 Nm difference), at 90°/sec and at 180°/sec elbow extensors seem to be stronger by a difference of 2-3 Nm. However, no sufficient descriptive data and statistics are provided. Therefore, the statistical significance of the differences noted before is not known. In addition, the authors do not give other important information, such as the forearm and shoulder positioning during isokinetic testing.

Knapik et al[9] published another study in 1983 examining the elbow flexion and extension on 16 young ($\bar{x}$ = 26 yrs) males, with their upper limb not specially trained. The peak torque values of elbow flexors and extensors were similar at all testing speeds (36°/sec, 108°/sec and 180°/sec), with the differennce between them ranging from 0 to 2 Nm.

Knapik and Ramos[6] in 1980 reported a peak torque of 26-28 Nm for elbow flexors and extensors at 180°/sec. Knapik et al[9] in 1983, reported 42-43 Nm at 180°/sec. In the present study, the peak torque of elbow flexors and extensors at 180°/sec ranged between 34-36 Nm. The variations noted before can be explained by population, sampling and experimental design differences (positioning, stabilization, gravity correction etc.).

In another study, the peak torque of elbow flexors was found significantly lower than extensors at 45°/sec, 240°/sec and 300°/sec. The flexors to extensors peak torque ratio ranged between 63% and 70%. However, the subjects of this study were sampled from a highly skilled athletic population, namely, the U.S.A. Cross Country Ski team.

As Table 7 indicates, the extensors work measurements were significantly higher than flexors at both shoulder positions. A search of the literature, did not reveal any studies that examined the work capacity and performance of elbow flexors and extensors. Since all subjects in the present study were healthy students with their upper limb never trained, differences in distribution of muscle fiber types and histological structure may be responsible for the higher work values of the extensors that were noted.

Angle of peak torque

The angle of peak torque has been found to be one of the least reliable measurements that can be recorded during isokinetic evaluation of a muscle group[16], and it is usually highly variable in individual subjects.[9] Many studies provide data regarding the angle of maximum isometric strength of elbow flexors and extensors, while fewer studies examine the angle of peak torque measured isokinetically. In attempting to discuss the results of the present studies, one must bear in mind that there is no agreement in the literature on whether isometric values can be used to predict isokinetic performance.

In the present study, elbow extensors had their peak torque near 63° from full extension. Currier[17] examined the isometric strength of elbow extensors at 60°, 90° and 120° from full extension. The highest isometric tension occured at 90°. Ostering[4] reported that maximum isometric torque was recorded at 80°, while isokinetic testing gave the angle of extensors peak torque at 90° from full extension. Singh and Karpovich[18] found that after 90° the peak torque of elbow extensors declined, while their results indicated very little change in isometric and isotonic-concentric force from 40° to 90°. The angle of maximum isometric torque of elbow extensors was recorded at 90° for men and at 70° for women in the study by Knapik et al.[9] When the mode of exercise was shifted to the study by isokinetics, the peak torque angle was near 70° for both men and women.

As Table 8 indicates, the angle of peak torque for the flaxors was near 90° from full flexion, with the shoulder at 45° of abduction. The results derived from different studies indicate that little isometric difference exists between the range of 70° to 90°.[18,19] Knapik et al[9] reported an angle of 90° for maximum isometric torque in men and women, while during isokinetic testing the flexors peak torque angle was 70° for men and 90° for women.

It has been found that by increasing the speed during isokinetic testing, the angle of peak torque tended to occur later in the range of motion. In the present study, no significant changes were noted between the 60°/sec and 180°/sec as the angle of peak torque of both muscle groups in concerned. Also, Knapik et al[9] reported that the shift of peak torque angle occured less often in the elbow joint, compared with the knee, and in fact, occured only in elbow extension of men.

CONCLUSIONS

The major findings of this study may be summarized as folloes:

1. No statistically significant differences were found between the torque values of elbow flexors and extensors at both testing positions and speeds. On the other hand, work measurements were significantly higher for elbow extensors at both testing positions.
2. The torque values of both muscle groups were significantly lower when testing at 180°/sec, compared with the 60°/sec. The rate of decrease was similar for both muscle groups, and it was higher when going from 80° to 45° of shoulder abduction.
3. During all tests, the Max R.O.M. tested was not affected by arm position and testing speed, ranging from 154° to 156°.
4. The peak torque angle of elbow flexors was near 90° from full flexion. Changing the speed from 60°/sec to 180°/sec did not affect significantly the results, while testing at 80° of shoulder abduction gave higher values (95°). For three fourths of the subjects, the extensor's angle of peak torque was found near 63°, not affected by testing position and speed; however, for the remainning subjects the angle ranged from 128° to 145°, resulting in a rather complicated situation difficult to explain.
5. Altering the position of the shoulder, from 45° to 80° of abduction decreased the torque values of elbow flexors, while the respective values of elbow extensors remained unaffected. Shoulder abduction did not affect the work measurements of both muscle groups.

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