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Electromyographic analysis of the glenohumeral muscles during a baseball rehabilitation program

HAL TOWNSEND,*† MD, FRANK W. JOBE,*† MD, MARILYN PINK,*‡ MS, PT, AND JACQUELIN PERRY,* MD

*From the *Biomechanics Laboratory, Centinela Hospital Medical Center, and the †Kerlan-Jobe Orthopaedic Clinic, Inglewood, California*

ABSTRACT

Many exercises are used to strengthen the glenohumeral muscles, but there have been limited studies to evaluate the exercises. Thus, the purpose of this study was to decide how the muscles responsible for humeral motion can best be exercised in a rehabilitation program for the throwing athlete. Dynamic, fine wire, intramuscular electromyography was carried out in 15 normal male volunteers performing 17 shoulder exercises derived from a shoulder rehabilitation program used by professional baseball clubs. The four rotator cuff muscles were studied, as well as other positioners of the humerus, including the pectoralis major, latissimus dorsi, and three portions of the deltoid. The electromyographic activity was synchronized with cinematography and averaged over 30° arcs of motion. An exercise was considered to be a significant challenge for a muscle if it generated at least 50% of its predetermined maximum contraction over three consecutive arcs (i.e., a 90° range). Four exercises were consistently found to be among the most challenging exercises for every muscle. These shoulder exercises consisted of 1) elevation in the scapular plane with thumbs down, 2) flexion, 3) horizontal abduction with arms externally rotated, and 4) press-up. This study documents that the minimum for an effective and succinct rehabilitation protocol for the glenohumeral muscles would include these exercises.

The normal shoulder demonstrates an important balance between stability and mobility. The shallow glenoid affords the large degree of motion necessary to position the hand in space, while rotator cuff action is crucial to dynamic glenohumeral stability. Inman et al.[9] described the importance of force coupling between the deltoid and rotator cuff, noting their synergistic actions during arm abduction. The shear forces across the joint resulting from the upward pull of the deltoids are balanced by the synchronous firing of the cuff, allowing efficient elevation of the arm. DeLuca and Forrest[5] provided further insight to the deltoid-supraspinatus interaction by publishing a quantitative description of moments and instant centers from shoulder radiographs in 1973. In a recent work, Bassett et al.[2] used a computer-assisted, gross muscle, cross-section analysis to provide a three-dimensional model to calculate moments and vector forces of the shoulder musculature. Saha[11] grouped the muscles acting across the glenohumeral joint into three functional categories on an anatomical basis. He believed that the "prime movers," consisting of the deltoid and clavicular head of the pectoralis major, had the large mechanical advantage, while the "steering muscles," including the supraspinatus, subscapularis, and infraspinatus, were responsible for maintaining the humeral head in the glenoid. The latissimus dorsi, teres major and minor, and sternal head of the pectoralis major were grouped as "depressors."

Most shoulder rehabilitation programs in the past have been based on knowledge of anatomy, clinical experience, and undocumented electromyography (EMG) work, but there has been limited information available to evaluate the exercises. Even though a muscle seems to have the origin and insertion aligned to perform a particular motion, it may be inactive during performance of that motion.[4] In a recent study by Moseley et al.,[10] the scapular rotator muscles were examined by EMG analysis during a shoulder rehabilitation program. Four exercises (scapular plane elevation, rowing, "push-up plus," and press-up) were considered key to the strengthening of these muscles.

The purpose of this study was to determine the optimal

‡ Address correspondence and reprint requests to: Marilyn Pink, MS, PT, Centinela Hospital Medical Center, Biomechanics Laboratory, 555 East Hardy Street, Inglewood, CA 90301.

exercises for the glenohumeral muscles as part of a shoulder rehabilitation program for the throwing athlete.

MATERIALS AND METHODS

The dominant shoulder of 15 male subjects, aged 23 to 34 years, was studied in the Biomechanics Laboratory at Centinela Hospital in Inglewood, California. None had a prior history of shoulder instability or abnormality.

The muscles studied included the nine glenohumeral muscles: three parts of the deltoid (anterior, middle, and posterior), the pectoralis major, the latissimus dorsi, and the rotator cuff (subscapularis, supraspinatus, infraspinatus, and teres minor).

Each subject performed 17 exercises based on a shoulder rehabilitation program used at the Kerlan-Jobe Orthopaedic Clinic, and by the Los Angeles Dodgers and the California Angels baseball teams. The exercises were done concentrically with the subject pausing at the top of the range, then eccentrically to bring the arm back to the starting position. Each was carried out in a highly controlled manner, emphasizing low intensity using light weights and low speeds. The 17 exercises used are shown in Figures 1 to 17.

Dual 50 micrometer insulated wires with 2 to 3 mm bared tips were inserted into the desired muscle using a 25 gauge hypodermic needle as a cannula in the technique described by Basmajian and Bazant.[1] The wires from each muscle were attached to ground plates and taped to the subject's body. The signals from the wires were transmitted using an FM-

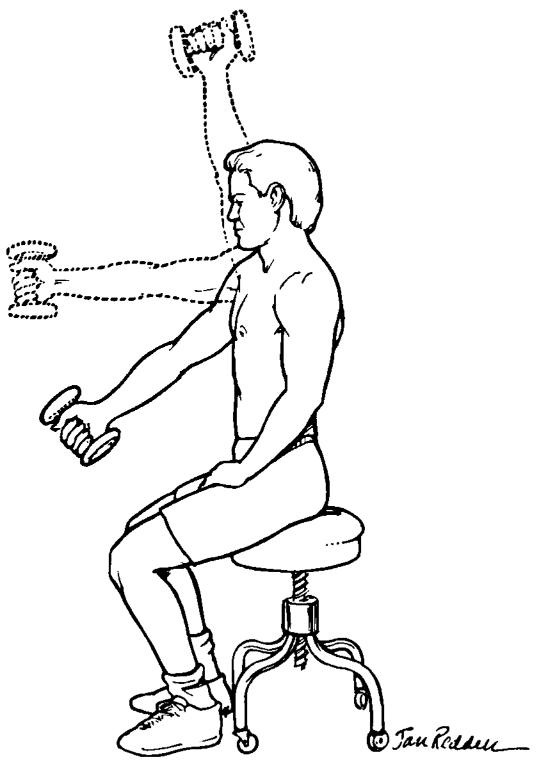

Figure 1. Elevation of the arm in the sagittal plane (flexion).

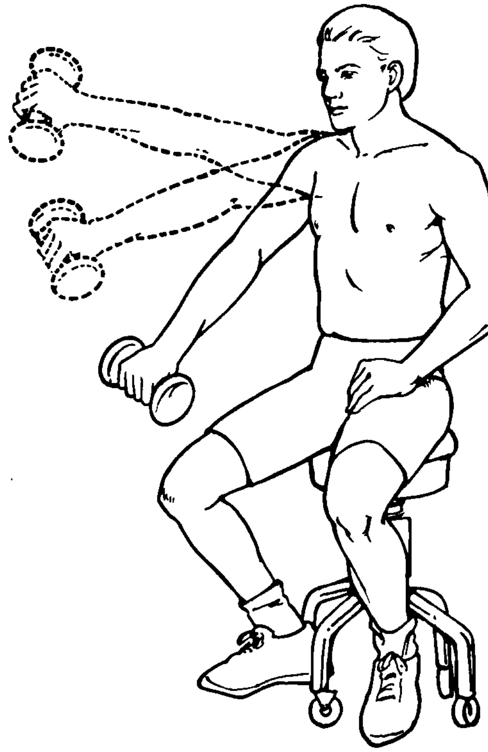

Figure 2. Elevation of the arm in the scapular plane (scaption) with the arm internally rotated (thumbs down).

FM telemetry system (model 4200-A, Biosentry Telemetry, Torrance, CA) which was capable of transmitting up to five muscles simultaneously. Correct wire electrode placement was confirmed by electrical stimulation of the muscle through the inserted wires, or by a manual muscle test specific to the inserted muscle with the telemetry signal monitored on an oscilloscope. The EMG information was filtered at a center frequency of 300 Hz and recorded on a multichannel instrumentation recorder for later retrieval and review.

The EMG data were converted from analog to digital signals by computer at a sampling rate of 2500 Hz and was quantified by computer integration. After excluding the noise identified by the resting recording, the peak 1 second EMG signal during a maximum manual muscle strength test (MMT) was selected as a normalizing value (100%) for each subject. Activity patterns were assessed every 20 msec and expressed as a percent of the normalization base (% MMT).

The muscle activity generated was synchronized to the subject's motion using a 16 mm high-speed motion picture camera operating at 50 frames per second. Marks were electronically placed on the film and EMG data to allow for synchronization. All of the exercises, except the press-up, were divided into 30° arcs of concentric and eccentric motion with an isometric contraction at the top of the range. The press-up was divided into seven arcs, reflecting the first two halves of the upward motion, the three seconds of holding the motion, and the two halves of the downward motion. The EMG activity was averaged for each arc and expressed as a % MMT. Each subject thus generated a number, rep-

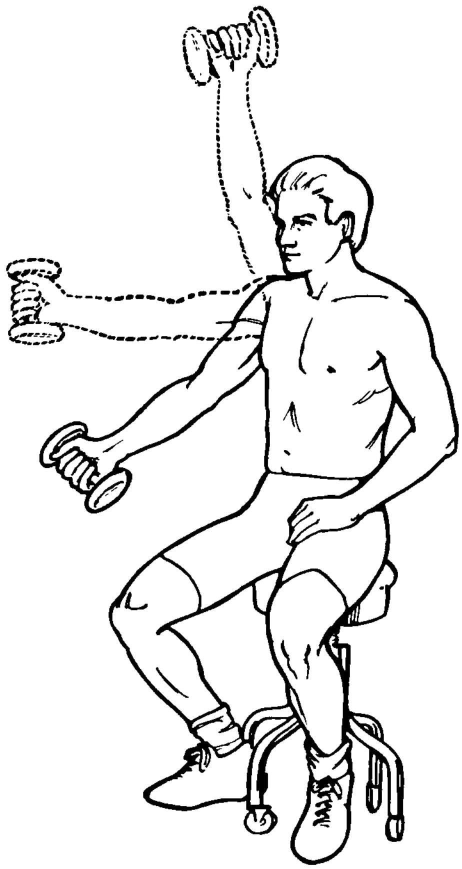

Figure 3. Elevation of the arm in the scapular plane (scaption) with the arm externally rotated (thumbs up).

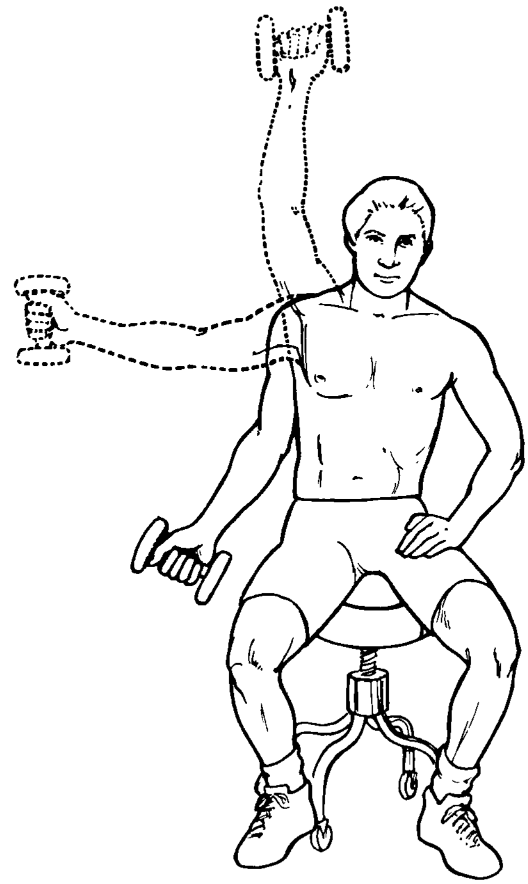

Figure 4. Elevation of the arm in the coronal plane (abduction).

resenting the average muscle activity for each muscle, during each arc of each exercise.

Once the data were collected, outliers were evaluated to determine the validity of the signal (i.e., noise, interference, poor signal). If it was an invalid signal, the data were deleted. The data from all 15 subjects were used to calculate the means and standard deviations of activity generated by each muscle during each arc of each exercise.

Both intensity and duration were thought to be important factors in evaluating the exercises. An exercise was considered to qualify as a significant challenge for a particular muscle if the EMG activity generated was greater than 50% MMT over at least three consecutive arcs of motion for that muscle. The amount of time the exercise met the qualifying criterion (i.e., the number of arcs) was called the duration and was expressed as a percent of the exercise. The one arc with the greatest activity was called the peak, and the exercise ranked according to this peak value. The only exception was the subscapularis for which no exercise qualified under this criterion. Therefore, two consecutive arcs exceeding 50% MMT, and three arcs over 40% were used.

RESULTS

The anterior deltoid had five exercises that met the criterion. The leading exercise was elevation of the arm in the scapular

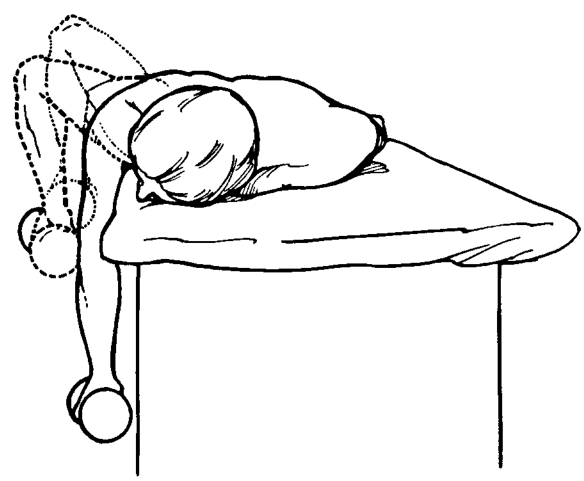

Figure 5. Rowing.

plane (scaption) with the arm internally rotated. This had a peak activity of 72% MMT at the fourth concentric arc and a duration of 50%. The next highest qualifiers were scaption in external rotation, and flexion both with peak activities in the fourth concentric arcs of 71% and 69% MMT, respectively, and durations of 30% and 31%. Military press and abduction both had peaks of 62% MMT in the

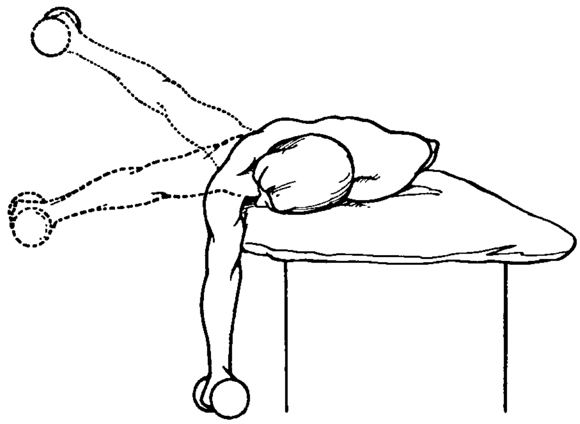

Figure 6. Horizontal shoulder abduction with the arm internally rotated.

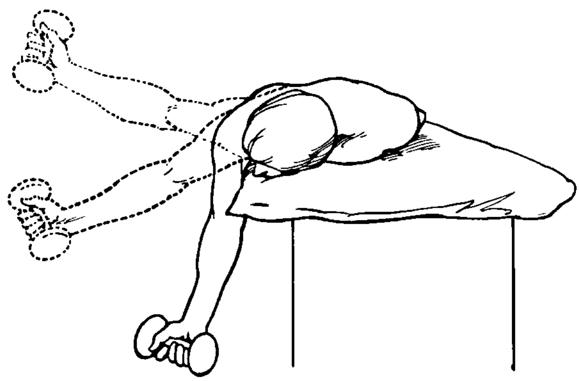

Figure 7. Horizontal shoulder abduction with the arm externally rotated.

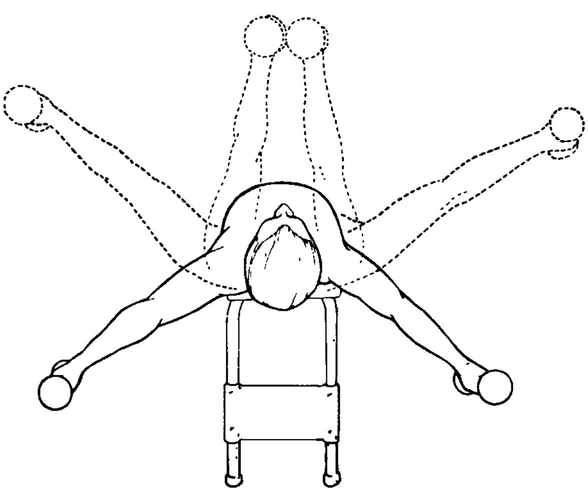

Figure 8. Horizontal adduction.

second and fourth concentric arcs, respectively, and durations of 50% and 31% (Table 1).

Scaption in internal rotation was also the top exercise for the middle deltoid, with a peak of 83% MMT during the fourth concentric arc and a duration of 70%. Horizontal abduction in internal rotation, horizontal abduction in ex-

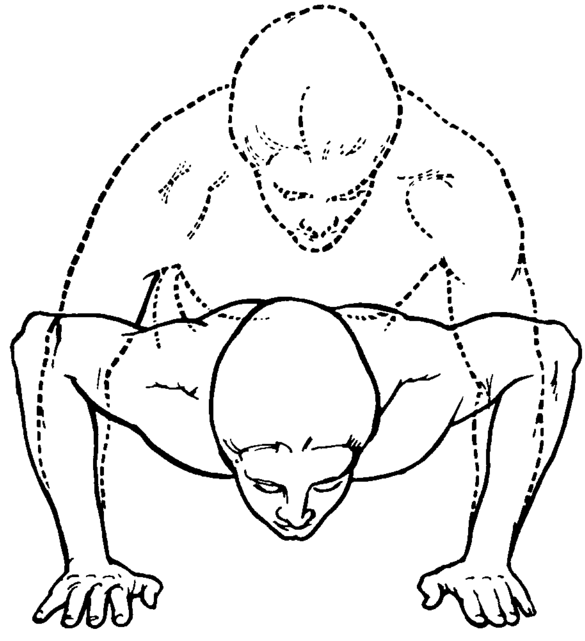

Figure 9. Normal push-up.

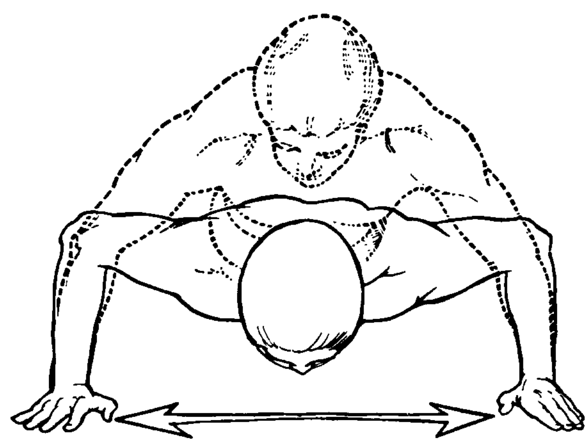

Figure 10. Push-up with the hands apart.

ternal rotation, and flexion were next highest with peak activities in the fourth concentric arcs of 80%, 79%, and 73% MMT, and durations of 38%, 57%, and 31%, respectively. Scaption in external rotation, rowing, and military press all had peaks of 72% MMT in the fourth concentric arc, and durations of 58%, 43%, and 38%, respectively. Abduction had 64% MMT in the fourth concentric arc and a duration of 31%. Deceleration had a 58% peak MMT in the third concentric arc of motion and a 27% duration (Table 1).

The leading exercises for the posterior deltoid were horizontal abduction both with the arm in internal (peak of 93% MMT) and external rotation (peak of 92% MMT) during the fourth concentric arc and durations of 63% and 57%, respectively. Rowing was third with a peak of 88% MMT in the fourth concentric arc and a duration of 57%. External rotation displayed a peak of 64% MMT at the third concentric arc and a 43% duration. A peak activity of 63% MMT

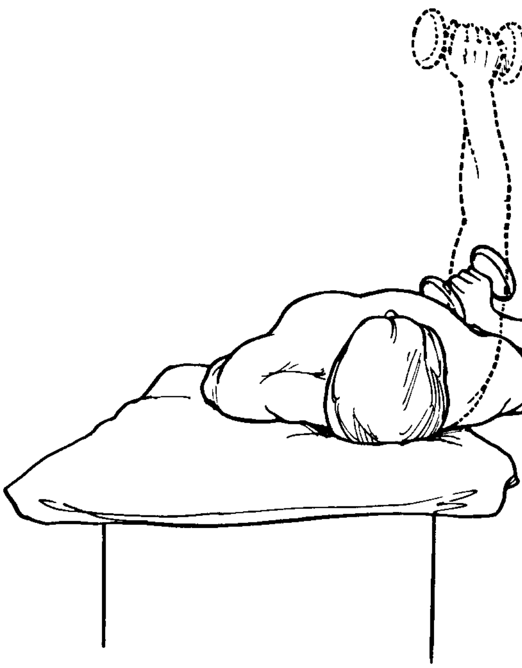

Figure 11. Bench press.

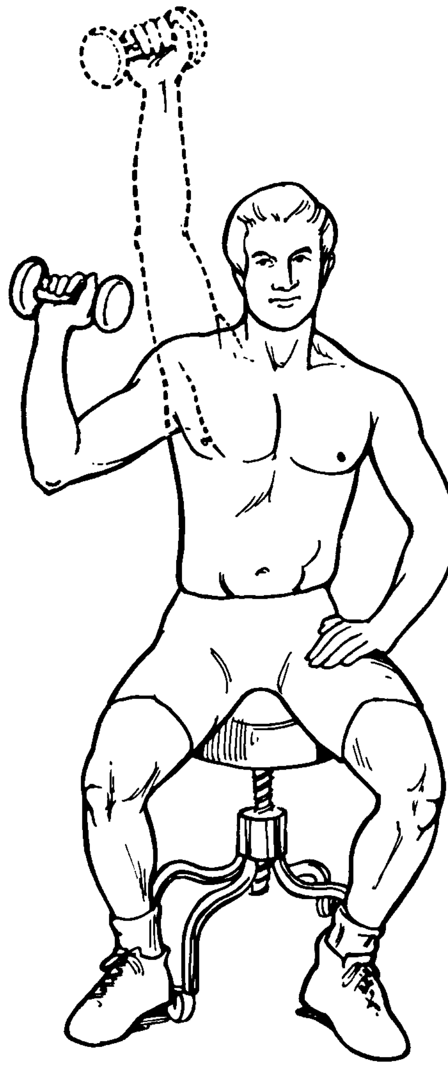

Figure 12. Military press.

in the third concentric arc was noted in deceleration, having a duration of 27% (Table 1).

The supraspinatus had four exercises that met the criterion. The top exercise was military press, which had a peak activity of 80% MMT at the first concentric arc and duration of 50%. Scaption with internal rotation was second with a peak value of 74% MMT at the fourth concentric arc and a duration of 40%. Flexion had a peak at the fourth concentric arc of 67% MMT and a duration of 31%. Scaption with external rotation had a peak of 64% MMT and duration of 25% (Table 1).

The subscapularis had no exercises meeting the initial criterion. Therefore, the qualifying criterion was decreased to two arcs of motion over 50% MMT. At this level only one exercise, scaption with internal rotation, qualified. The peak activity was 62% MMT seen at the fifth concentric arc with a duration of 22%. If the criterion was decreased to 40% MMT, three more exercises qualified. Military press had a peak of 56% MMT at the fourth concentric arc and a duration of 50%. Both flexion and abduction had peaks in the fifth concentric arc of 52% and 50% MMT, respectively, and durations of 23% (Table 1). Internal rotation had a peak arc of 31% MMT.

The leading exercise for the infraspinatus was horizontal abduction with external rotation. This had a peak activity level of 88% MMT at the fourth concentric arc and a duration of 71%. External rotation had a peak of 85% MMT at the third concentric arc and a duration of 43%. Horizontal abduction in internal rotation had a peak of 74% MMT at the fourth concentric arc and a 38% duration (Table 1). Five other exercises qualified for the infraspinatus: abduction, flexion, scaption in external rotation, deceleration, and push-up (hands together).

The leading exercises for the teres minor were external rotation and horizontal abduction in external rotation, with peak activities of 80% and 74% MMT, respectively, and durations of 57%. The only other qualifier was horizontal abduction with internal rotation. It generated 68% MMT during the second concentric arc and had a duration of 43% (Table 1).

The press-up and push-up with hands apart both qualified for the pectoralis major with peak arcs of 84% and 64% MMT. The durations were 75% and 50%, respectively (Table 1).

The press-up was the only exercise to meet the criterion for the latissimus dorsi. This had 55% peak activity during the 1st second of isometric contraction and a duration of 50% (Table 1).

Internal rotation, bench press, and horizontal adduction did not meet the qualifying criterion for any of the muscles tested.

DISCUSSION

Previous work by Stookey,[12] Inman et al.,[9] and Yamshon and Bierman[13] have all shown the importance of deltoid

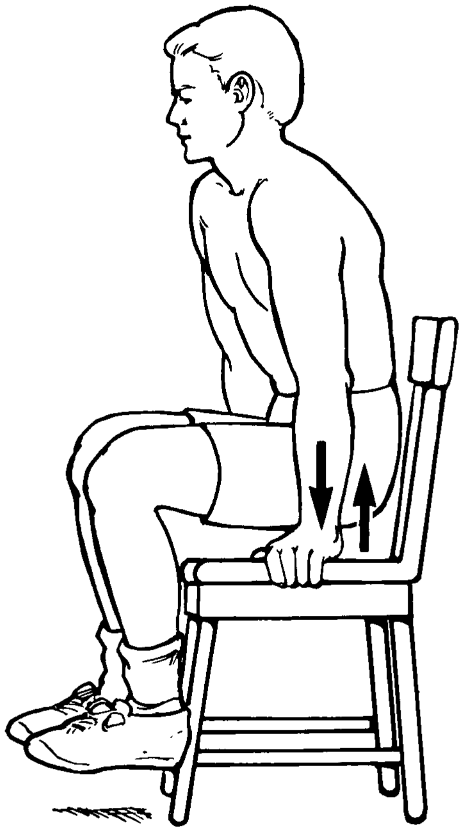

Figure 13. Press-up.

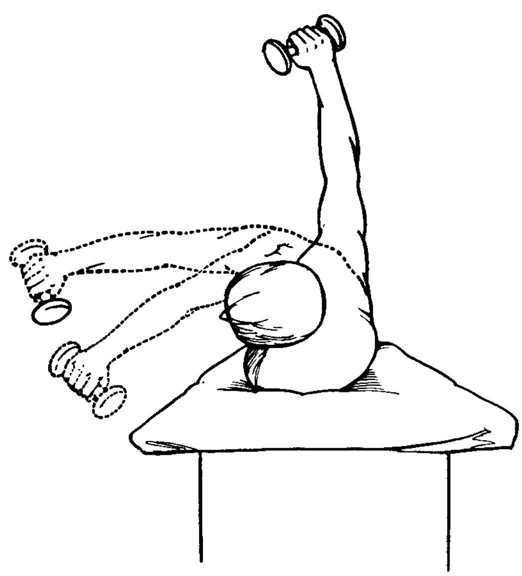

Figure 14. Deceleration (simulating the pitching follow-through).

function during elevation in all planes. This correlates with our findings showing that the exercises of elevation in the frontal, sagittal, and scapular planes all met our qualifying criterion for both the anterior and middle deltoids. None of these exercises, however, qualified for the posterior deltoid,

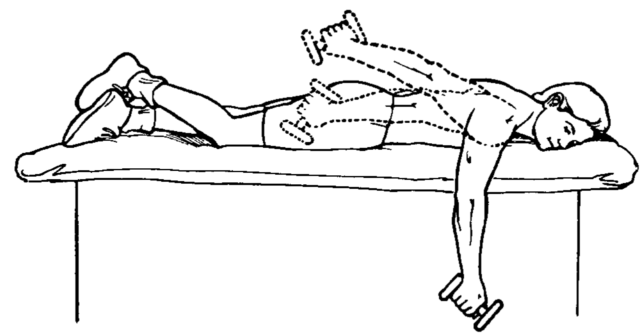

Figure 15. Shoulder extension prone.

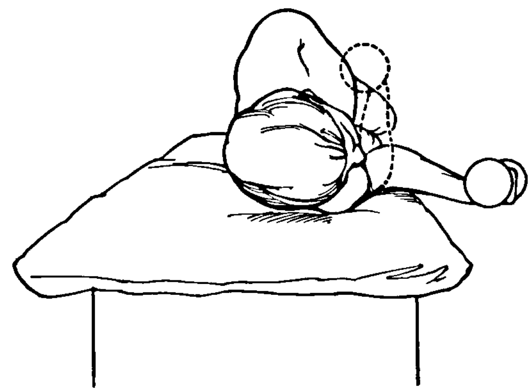

Figure 16. Internal rotation.

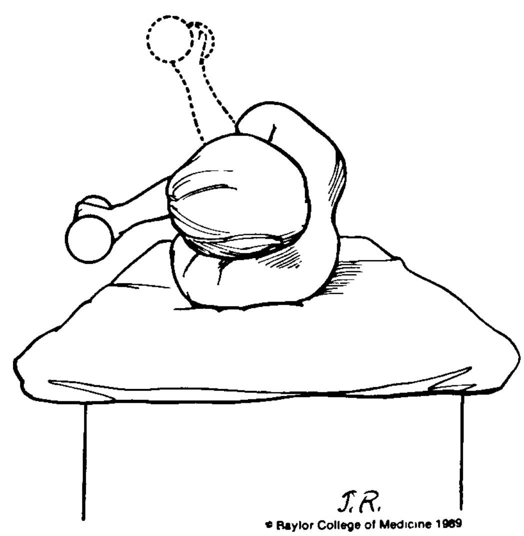

Figure 17. External rotation.

which was more active in horizontal abduction, extension, and external rotation.

Of the four exercises meeting the criterion for the supraspinatus (military press, both scaption maneuvers, and flexion), all were involved in humeral elevation. This is consistent with the work of Howell et al.,[8] who used isolated paralysis of the suprascapular and axillary nerves. They found essentially equal torque contributions from the deltoid and the supraspinatus/infraspinatus complex in forward

TABLE 1
Qualifying exercises for each muscle[a]

Muscle	Exercise	Peak (% MMT ± SD)	Duration (% Exercise)	Peak arc range (deg)
Anterior deltoid	Scaption IR	72 ± 23	**50**	90–150
	Scaption ER	71 ± 39	**30**	90–120
	Flexion	69 ± 24	**31**	90–120
	Military press	62 ± 26	**50**	60–90
	Abduction	62 ± 28	**31**	90–120
Middle deltoid	Scaption IR	83 ± 13	**70**	90–120
	Horiz. abd. IR	80 ± 23	**38**	90–120
	Horiz. abd. ER	79 ± 20	**57**	90–120
	Flexion	73 ± 16	**31**	90–120
	Scaption ER	72 ± 13	**58**	90–120
	Rowing	72 ± 20	**43**	90–120
	Military press	72 ± 24	**38**	90–120
	Abduction	64 ± 13	**31**	90–120
	Deceleration	58 ± 20	**27**	90–60
Posterior deltoid	Horiz. abd. IR	93 ± 45	**63**	90–120
	Horiz. abd. ER	92 ± 49	**57**	90–120
	Rowing	88 ± 40	**57**	90–120
	Extension	71 ± 30	**44**	90–120
	External Rot.	64 ± 62	**43**	60–90
	Deceleration	63 ± 28	**27**	60–90
Supraspinatus	Military press	80 ± 48	**50**	0–30
	Scaption IR	74 ± 33	**40**	90–120
	Flexion	67 ± 14	**31**	90–120
	Scaption ER	64 ± 28	**25**	90–120
Subscapularis	Scaption IR[b]	62 ± 33	**22**	120–150
	Military press[c]	56 ± 48	**50**	60–90
	Flexion[c]	52 ± 42	**23**	120–150
	Abduction[c]	50 ± 44	**23**	120–150
Infraspinatus	Horiz. abd. ER	88 ± 25	**71**	90–120
	External rot.	85 ± 26	**43**	60–90
	Horiz. abd. IR	74 ± 32	**38**	90–120
	Abduction	74 ± 23	**31**	90–120
	Flexion	66 ± 15	**23**	90–120
	Scaption ER	60 ± 21	**38**	90–120
	Deceleration	57 ± 17	**27**	90–60
	Push-up (hands together)	54 ± 31	**38**	90–60
Teres minor	External rot.	80 ± 14	**57**	60–90
	Horiz. abd. ER	74 ± 28	**57**	60–90
	Horiz. abd. IR	68 ± 36	**43**	90–120
Pectoralis major	Press-up	84 ± 42	**75**	½ pk-pk
	Push-up (hands apart)	64 ± 63	**50**	60–30
Latissimus dorsi	Press-up	55 ± 27	50	pk-1 sec

[a] Ranked by intensity of peak arc.
[b] Criterion: Two arcs greater than 50% MMT.
[c] Criterion: Three arcs greater than 40% MMT.

flexion and scapular plane elevation. Inman et al.,[9] in their dynamic EMG studies, found significant activity in all four muscles of the rotator cuff during flexion and extension; however, Blackburn et al.[3] found the EMG activity in the supraspinatus to be greatest when the prone subject was asked to lift the arm into horizontal abduction at 100° in external rotation.

Basmajian and Bazant[1] found that the infraspinatus and teres minor generally exhibited synchronous firing. Similarly, in our study, the top three qualifiers were the horizontal abduction exercises and external rotation in both of these muscles. Blackburn et al. also found the horizontal abduction exercises in external rotation to be a valuable exercise for the infraspinatus and teres minor. The infraspinatus had additional exercises fulfilling the criterion. These included elevation in the frontal, sagittal, and scapular planes. This suggests that the infraspinatus may also play a valuable role in force coupling with the deltoid for joint stabilization.

The top exercises for the subscapularis included those primarily involved with elevation (scaption in internal rotation, military press, flexion, and abduction). Interestingly, internal rotation, which is commonly used in rehabilitation programs for anterior instability and selective subscapularis strengthening, was not among its leading exercises.

Press-up was the leading exercise for both the pectoralis major and the latissimus dorsi. These muscles primarily function as depressors, essential for manual transfers and crutch ambulation. This is consistent with the findings of

TABLE 2
Order of exercises that qualified for a given muscle

Exercise	Muscle								
	Ant. del.	Mid. del.	Post. del.	Pec.	Lat.	Supra.	Infra.	Teres	Subscap.
Flexion	3	4				3	5		3
Scaption IR	1	1				2			1
Scaption ER	2	5				4	6		
Abduction	5	8					4		4
Rowing		6	3						
Horiz. abd. IR		2	1				3	3	
Horiz. abd. ER		3	2				1	2	
Horiz. add.									
Push-up (hands together)							8		
Push-up (hands apart)				2					
Bench press									
Military press	4	7				1			2
Press-up				1	1				
Deceleration		9	6				7		
Extension			4						
Internal rot.									
External rot.			5				2	1	

Inman et al.,[9] who found that the pectoralis major was inactive during abduction.

In a comparative dynamic EMG study of pitchers, Gowan et al.[7] noted important differences in the firing patterns of the shoulder muscles between the amateurs and professionals. He noted increased activity of the supraspinatus and latissimus dorsi in professional pitchers, while the amateurs showed increases in supraspinatus and infraspinatus activity. In another comparative EMG study of throwing athletes, Glousman et al.[6] found differing muscular activity in those with shoulder instability. He noted a mild increase in activity of the supraspinatus, and a marked decrease of the pectoralis major, subscapularis, and latissimus dorsi compared with normals. The work by Gowan et al.[7] provides a basis for understanding improved performance and the development of a sport-specific rehabilitation program. Glousman et al.[6] showed a neuromuscular imbalance associated with instability which underscores the need to develop a rehabilitation protocol for chronic instability.

Fifteen of the 17 exercises in our study met the qualifying criterion for at least one muscle. Three of the exercises, however, were consistently among the top two for every muscle tested. Scaption in internal rotation was the leading exercise for the anterior and middle deltoids and subscapularis, and second for the supraspinatus. Horizontal abduction in external rotation displayed the greatest EMG activity for the infraspinatus, and the second highest for the teres minor and posterior deltoid. Press-up was the top exercise for both the pectoralis major and latissimus dorsi.

Even though scaption demonstrated high EMG activity at elevations above 90°, such a level of elevation is not clinically recommended. Once the arm is elevated above 90° in the scapular plane, impingement can occur. In a clinical reality, the chance for impingement outweighs and negates the high electrical activity in the higher elevation. Thus, scaption above 90° is not recommended. Scaption can be done up to 90° with a heavier weight which would produce the enhanced muscle activity, or flexion can be selected as a more ideal exercise. Flexion involves a very similar pattern of muscle activity to scaption in internal rotation (Table 2) without risking impingement.

From our results, it appears that these exercises (scaption or flexion, horizontal abduction in external rotation, and press-up) should be the core for a shoulder rehabilitation program of the glenohumeral muscles. Extrapolating from the data from Gowan et al.,[7] additional exercises can then be added for specific muscular strengthening to increase pitching performance. In treating chronic anterior instability, one may supplement this core for selective treatment of the neuromuscular imbalance noted by Glousman et al.[6]

CONCLUSIONS

Fifteen of the 17 exercises tested were found to generate electrical activity in at least one of the glenohumeral muscles. A combination of exercises (scaption in internal rotation or flexion, horizontal abduction in external rotation, and press-up) were responsible for a high level of EMG activity in all muscles. This combination can be considered as a core program for an effective and succinct rehabilitation protocol for the rotator cuff and humeral positioners. Further exercises can be added to supplement the core depending on the clinical diagnosis or nature of the rehabilitation program.

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ERRATUM

The authors (Roberts et al.) of "Anterior Cruciate Ligament Reconstruction Using Freeze-dried Ethylene Oxide-sterilized Bone-Patellar Tendon-Bone Allografts: Two Year Results in Thirty-six Patients" (January/February 1991; pages 35 to 41) would like to make a correction of a statement that appeared in their article. Please refer to page 40, paragraph one, line three, where it now reads "greater than 10^2 rads . . . ." That sentence should read: "Unfortunately, radiation of greater than 2 megarads causes loss of graft strength and changes the structural properties of the graft."

They also refer readers to an article entitled "Effects of Gamma Radiation on Initial Mechanical Material Property of Goat Bone-Patellar Tendon-Bone Allografts" by Gibbons et al. (*J Orthop Res 9:* 209–218, 1991). This study showed a significant loss of strength at 3 megarads, whereas no significant alteration occurred following 2 megarads of radiation.