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Electromyographic analysis of posterior deltoid, posterior rotator cuff and trapezius musculature in different shoulder exercises

[1]Mr Sérgio MA Marta, MSc, [1]Dr Pedro LC Pezarat-Correia, PhD, [2]Dr Orlando JSM Fernandes, PhD, [1]Dr Ana I Carita, PhD, [3]DrJan MH Cabri, PhD, [4*]Dr Antonio C de Moraes, PhD

[1] Faculty of Human Kinetics, Technical University of Lisbon, Portugal
[2] Sport and Health Department, Évora University, Portugal
[3] Physical Performance Department, Norwegian School of Sport Sciences, Norway
[4] Faculty of Physical Education, University of Campinas – UNICAMP, Brazil

***Corresponding author. Address at the end of text.**

Abstract

Background: The shoulder external rotator muscles and the different portions of the trapezius muscle have never been studied in exclusivity. However, the literature has provided several exercises which have been used in this study.
Purpose: To quantify electromyographic activity of the shoulder external rotator muscles and the upper, middle and lower trapezius in seven exercises. **Methods:** 20 healthy males performed 7 exercises in random order. Surface electromyography was recorded for the posterior deltoid, infraspinatus, teres minor, upper, middle and lower trapezius. **Results:** The four prone exercises presented the highest levels of EMG activation in the External Rotators Synergy (the average activation of arm external rotator muscles group) and in the Trapezius Synergy (the average activation of the three portions of trapezius). The infraspinatus muscle obtained the highest activation values in exercises 1 (prone horizontal abduction at 90° with full external rotation, thumb up), 4 (prone external rotation at 90º abduction and elbow at 90º), and 5 (side-lying ER with elbow on the trunk). The highest activation level of the teres minor muscle was found in Exercise 1. **Conclusions***:* The four prone exercises demonstrated the highest EMG activity in the shoulder, considering both the external rotator muscles and the trapezius. However, if the focus of the strength training process is mainly to strengthen the two external rotator muscles of the rotator cuff, with an adequate intramuscular coordination pattern for the trapezius, the side lying ER with the elbow resting on the trunk seems to be the most appropriate exercise. **Keywords:** rotator cuff, posterior deltoid, trapezius, electromyography

Mr Sérgio MA Marta, MSc
Mr Marta works at the Secondary School of Pinhal Novo, Portugal. His main research interests are exercise physiology, kinesiology
Email: smamarta@gmail.com

Dr Pedro LC Pezarat-Correia, PhD
Dr Pezarat-Correia is employed at the Faculty of Human Kinetics, Technical University of Lisbon, Portugal. His main research interests are exercise physiology, kinesiology
Email: ppezarat@fmh.utl.pt

Dr Orlando JSM Fernandes, PhD
Dr Fernandes is employed at the Sport and Health Department, Évora University, Portugal. His main research interests are biomechanics, kinesiology.
Email: orlandoj@uevora.pt

Dr Ana I Carita, PhD
Dr Carita is employed at the Faculty of Human Kinetics, Technical University of Lisbon, Portugal. Her main research interests are statistics, kinesiology.
Email: acarita@fmh.utl.pt

Dr Jan H Cabri, PhD
Dr Cabri is employed at the Department Physical Performance, Norwegian School of Sport Sciences, Oslo, Norway. His main research interests are physiotherapy, kinesiology.
Email: jan.cabri@nih.no

***Dr Antonio C Moraes**
Dr Moraes is employed at the University of Campinas, Campinas, SP, Brazil. His main research interests are exercise physiology, kinesiology.

Introduction

An important cause of shoulder injury is an imbalance between the strong internal rotator muscles accelerating the arm and the external rotator muscles responsible for the deceleration of the arm at the end of the movement through its eccentric action[1-5]. Increased internal rotation strength normally occurs in athletes practising swimming and throwing, creating an imbalance with the external rotator group that may cause serious injuries in the posterior capsule of the glenohumeral joint.

Two of the external rotator muscles, the infraspinatus and the teres minor, muscles of the rotator cuff, are also thought to be very important in the dynamic stability of the glenohumeral joint. Together with the other two muscles of the rotator cuff (subscapularis and supraspinatus), they appear to be fundamental in maintaining the humeral head centred in the glenoid surface, when powerful arm movements are performed during the acceleration phase of overhead throws or swimming skills[6] .A lack of strength in these muscles may induce instability in the glenohumeral joint and allow excessive translation of the humeral head during overhead arm movements[7-9].

Thus because it is very important to maintain an adequate balance between external and internal shoulder rotators, specific exercises for strength development of the external rotator muscles are fundamental for injury prevention[8-24] as swimmers and throwers will perform a large number of repetitions of ballistic shoulder internal rotations during their sporting career. Exercises based on arm external rotation or arm horizontal abduction are recommended to strengthen the external rotator muscle group.[10-18].

Escamilla et al.,[24] have a review article retrieving the shoulder muscle activity and function in common shoulder rehabilitation exercises. Some exercises exhibit high activity from the rotator cuff, deltoid and scapular muscles, such as prone horizontal abduction at 100º abduction with the arm positioned in external rotation, flexion and abduction with the arm positioned in external rotation , standing elevation in the scapular plane and standing elevation in the scapular plane with the arm positioned in internal rotation.

Blackburn et al.,[12] compared exercises of external rotation at 90º of abduction in the prone position with the elbow at 90º of flexion, and in the side-lying exercise with the elbow at 90º of flexion. It was the first exercise to recommend strengthening the supraspinatus muscle. Townsend et al.[10] compared the activation level of nine muscles acting on the shoulder and three exercises (prone horizontal abduction at 90º abduction with internal rotation with thumb down, prone horizontal abduction at 90º abduction with ER with thumb up and side-lying ER at 0º abduction) were consistently found to be among the exercises elevating greater levels of activation for the external rotation muscles. Ballantyne et al.[13] analysed the infraspinatus, teres minor, supraspinatus and lower trapezius muscles in the execution of therapeutic exercises in individuals with and without shoulder pathologies and showed that subjects with shoulder pain had more EMG activity in the infraspinatus and less in the supraspinatus muscles in the prone lateral rotation exercise.

A study by Malanga et al.[14] concluded that exercises carried out in the prone position and arm external rotation at 100º abduction presented higher levels of activation of the posterior deltoid in comparison to full arm external rotation. The infraspinatus and teres minor muscles were not analysed.

Kelly et al.[15] carried out a study to identify the ideal positioning for achieving the higher isometric activation of shoulder muscles by using a bipolar wire electrode placement. Fleisig et al[16] .,carried out one of the first in-depth studies comparing the activation level of external rotators in different exercises through EMG recorded with fine-wire electrodes. Reinold et al.,[17] also compared the activation level of the external rotator muscles in different exercises, but by using fine-wire electrodes, and showed that the prone ER at 90º abduction and side-lying ER at 0º abduction had a moderate to high level of activity.

Previous research emphasises the role of scapular muscle training as an essential component of shoulder rehabilitation.[9,13,18.] The high activity of the upper trapezius (UT) is frequently combined with low activity of the middle (MT) and lower trapezius (LT) and the serratus anterior in athletes with impingement symptoms contributing to abnormal scapular motion.[19-22] So, exercises promoting LT and MT, and serratus anterior activation with minimal activity in the UT are recommended. In this perspective the balance ratios between different portions of the trapezius muscle could be an important tool to evaluate and compare different exercises prescribed for shoulder and scapular muscle training and rehabilitation.[22].

The purpose of the present study was to quantify, through EMG, the activation level of the shoulder external rotator muscles in seven selected exercises performed with the same weight (4Kg). Additionally, this study also aimed at evaluating the solicitation of the different portions of the trapezius muscle which are relevant to scapular stabilisation.

Methods

Participants

Twenty males (mean age 22±3,6 years, age range 16-34 years) participated in this investigation. All the subjects were Sports Science students. The inclusion criteria were: subjects had to be right-handed, undertaking regular physical activity, healthy, and had not trained extensively 24-hours prior to the test, in order to prevent exercising under fatigued conditions. Exclusion criteria were: any shoulder injury, surgery or history of shoulder pain during the past 3 years. Prior to the investigation, and after being informed about the purpose of the study and the related procedures and the experimental risks, subjects signed an informed consent document. The study was approved by the Research Ethics Committee of the Faculty of Human Kinetics from the Technical University of Lisbon in accordance with the document number 09/2009.

Procedure

Each participant was tested in the seven different exercises, according to Figure 1. Each subject performed eight repetitions for each exercise. The first and the last repetition were discarded, and only the six remaining repetitions were used. The speed of the repetitions was regulated by a computerized metronome and set to 45 beats per minute. Each subject was instructed to exhale during the concentric phase and inhale during the eccentric phase. The concentric and eccentric phases were performed at one beat each.

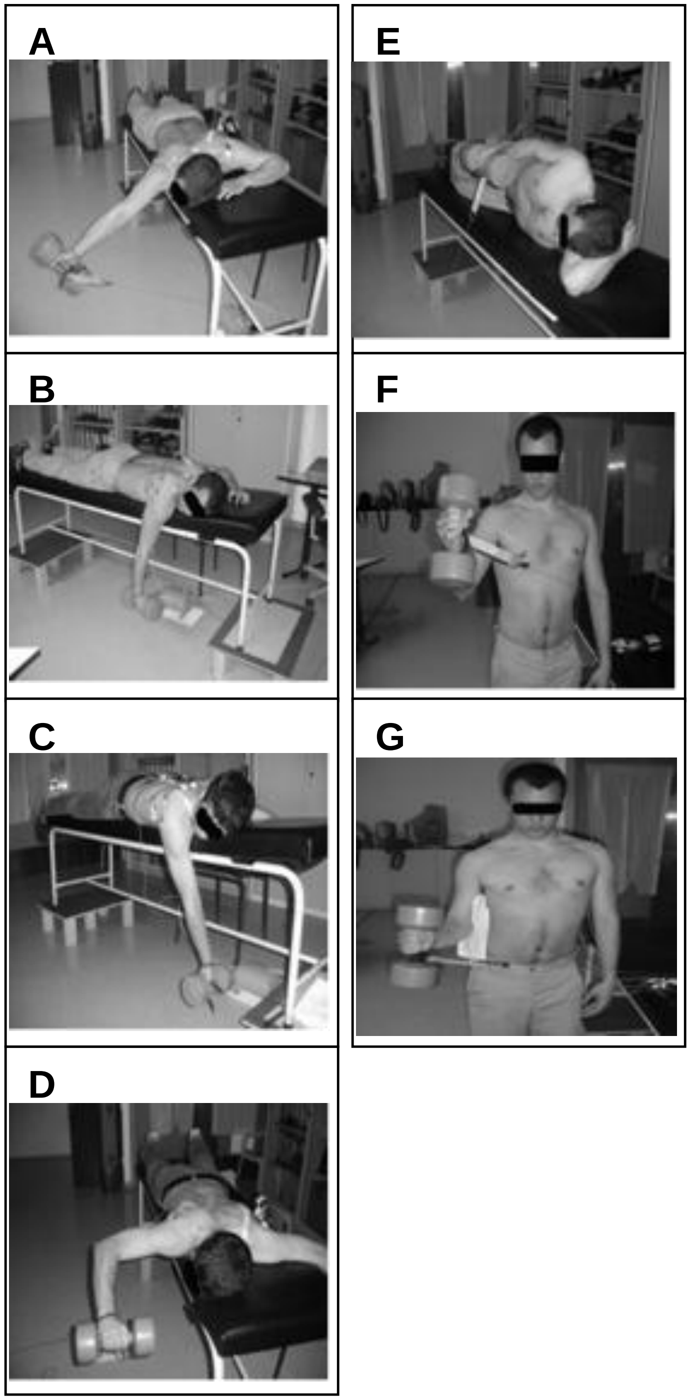

Figure 1: (A) Exercise 1 – prone horizontal abduction at 90° with full external rotation (ER) with thumb right up; (B) Exercise 2 – prone horizontal abduction at 90° abduction with middle ER with thumb up; (C) Exercise 3 – prone horizontal abduction at 100º abduction with full ER; (D) Exercise 4 – prone ER at 90º abduction and elbow at 90º; (E) Exercise 5 – side lying ER with elbow on the trunk; (F) Exercise 6 – standing ER in the scapular plane (45° abduction, 30° horizontal abduction); (G) Exercise 7 – standing ER with a towel roll placed between the trunk and elbow.

The subjects performed each exercise holding a 4kg dumbbell. A pre-test was done to ensure that this load could be used in all the seven exercises without fatigue. In order to normalise the EMG signals, each subject performed two maximal isometric voluntary contractions (MVC) in the middle of the range of arm movement of each exercise, one before and one after the eight repetitions. For the MVC, the subject was instructed to use maximum strength for five seconds against an immoveable resistance and then relax for two minutes. After the series, the subject rested for two minutes before performing the second MVC. After the second MVC, the subject rested for four minutes before carrying out the next exercise.

To separate the different repetitions and EMG phases (concentric and eccentric), a movement sensor was used for each exercise tested. The signal from the movement sensor was captured by a BIOPAC channel to the Acknowledge® software and synchronised with the EMG signals. After the acquisition, the signals of the movement sensor were low-pass filtered with a Butterworth 2nd order and a frequency cut-off of 10Hz. The first derivative of position signals was used for the determination of velocity curves. Each movement phase was determined through the velocity curves, when the velocity value crossed zero.

Surface EMG was recorded with active bipolar electrodes (Analog Devices mod. AD620, gain of 1000±2%) from the posterior deltoid, infraspinatus, teres minor, upper, middle and lower trapezius. Electrode placement was assisted by palpation and visual localisation in the middle portion of the muscle belly, as suggested by Leis AA[23]: *Deltoid Posterior*- 3-4 cm directly beneath the posterior margin of the acromion; *Teres Minor*- lateral to the middle third of the lateral border of the scapula; *Infraspinatus*- into the infraspinous fossa 2-4 cm below the medial third of the spine of the scapula; *Upper Trapezius*- at the angle of the neck and shoulder; *Middle Trapezius*- midway between the spine of the scapula and the spinous processes at the same level and Lower Trapezius- 3-4 cm lateral to the spinous processes of the lower thoracic vertebrae. Alcohol and a razor were used for cleaning the areas. In order to minimize possible interference, all EMG procedures were in accordance to the International Society of Electrophysiology and Kinesiology[25] recommendations.

The evaluation of the EMG activity of the trapezius muscle was performed, since this muscle is involved in the positioning and fixation of the scapula supporting the dynamic action of the external rotator muscles to move the arm. Thus the activation level of the different parts of the trapezius muscles provides important information about the total muscular solicitation of the shoulder in each exercise.

The EMG signal was high-pass filtered at 20±5Hz and low-pass filtered at 450±50Hz with a Common Mode Rejection Ratio >80dB, and an input impedance 10^{15} Ω // 0.2 pF was used. The signals were digitised with an A/D converter (MP100, 16 bits, Biopack Systems Inc, USA) at a sample rate of 1000Hz. Data acquisition was carried out using the Acknowledge v3.8.1 software (Biopack Systems Inc, Santa Barbara, CA, USA).

Once the EMG data were recorded, and after visual inspection, the raw EMG signals were digitally band-pass filtered (20 to 500Hz), full-wave rectified, low-pass filtered with a Butterworth 2nd order and a frequency cut-off of 25Hz, using the EMG in each studied muscle. Then the EMGs were amplitude-normalised using as reference the EMG of MVCs, and the mean EMG value was determined for each phase (concentric and eccentric) and for the total movement duration (concentric phase + eccentric phase). For data processing, automatic routines using the MATLAB® software (The Mathworks Inc, Natick Massachusetts, USA) were developed and used.

The Shoulder Synergy was calculated by the formula [(External Rotator Synergy + Trapezius Synergy)/2]. The

External Rotator Synergy (ER Synergy) was calculated through the average values of the EMG values from the Infraspinatus, Teres Minor and Posterior Deltoid muscles. The Trapezius Synergy was calculated with the average of the EMG value from the upper, middle and lower trapezius.

Trapezius intramuscular ratios were calculated by dividing upper trapezius normalised EMG values by middle and lower trapezius normalised EMG values. These values were multiplied by 100 to obtain relative activity (%). Values lower than 100% reflect UT muscle activity was lower and values higher than 100% reflect that UT muscle activity was superior then MT and LT muscle activity.

Data analysis

For each muscle, synergy, and ratio values, differences among exercises were tested for statistical significance, using the one-way analysis of variance (ANOVA) for repeated measures. A Shapiro-Wilk test was conducted in order to ascertain if there was a normal distribution among the subjects. When a normal distribution among the subjects was not found a non-parametric test (Wilcoxon test) was used. For all statistical tests, the 0.05 probability was accepted as the criterion for statistical significance.

Results

The EMG values of each muscle, in each phase and in each exercise, are listed in Table 1 and 2. The values corresponding to the different synergies in each exercise are presented in Table 3.

Table 1: Mean (±Sd) EMG activation of the Posterior Peltoid, Infraspinatus, Teres minor in the total movement (AvgEMG), in the concentric phase (ConAvgEMG) and in the eccentric phase (EccAvgEMG), expressed in %MVC for the seven tested exercises

Exercises	**Posterior deltoid**			**Infraspinatus**			**Teres minor**		
	AvgEMG	**ConEMG**	**EccEMG**	**AvgEMG**	**ConEMG**	**EccEMG**	**AvgEMG**	**ConEMG**	**EccEMG**
1	48.51 ± 12^{e,f,g}	64.15 ± 16	32.86 ± 8	38.85 ± 17^{b,g}	45.72 ± 21	29.29 ± 14	47.01 ± 2^{b,e,f,g}	58.22 ± 28	34.99 ± 21
2	51.90 ± 14^{e,f,g}	68.11 ± 18	35.69 ± 10	33.57 ± 14^{a,d}	41.32 ± 17	25.82 ± 12	36.61 ± 15^{a,d,g}	44.91 ± 18	27.70 ± 12
3	49.40 ± 11^{d,e,f,g}	64.30 ± 16	33.91 ± 7	34.99 ±14	43.31 ± 18	26.52 ± 10	39.10 ± 14^{g}	47.96 ± 18	29.60 ± 10
4	44.24 ± 15^{c,e,f,g}	52.51 ± 18	35.96 ± 12	38.27 ± 17^{b,g}	46.68 ± 20	29.86 ± 14	43.21 ± 17^{b,e,f,g}	50.77 ± 21	34.94 ± 14
5	20.60 ± 8^{a,b,c,d,f,g}	26.97 ± 12	14.23 ± 5	41.44 ± 18^{f,g}	56.58 ± 24	26.31 ± 13	33.47 ± 14^{a,d,g}	44.70 ± 18	20.92 ± 8
6	7.83 ± 3^{a,b,c,d,e,g}	9.74 ± 4	5.92 ± 3	31.55 ± 12^{e}	42.83 ± 18	20.26 ± 8	30.64 ± 12^{a,d,g}	40.94 ± 16	19.74 ± 7
7	4.06 ± 2^{a,b,c,d,e,f}	5.03 ± 3	3.08 ± 2	28.97 ± 14^{a,d,e}	42.02 ± 21	15.92 ± 8	17.04 ± 7^{a,b,c,d,e,f}	22.59 ± 10	10.91 ± 5

Legend:- Prone horizontal abduction at 90° with full ER with thumb right; 2 - Prone horizontal abduction at 90° with middle ER with thumb up; 3 - Prone horizontal abduction at 100º abduction with full ER; 4 - Prone ER at 90º abduction and elbow at 90º; 5 - Side lying ER at maximal abduction with elbow on the trunk; 6 - Standing ER in the scapular plane; 7 - Standing ER at maximal abduction with a towel roll placed between the trunk and elbow; Avg – Average; Con – Concentric; ECC- Eccentric; a – significant differences with exercise 1; b – significant differences with exercise 2; b – significant differences with exercise 3; d – significant differences with exercise 4; e – significant differences with exercise 5; f – significant differences with exercise 6; g – significant differences with exercise 7

Table 2: Mean (±SD) EMG activation of the Upper trapezius, Middle trapezius and Lower trapezius in the total movement (AvgEMG), in the concentric phase (ConAvgEMG) and in the eccentric phase (EccAvgEMG), expressed in %MVC for the seven tested exercises

Exercises	upper Trapezius			middle Trapezius			lower Trapezius		
	AvgEMG	**ConEMG**	**EccEMG**	**AvgEMG**	**ConEMG**	**EccEMG**	**AvgEMG**	**ConEMG**	**EccEMG**
1	37.80 ± 13[c,e,f,g]	48.15 ± 19	27.45 ± 9	51.55 ± 20[e,f,g]	70.02 ± 23	33.08 ± 20	54.35 ± 19[b,e,f,g]	72.79 ± 27	35.72 ± 13
2	32.32 ± 14[c,e,f,g]	40.45 ± 20	24.20 ± 10	44.68 ± 18[e,f,g]	60.11 ± 24	29.25 ± 14	40.44 ± 17[a,c,d,f,g]	52.38 ± 23	27.68 ± 13
3	47.09 ±17[a,b,d,e,f,g]	58.01 ± 23	36.17 ± 12	46.59 ± 17[e,f,g]	63.74 ± 24	29.44 ± 10	55.92 ± 2[b,c,e,f,g]	72.97 ± 28	38.86 ± 15
4	33.33 ±19[c,e,f,g]	37.51 ± 23	29.16 ± 16	52.64 ± 22[e,f,g]	60.98 ± 27	44.30 ± 18	54.38 ± 24[e,f,g]	65.49 ± 33	43.27 ± 16
5	10.88 ± 8[a,b,c,d,f]	12.66 ± 9	9.11 ± 7	29.88 ± 13[a,b,c,d,f,g]	40.08 ± 16	19.68 ± 9	39.01 ± 13[a,c,d,f,g]	53.36 ± 17	24.66 ± 9
6	17.25 ± 9[a,b,c,d,e,g]	18.76 ± 10	15.74 ± 9	12.45 ± 5[a,b,c,d,e]	15.62 ± 6	9.28 ± 4	25.05 ± 9[a,b,c,d,e]	31.05 ± 12	19.05 ± 7
7	6.85 ± 6[a,b,c,d,f]	7.37 ± 6	6.32 ± 6	11.37 ± 6[a,b,c,d,e]	14.51 ± 7	8.22 ± 4	22.96 ± 8[a,b,c,d,e]	28.37 ± 11	17.54 ± 6

Legend: 1 - Prone horizontal abduction at 90° with full ER with thumb right; 2 - Prone horizontal abduction at 90° with middle ER with thumb up; 3 - Prone horizontal abduction at 100º abduction with full ER; 4 - Prone ER at 90º abduction and elbow at 90º; 5 - Side lying ER at maximal abduction with elbow on the trunk; 6 - Standing ER in the scapular plane; 7 - Standing ER at maximal abduction with a towel roll placed between the trunk and elbow; Avg – Average; Con – Concentric; ECC- Eccentric; a – significant differences with exercise 1; b – significant differences with exercise 2; b – significant differences with exercise 3; d – significant differences with exercise 4; e – significant differences with exercise 5; f – significant differences with exercise 6; g – significant differences with exercise 7

Table 3: Mean (±SD values of normalized averaged EMG (% of the EMG of the MVC) of the External Rotator synergy (ERsyn), Rotator Cuff synergy (RCsyn), Trapezius synergy (Tsyn), UT/MT ratio (UT/MT), UT/LT ratio (UT/LT), Shoulder total (STotal) in the total movement

Exercises	**ERsyn** (IS+TM+DP)	**RCsyn** (IS+TM)	**Tsyn** (ST+MT+IT)	**UT/MT**	**UT/LT**	**STotal** (ERsyn+ Tsyn)
1	44.79 ± 12.97	42.93 ± 17.62	47.90 ± 10.40	78.38 ± 34.76	77.45 ± 35.67	46.35 ± 9.77
2	40.69 ± 10.63	35.09 ± 12.91	39.15 ± 12.46	77.27 ± 44.03	88.88 ± 44.74	39.92 ± 9.23
3	41.16 ± 9.39	37.05 ± 12.76	49.87 ± 12.05	112.36 ± 54.07	95.14 ± 43.65	45.52 ± 8.79
4	41.91 ± 12.65	40.74 ± 14.47	46.79 ± 12.58	71.57 ± 58.42	79.41 ± 69.70	44.35 ± 10.37
5	31.84 ± 10.27	37.46 ± 13.70	26.59 ± 7.75	38.39 ± 31.08	33.57 ± 36.75	29.21 ± 7.28
6	23.34 ± 7.64	31.10 ± 10.62	18.25 ± 4.17	164.44 ± 132.93	90.48 ± 83.56	20.80 ± 4.23
7	16.69 ± 7.02	23.01 ± 9.79	13.72 ± 4.57	67.05 ± 55.88	35.04 ± 33.16	15.21 ± 4.60

Legend: 1 - Prone horizontal abduction at 90° with full ER with thumb right; 2 - Prone horizontal abduction at 90° with middle ER with thumb up; 3 - Prone horizontal abduction at 100º abduction with full ER; 4 - Prone ER at 90º abduction and elbow at 90º; 5 - Side lying ER at maximal abduction with elbow on the trunk; 6 - Standing ER in the scapular plane; 7 - Standing ER at maximal abduction with a towel roll placed between the trunk and elbow; Avg – Average; Con – Concentric; ECC- Eccentric

Posterior Deltoid

The highest levels of activation of the posterior deltoid were observed in the three horizontal abduction exercises (exercises 1, 2 and 3 – 49%, 52% and 49% MVC, respectively). No significant differences were found between the four prone exercises. The highest activation level was observed in exercise 2, the prone horizontal abduction at 90° with thumb up. When compared with the other three exercises (exercises 5, 6 and 7 – 21%, 8% and 4% MVC, respectively); the four prone position exercises presented significantly higher ($p<0.05$) activation levels of the Posterior Deltoid. The lowest level of activation was found in exercise 7, the standing ER with a towel roll placed between the trunk and elbow (Table 1).

Infraspinatus

The infraspinatus muscle reached its highest activation values in exercises 1, 4 and 5 (39%, 38% and 41% MVC, respectively). No significant differences were found between those three exercises. The infraspinatus was the rotator muscle that presented the highest EMG activation values in the side lying and standing exercises (exercises 5, 6 and 7) – (Table 1).

Teres minor

The activation level of the teres minor muscle was always higher than 30%, except in exercise 7 (17% MVC), in which significantly lower ($p<0.05$) levels of activity were observed, in comparison to the other exercises. The highest activation level of this muscle was found in exercise 1 (47% MVC), but with the exception of exercise 7, this was not significantly different from the mean values of the other exercises (Table 1).

Upper Trapezius

The upper portion of the trapezius was the least activated when compared to the other portions of this muscle in the exercises studied. Only in exercise 6 did its activation demonstrate higher levels than the middle portion of the muscle. In exercises 5 (11% MVC) and 7 (7% MVC), this muscle was significantly less activated ($p<0.05$) than in the other exercises. Its highest activation level was reached in exercise 3 (47% MVC), that showed significant differences ($p<0.001$) to all the other exercises except for the exercise 1 – (Table 2).

Middle Trapezius

The middle trapezius was the second most activated muscle portion of the trapezius in most exercises, except in exercise 2, in which it was the most activated (45% MVC). In the prone exercises, the muscle presented higher activation levels than in the other three exercises. When the comparison between different prone exercises (with intensity levels between 45% and 53% MVC) was made, no significant differences were found. The standing exercises (6 and 7) presented a significantly ($p<0.05$) lower level of activation than all the other exercises. In the side lying ER (exercise 5), the muscle was less activated ($p<0.05$) than in exercises 1, 3 and 4 – (Table 2).

Lower Trapezius

The lower trapezius was the most strongly recruited muscle portion of the trapezius in all exercises, except for exercise 2. The muscle presented the highest mean activation values in exercises 1, 3 and 4, with values between 54% and 56% MVC. This finding was significant ($p<0.05$) in comparison to the other four exercises. In exercises 2 and 5, the muscle presented values close to 40% MVC, being significantly ($p<0.05$) inferior to the three previously mentioned exercises and significantly higher ($p<0.01$) than the two standing exercises (6 and 7 – values between 23% and 25% MVC) – (Table 2).

Muscular synergies / Trapezius intramuscular ratios

The prone exercises (1 to 4) presented significantly ($p<0.05$) higher levels of EMG activation in the ER Synergy, Trapezius Synergy and Shoulder Synergy, than exercises 5, 6 and 7. For these synergies, no significant differences were found between the four prone exercises. Exercises 1 and 4 showed the highest mean values of EMG activation for the rotator cuff muscles, but no systematic significant differences were found for the other exercises, except when the comparison was made with exercise 7, that presented significantly less activity than the other six studied exercises ($p<0.01$) – (Table 3).

The UT/MT ratio showed values under 100% in exercises 1, 2, 4, 5 and 7. The exercises 3 and 6 had values higher than 100%. The exercises 1, 2 and 7 had statistical similarity with p. values greater than 0,05. The group of exercises 3 and 6 and the group of exercises 2, 4, 7 had also statistical similarity. The exercise 5 showed statistical difference with all the other exercises and presented the lower ratio with 38,40%±31%.

The UT/LT ratio had presented values under 100% in all exercises. The exercises 5 (33,57%±36%) and 7 (35,04%±33%) presented the lower ratio. The exercises 1, 2 and 6, the exercises 5 and 7 and the exercises 2, 3 and 6 had statistical similarity. Exercise 4 had similarity only with exercise 6.

Discussion and conclusions

This study's observations for the Posterior Deltoid muscle, i.e. showing the highest levels of activation in the three horizontal abduction exercises, are consistent with the results of previous studies.[10,14,16,17]. In these studies, the highest activity levels were found during prone horizontal abduction at 100º abduction with full ER, but with higher MVC percentages than the ones found in the present study. This finding may be explained by the methodological differences between the studies, namely in the normalization process. In every aspect, the trends found in the comparison of muscle activation during the concentric and eccentric phases reflect what had previously been verified in the total analysis of the exercise, although the percentage activation levels were higher in the concentric phase than in the eccentric one, as expected.

The highest mean value of activation of the infraspinatus muscle was found in the side lying ER (exercise 5), in line with the results of Fleisig et al.[16] and Reinold et al.[17]. However, the present authors did not find significant differences between exercises 5, 1 and 4. Exercise 1, prone horizontal abduction at 90° with full ER and thumb up, was the exercise with maximal activation of the infraspinatus, but with a very similar percentage value to the side lying ER. As Escamilla et al.,[24] stated the infraspinatus muscle is a more effective external rotator at lower abduction angles as was demonstrated by the side-lying ER exercise 5, being an optimal position to isolate it. In the study of Blackburn et al.,[12] exercise 1 and exercise 4, prone ER, were the exercises that showed higher levels of infraspinatus activation.

The finding that the Teres Minor presented high values of EMG activation in prone horizontal abduction at 90° with thumb up (exercise 1) is not consistent with previous findings of Fleisig et al.,[16,] Townsend et al.,[10,] Reinold et al.,[17], that demonstrated highest activity during external shoulder rotation in the side lying position. The different weights used in the exercises, and the fact that those studies were performed with indwelling EMG, may explain in part the different results. It should also be pointed out that, in Fleisig et al.'s study[17], they did not test exercise 1, prone horizontal abduction at 90° with full ER and thumb up. On the other hand, Blackburn et al.,[11] also found that the teres minor presented higher activity in prone horizontal abduction at 90° with thumb up than in the side-lying ER.

Considering the three external rotator muscles together in the ER Synergy, the highest activity levels were recorded in the four prone exercises (exercises 1-4). Horizontal abduction performed with the arm in external rotation (exercise 1) presented the highest EMG value, but significant differences were found only for exercises 5, 6 and 7. In the four exercises performed in the prone position, the posterior deltoid showed the highest percentage of normalised

EMG activity when compared to the teres minor and the infraspinatus. If the Rotator Cuff Synergy is considered, the prone horizontal abduction with thumb up (exercise 1), the prone ER (exercise 4) and side-lying external rotation (exercise 5) are the exercises presenting the highest activation.

The Trapezius Synergy demonstrated higher activation levels in the prone exercises than in the other three exercises as was found by Ekstrom et al.,[26] and Moseley et al.,[27]. This behaviour may be explained by the higher demand required in prone position in the stabilisation of the scapula. The lower portion of the trapezius was the most strongly recruited portion of the muscle in all exercises, except in exercise 2. Furthermore, the highest activation was demonstrated in exercises 1, 3 and 4.

In most exercises, the middle trapezius presented higher activation level than the upper portion (except in exercises 3 and 6) as showed by Ekstrom et al.,[26] and Moseley et al.,[27]. The upper portion was quite often the least activated part, when compared to the others, except during exercise 6 in which higher activation was found in comparison to the middle portion. The maximum activation level in the upper trapezius was reached in exercise 3. The explanation for this may be the placement of the scapula in superior rotation and elevation required by the arm position at 100º of abduction.

It was proposed that excess activation of the upper trapezius combined with low activations of the lower and middle trapezius contribute to abnormal scapular motion.[19,22] As previously mentioned, this study's results showed that the UT/MT ratio presented values higher than 100% in the exercise 3 and 6. The UT/LT ratio showed values under 100% in all the exercises but in those two exercises (3 and 6) we found the higher values, between (95 and 90% respectively). So, the exercises 3 (prone horizontal abduction at 100º abduction with full ER) and 6 (standing ER in the scapular plane) are inadvisable to maintain the adequate balance between different trapezium portions. Since it presented the lower UT/MT and UT/LT ratio, the exercise 5, side-lying external rotation, was the exercise that seems to be the most appropriate considering the relative activation between different trapezium portions.[22.]. In addition, this exercise showed a strong solicitation of lower and middle portions of the trapezius, minimising the activity of the upper portion.

The Shoulder Synergy was defined as the average of the EMG values from the external rotator muscles (ER Synergy) and from the different portions of the trapezius (Trapezius Synergy). This Shoulder Synergy was evaluated to provide a general measure about the overall solicitation of the different muscles involved in the exercises studied, combining the muscles acting as prime movers and the portions of the trapezius acting as scapula stabilizers. This synergy showed that in the exercises performed in a prone position (exercises 1-4) the shoulder muscles were recruited more intensively in comparison to exercises performed in side-lying or standing positions. No differences were found in the Shoulder Synergy between the exercises performed in the prone position.

As final conclusions, if the main goal is to strengthen the posterior deltoid and trapezius muscles, the exercises based on the prone horizontal abduction (1 to 4) are the best choice. However, if the focus of the strength training program is mainly to strengthen the two external rotator muscles from the rotator cuff, responsible for the dynamic stabilisation of the glenohumeral joint, the prone external rotation (exercise 4) and the side-lying external rotation (exercise 5) seem to be the most appropriate exercises. This choice is justified because these exercises combine two important factors: a strong solicitation of the rotator cuff muscles, mainly the infraspinatus, and a relatively low level of activation of the posterior deltoid. This may be useful for subjects with a risk of subacromial impingement, since the reduction in the deltoid participation minimises the migration of the humeral head in the glenoid fossa of the scapula.[14,17] The side-lying external rotation is the most adequate exercise if the main concern is to isolate the recruitment of the infraspinatus muscle. Moreover, as these authors have pointed out, this was the exercise that was shown to be the most appropriate considering the relative activation between different trapezius portions. Therefore, this exercise should be included in rehabilitation programs directed to subjects demonstrating weakness of the lower trapezius muscle. Individuals suffering from posterior rotator cuff tendinitis, or subjects presenting with an anterior tilt of the scapula, which leads to high probability of subacromial impingement [9] frequently seen in over-arm athletes, may benefit from this exercise. In addition, this exercise, since it was performed with 0º of arm abduction, produces less stress in the anterior structures of the glenohumeral joint (anterior portion of the capsule and the glenohumeral inferior ligament). Exercise 4 has the advantage of being more specific for over-arm throwing athletes since it replicates the arm position where the external rotators are eccentrically activated during the throwing, but it places more strain in the anterior structures of the glenohumeral joint.

The two standing exercises, 6 and 7, also represent a way of strengthening the external rotator muscles of the rotator cuff with minimal involvement of the posterior deltoid. However, the exercise 6, standing ER in the scapular plane, presented an intramuscular coordination pattern for the trapezius that is not favourable since the recruitment of the upper trapezius was higher than the middle portion, with values higher than 100%.

In conclusion, the prone exercises demonstrated the highest EMG activity in external rotators and trapezius muscles. But, in order to strengthen the infraspinatus and teres minor muscles, with adequate intramuscular coordination patterns for the trapezius, the side-lying ER with elbow on the trunk exercise appears to be the most appropriate.

Address for correspondence:

Dr Antonio Carlos de Moraes, Rua Érico Verissimo, 701 – Faculdade de Educação Fisica – Universidade Estadual de Campinas – UNICAMP 13.083-851 Campinas, São Paulo, Brazil.
Email:
acmoraes@fef.unicamp.br

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