

Coactivation of the shoulder and arm muscles during closed kinetic chain exercises on an unstable surface

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ABSTRACT

Introduction: The purpose of this study was to compare the electromyography index of muscle coactivation of the following muscle pairs: posterior deltoid and pectoralis major (PD/PM); triceps brachii and biceps brachii (TB/BB); and serratus anterior and upper trapezius (SA/UT) during three different closed kinetic chain exercises (wall-press, bench-press and push-up) on an unstable surface at the maximal load.

Methods: A total of 20 healthy sedentary men participated in the study. Integral linear values were obtained from three sustained contractions of six seconds each for the three proposed exercises. Mean coactivation index values were compared using the mixed-effects linear model, with a five percent significance level.

Results: Electromyography indexes of muscle coactivation showed significant differences for the PD/PM and TB/BB muscle pairs. No differences were found between exercises for the SA/UT muscle pair.

Conclusion: Our results seem to differ from those of previous studies, which reported that the similarity in exercises performed is responsible for the comparable muscle activation levels.

Keywords: coactivation, closed kinetic chain, electromyography, shoulder

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INTRODUCTION

In recent times, axial load exercises for the upper limbs have gained recognition and have been increasingly used in rehabilitation protocols.⁽¹⁾ These exercises, mostly classified as closed kinetic chain,⁽²⁾ have been recommended in different phases of treatment.⁽¹⁾ Furthermore, some authors have advocated similar exercises performed on a relatively unstable base for more advanced phases of the rehabilitation

programme.^(3,4) It was believed that such exercises promote an increased demand on the neuromuscular system to stabilise articular joints, increasing proprioception, muscle control and muscle coactivation.^(1,3,4,5)

Muscle coactivation is a phenomenon characterised by simultaneous activation of two or more muscles around a joint.⁽⁶⁾ It represents one of the central nervous system's action mechanisms that is responsible for joint stability^(7,8) as well as for adaptation of the limbs to changes in the environment, such as changes in surface stability.⁽⁹⁾ Muscle coactivation has been studied using electromyography (EMG) amplitude values obtained while performing static and dynamic exercises through mathematical equations that indicate the ratio of electric activity of a muscle in relation to another.⁽¹⁰⁻¹³⁾

Dillman et al and Blackard et al have both observed the EMG activity of muscles classified as primary movers during upper limb exercises in open and closed kinetic chain with or without loads. Results from both studies showed that the EMG activities of primary movers were similar for exercises performed in closed kinetic chain using the same load. Thus, the authors concluded that exercises performed with similar load quantity and direction generate similar EMG activity values in primary movers.^(14,15)

Recently, some studies have investigated the influence of unstable surfaces on shoulder muscle activities. Anderson and Behm have studied electric activity and the strength of primary movers during bench-press exercises on both stable and unstable surfaces. They reported that a lower force amount was reached when the exercise was performed on an unstable surface.⁽¹⁶⁾ However, there was no difference in the EMG values for both variations of the exercise. These results suggest that greater levels of muscle activity are required on an unstable surface in order to reach the same load as on a stable surface.

Some authors have developed EMG studies that evaluated axial load exercises, where volunteers performed exercises on stable and unstable surfaces. It was observed that some of the muscles studied showed greater EMG activity when exercises were performed

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on an unstable surface, although the increase in activity varied for each of the five muscles studied.^(17,18) Although most studies compare the EMG activity between different types of upper limb exercises, there is still a scarcity of studies that control the same biomechanical characteristics between the exercises, such as load direction and intensity, contraction type and limb condition.

For this reason, there is a need to evaluate the muscle coactivation and load values during three closed kinetic chain upper extremity exercises (wall-press, bench-press and push-up) performed at the same level of isometric effort, an evaluation that should be helpful for clinicians who are selecting the type of exercises for shoulder rehabilitation. Previous studies comparing different types of exercise with the same load value have been published.^(14,15,17,24,25) However, using the same load value during the comparison of exercises would result in unfavourable muscle activity results, since each person has a specific load considered appropriate for performing an exercise. Thus, if the same level of isometric effort is used when performing the exercise, the comparison of EMG analysis is likely to be more reliable. Based on previous studies that show similar EMG amplitude values for primary motor muscles between closed kinetic chain exercises,^(14,15) this study aimed to verify if closed kinetic chain isometric exercises performed with the maximal axial load level have the same muscle coactivation index.

METHOD

The study consisted of 20 healthy male volunteers (mean age \pm standard deviation [SD] 22 ± 3 years, mean height \pm SD 175 ± 0.05 cm, mean body mass \pm SD 68 ± 7 kg). Upper limb conditions were verified through clinical tests, inspection, palpation and history. The participants were excluded if they had previous history of trauma of the scapular girdle or upper limbs and positive results from the clinical tests for impingement syndrome, lateral or medial epicondylitis and joint instability of the shoulder, elbow or wrist. Volunteers signed a consent form, according to norm 196/96 of the Brazilian National Health Council, which was approved by the ethics committee of the University Hospital of the Ribeirão Preto Medical School at the University of São Paulo, Brazil.

Surface EMG signals were captured using six differential electrodes with two Ag-AgCl bars, a 10-mm interelectrode distance, a gain of 20, an input impedance of $10 \text{ G}\Omega$ and a common mode rejection ratio $> 80 \text{ dB}$. Based on the Surface Electromyography for the Non-Invasive Assessment of Muscles recommendations,

the electrodes were positioned on the long head of the biceps brachii (BB), the long head of the triceps brachii (TB), posterior portion of the deltoid (PD) muscles and the trapezius upper fibers (UT).⁽²⁰⁾ For the clavicular portion of the pectoralis major (PM) and the serratus anterior (SA), the positioning of the muscles electrodes was based on the recommendations by Hintermeister et al.⁽²¹⁾ A circular electrode (3 cm^2), used as a reference electrode for reducing acquisition noise, was attached to the sternum with adhesive tape, as described by Araújo et al.⁽¹⁹⁾ The skin at the electrodes' sites was shaved and cleaned with alcohol before the attachment of electrodes so as to reduce skin impedance and achieve good fixation.

A cell load Model MM (Kratos Dinamometros Ltda, São Paulo, SP, Brazil), with a nominal capacity of 100 kgf was attached to an electromyograph, and load values were recorded simultaneously with electromyography signals. Auditory feedback was used to inform volunteers about the produced load level, allowing the force to be maintained during the collection time.⁽¹⁹⁾ Simultaneous acquisition of EMG signals and force output was sampled by a 12-bit A/D converter board with a 4-KHz frequency and digital filter pass-band of 10–500 Hz, and the linear envelope EMG integrated activity (LEI) was calculated, as described by Araújo et al.⁽¹⁹⁾

The procedure of this study consisted of two stages. During the first stage, the participants were evaluated, made aware of the testing procedure and trained to execute the maximum isometric efforts during three repetitions of each exercise. Maximal individual load was determined for each exercise based on the average force collected by the load-cell in the three exercises.⁽¹⁹⁾ During the second stage, EMG signals of the following muscles were recorded: BB, TB, UT, SA, PD and PM muscle of the dominant limb during three maximal voluntary isometric contractions (MVIC) in a muscular testing position for manual muscle testing.⁽²²⁾ After a six-minute rest, the volunteers performed another three exercises, which included wall-press, bench-press, and push-up accomplished with 100% of maximum pre-determined effort (Fig. 1). The dominant shoulder was tested for all the participants, and all the exercises were performed unilaterally.

A description of the three exercises is shown in Table I. The exercises were performed in a random sequence and repeated three times, each repetition lasting six seconds, with rest intervals of two minutes between isometric contractions and three minutes between exercises, to avoid the effects of muscle fatigue on EMG data. The participants performed the exercises with the elbow of the right limb fully extended and the shoulder flexed

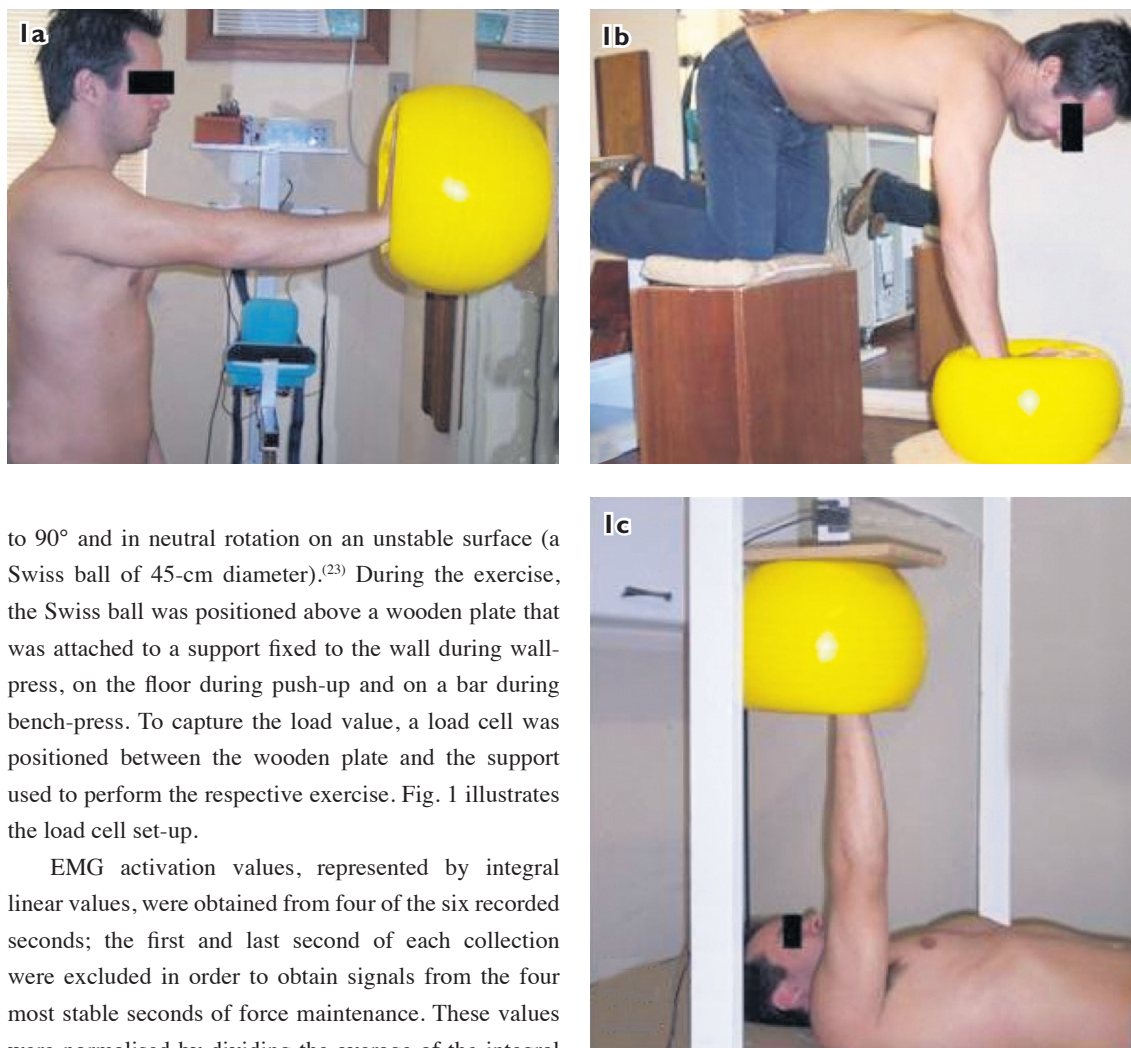


Fig. 1 Photographs show the execution of (a) wall-press; (b) push-up; and (c) bench-press exercises.

to 90° and in neutral rotation on an unstable surface (a Swiss ball of 45-cm diameter).⁽²³⁾ During the exercise, the Swiss ball was positioned above a wooden plate that was attached to a support fixed to the wall during wall-press, on the floor during push-up and on a bar during bench-press. To capture the load value, a load cell was positioned between the wooden plate and the support used to perform the respective exercise. Fig. 1 illustrates the load cell set-up.

EMG activation values, represented by integral linear values, were obtained from four of the six recorded seconds; the first and last second of each collection were excluded in order to obtain signals from the four most stable seconds of force maintenance. These values were normalised by dividing the average of the integral envelope value for each muscle in each exercise by the maximum integral linear envelope value obtained through one of three MVICs of the corresponding muscle, i.e. the ratio between mean integral envelope value obtained in each exercise studied and the maximum MVIC integral envelope value recorded for each muscle during manual strength testing position.

Coactivation indexes were analysed using the equation proposed by Hammond et al, which considers the proportion of antagonistic activity in relation to total EMG activity, as well as agonistic and antagonistic activities as an indicator for coactivation.⁽¹³⁾ This calculation is represented by the following equation:

$$COACTIVATION = \frac{ANTAGONIST_{ACTV.}}{AGONIST_{ACTV.} + ANTAGONIST_{ACTV.}}$$

Based on this equation, we determined which of the muscles analysed would respond as agonist and antagonist when performing the exercise. The PD/PM pair of muscles was selected due to their role in stabilising the shoulder in relation to the trunk during unilateral exercises, such as those performed in this study.

The TB/BB pair was chosen as they help in maintaining elbow extension while performing the exercises. The SA/UT pair was selected because of the important role these muscles play in stabilising the scapula while the exercises are performed. Coactivation was calculated for all the three tasks analysed, with the PD as antagonist and the PM as agonist in the PD/PM pair, BB as agonist and TB as antagonist in the TB/BB pair, and SA as agonist and UT as antagonist in the SA/UT pair. By substituting the values in the equation, it was possible to identify the coactivation indexes, with 0.5 corresponding to equal EMG activity levels for both muscles, < 0.5 corresponding to greater EMG activity for muscles that were agonistic, and > 0.5 corresponding to greater EMG activity of muscles that were antagonistic.

The mixed-effects linear model was used to compare coactivation index values. This type of analysis is proposed when the responses of an individual are grouped and when independence between observations

Table I. Description of upper limb fixed boundary and external axial load exercises used in the study.

Exercise position	Description
Wall-press	The participant maintains one arm in the orthostatic position with the dominant upper limb flexed to 90° in the frontal plane, arm in neutral position (no rotation) and elbow extended. This exercise is performed by applying axial compression force on the ball equal to 100% of maximum effort. Nondominant upper limb was placed behind the body during the exercise.
Push-up	The participant performed this exercise in the ventral decubitus position, with hips and knees flexed to 90°, neutral trunk position, and with the dominant upper limb at 90° of shoulder flexion, neutral arm rotation, elbow fully extended and palm of the hand in contact with the ball, unloading body weight with 100% maximum effort. To obtain this position, a wooden box was used for kneeling. Nondominant upper limb was placed behind the back during the exercise.
Bench-press	The participant performed this exercise in dorsal decubitus position, with knees flexed, feet supported on the stretcher, dominant upper limb at 90° of shoulder flexion, arm in neutral position and elbow fully extended. During the exercise, the participant employed axial compression force on the ball, equal to 100% maximum effort. Nondominant upper limb was placed behind the back during the exercise.

of that group is assumed to be inappropriate. The information of each volunteer submitted for each of the three exercises performed at 100% of maximum effort is used within the model in the form of random effects. After building the model, residue analysis was performed and logarithmic transformation was adjusted to meet the assumptions associated with the proposed model. Model adjustment was performed using the PROC MIXED procedure of SAS software version 8 (SAS Institute Inc, Cary, NC, USA). A 5% significance level ($p < 0.05$) was considered to be statistically significant between the values compared.

RESULTS

Comparing the exercises performed at 100% maximum effort, the PD/PM pair showed differences in the coactivation index values for all exercises performed ($p < 0.05$), with the greatest value obtained during bench-press, followed by push-up and wall-press. The TB/BB pair showed significant differences only during wall-press ($p > 0.05$), reaching higher coactivation values than during bench-press and push-up. No differences in coactivation indexes were found between exercises for the SA/UT pair. The coactivation results are shown in Table II, while the results of the load reached during wall-press, bench-press and push-up are shown in Table III.

DISCUSSION

The purpose of this study was to verify if upper extremity closed kinetic chain isometric exercises would produce similar muscle coactivation indexes. The results obtained showed that the PD/PM coactivation index was greater during bench-press exercise, followed by push-up and wall-press. It was also observed that the TB/BB index was significant only during wall-press. Finally, the SA/UT coactivation index showed no significant

difference for the three exercises studied.

Before discussing our results, it is important to consider that the pairs of muscles evaluated in this study were determined based on the agonistic/antagonistic relationship among them when performing the exercise as well as on the anatomic characteristics of these muscles, i.e. whether they are single or multi-jointed. Thus, separate comparisons were made for the single and multi-jointed muscle groups, since it is known that the number of joints crossing a muscle could affect the levels of activity elicited during exercise. Another important consideration is the resting time given between exercise trials with the aim to avoid muscle fatigue. Therefore, our results were not influenced by physiological and anatomical issues.

The coactivation indexes for PD/PM showed significance between the tasks. The lower PD/PM wall-press index could be due to the standing position of the participant, which required more scapulothoracic muscle activation, and the lack of fixed dorsal support for the volunteer's back also made it difficult to apply a greater level of effort. Push-up exercises also showed an agonistic index because of the unilateral upper extremity positioning when performing this exercise. Previous research has shown that push-up exercises performed unilaterally favour PD muscle activity to hold the trunk in a parallel position to the ground, thus inverting these muscles' synergy, while a bilateral position favours PM activation.⁽¹⁾ On the other hand, bench-press showed a PD/PM antagonistic index due to the need for a greater PD muscle to maintain the trunk in the horizontal position while performing the exercise.⁽¹⁾

The BB/TB index was significant only on wall-press exercise. This is possibly related to the standing position when performing a wall-press, which generates an upper extremity axial load that requires more

Table II. Muscle coactivation index mean values and standard deviation for muscle pairs studied between wall-press, bench-press and push-up exercises performed at 100% maximum effort.

Muscle pair	WPI00 × BPI00	p-value	WPI00 × PUI00	p-value	BPI00 × PUI00	p-value
PD/PM	0.11 ± 0.06 × 0.77 ± 0.16*	< 0.0001	0.11 ± 0.06 × 0.41 ± 0.16	< 0.0001*	0.77 ± 0.16 × 0.41 ± 0.16	< 0.0001*
TB/BB	0.38 ± 0.16 × 0.16 ± 0.11*	< 0.0001	0.38 ± 0.16 × 0.14 ± 0.15	< 0.0001*	0.16 ± 0.11 × 0.14 ± 0.15	0.3717
SA/UT	0.19 ± 0.18 × 0.26 ± 0.16	0.0815	0.19 ± 0.18 × 0.21 ± 0.12	0.5499	0.26 ± 0.16 × 0.21 ± 0.12	0.2487

Values are obtained over a 6-sec electromyography sampling, mixed effects linear model ($p < 0.05$).

* denotes statistical significance.

PM: clavicular fibers of pectoralis major; BB: long portion of biceps brachii; TB: long portion of triceps brachii; UT: upper fibers of the trapezius; SA: serratus anterior muscles; PD: posterior deltoid; WP: wall-press; BP: bench-press; PU: push-up

glenohumeral synergic muscle activity to maintain the arm in 90° elevation. However, the execution of bench-press and push-up exercises has an axial load component, which results in greater stability in the glenohumeral and elbow joints, thus explaining the non-significant difference on BB/TB index when performing these tasks. It also explains why this index was lower when compared to the wall-press index in our study.

The SA/UT coactivation index showed no significant differences for the exercises studied. However, all the exercises were performed with no scapular protraction/retraction movement, which has been related with great SA activation.⁽²⁴⁾ A study that evaluated SA/UT ratios while performing wall push-up and push-up plus found a high trapezius/serratus relationship (about 2.0) for wall push-up exercises and a low trapezius/serratus relationship (below 2.0) for push-up plus.⁽²⁴⁾ Thus, it may be difficult to make comparisons, as our study analysed isometric contraction with no scapular protraction/retraction using a coactivation index, while the above research⁽²⁴⁾ analysed EMG activity of the SA and UT muscles during exercises performed dynamically using a ratio among them.

The level of effort used to perform each exercise in our study was determined by each volunteer. Thus, the standardisation of load exercises is referred to the level of effort required to perform each exercise, i.e. 100% of the maximum isometric effort that each exercise permitted the participants to exert against the unstable surface. This is different from previous studies, in which the subjects performed exercises with a similar axial load value.^(14,15,17,24,25) Thus, since the percentage of isometric effort instead of the load values was considered when performing the exercises, a more reliable EMG comparison between them could be obtained.

If an equal load instead of the percentage of isometric effort had been used to perform the three exercises, it would have been impossible to conduct this study, because each exercise positioning had an effect on the level of effort and consequently, on the value registered

Table III. The load values and standard deviation on wall-press, bench-press and push-up exercises performed at 100% maximum effort.

	Wall-press	Push-up	Bench-press
Load cell value	6.1 ± 1.7*	25.1 ± 4.2*	17.8 ± 5.1*

* denotes statistical significance

kgf : kilogram force

by the load cell. However, the facility of each exercise to promote effort was different and thus, different levels of effort should be expected. For example, in push-up and wall-press exercises, the level of effort reached in the push-up exercise is mostly determined by the participant's weight that is applied onto the ball, and such level of effort would be impossible to be repeated in the wall-press. Likewise, it would be impossible to perform the push-up with an inferior load, such as can be achieved during the wall-press.

Each exercise studied has a different effect on the discharge load (kgf), which can be explained by the positioning of the participant. As the level of effort was calculated in relation to the cell load value, consideration was given to the values based on kgf obtained in each exercise. During the wall-press exercise, for instance, the lack of fixed dorsal support for the participant's back made it difficult to apply a greater level of effort. In addition to full arm extension, adding force would imply a tendency for the trunk to move away from the orthostatic position that was standardised for the exercises. This resulted in an average force of only 6.1 ± 1.7 kgf.

While performing bench-press, fixed dorsal support, i.e. the stretcher and girder supporting the ball, remained still. This presents a situation similar to that proposed by Steindler⁽²⁾ called "strictly closed kinetic chain", in which the distance between the surface for back support and the surface for the palm of the hand is fixed or invariable, and slightly smaller than the length of the fully extended arm. This exercise position provided the participants with a much greater capacity to generate force against the ball without any imbalance while performing the exercise,

reaching an average force of 17.8 ± 5.1 kgf. In the push-up exercise, the participants sustained their trunk weight with support from only their right arm and did not have a fixed support for the back, thus avoiding the development of a force beyond that which was necessary to sustain the body in the test's standardised position. In this case, the participant's weight might have influenced the amount of effort required to perform the exercises. Hence, the average force level recorded by the load cell was 25.1 ± 4.2 kgf.

The present study demonstrated that bench-press exercises mostly favoured muscle activity for the PM and TB, while the push-ups favoured the PD and TB, and the wall-press favoured the PD and SA. However, in order to gain force in isometric contraction, it is important to emphasise that these exercises do not maximally activate each muscle involved as it would happen in specific activities such as contractions in muscle testing positions. This does not necessarily mean that there is an order or sequence of evolution in terms of muscle activity for using these exercises in rehabilitation protocols. In fact, each exercise may be used based on the objective to be achieved.

Our exercises were performed isometrically, whereas most clinical exercises are performed isotonically. Thus, precautions should be taken when extrapolating these data for dynamic exercises. However, isometric exercises are also clinically important, as isometric strength training would be useful in the initial phase of treatment, especially in cases where the patients present with limited or painful range of motion, acute injury and muscle weakness. Moreover, isometric contraction demands less effort from patients than isotonic exercises. This study was performed in young healthy sedentary volunteers, which implies that further studies should be conducted in shoulder dysfunction patients on unstable surface to analyse their muscle activity.

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