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Electromyographic analysis of shoulder muscles during press-up variations and progressions

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ABSTRACT

Due to the versatility of the press-up it is a popular upper extremity strengthening and rehabilitation exercise. Press-up programmes are often progressed by increasing weight-bearing load and using unstable bases of support. Despite the popularity of the press-up research examining press-up variations is limited. The aim of the study was to examine the influence of common press-up exercises on serratus anterior, infraspinatus, anterior deltoid, pectoralis major and latissimus dorsi muscles overall EMG activity. Twenty-one healthy individuals participated in this study. Surface electrodes were placed on pectoralis major, anterior deltoid, infraspinatus, serratus anterior and latissimus dorsi muscles. Participants were tested under 7 static press-up conditions that theoretically progressively increase weight-bearing load and proprioceptive challenge while surface electromyographic activity was recorded. There was a high correlation between increased weight-bearing load and increased EMG activity for all muscles in stable base conditions. The introduction of the unstable base conditions resulted in an activation decline in all muscles. Within the two-armed press-up the Swiss ball resulted in decreased activation in all muscles except pectoralis major. Serratus anterior demonstrated the greatest activation as a percentage of maximum isometric contraction across all exercises. The findings of this study indicate that by varying the weight-bearing load and base of support whilst in the press-up position results in significantly different demands on shoulder and scapula muscles.

1. Introduction

Optimal functioning and stability of the shoulder complex is reliant on scapulothoracic and glenohumeral stabilisation and humeral movement control (Lephart and Henry, 1996). Dysfunction of the scapulothoracic joint with altered scapula movement results in dyskinesis of the joint with associated abnormal glenohumeral motion (Ludewig and Cook, 2000). Abnormal shoulder motion has been linked to multiple shoulder pathologies and injury with shoulder pain being one of the most common musculoskeletal complaints (Lunden et al., 2010).

Within the upper extremity the acromioclavicular, sternocalvicular, glenohumeral and scapulothoracic joints are described as a kinetic chain (Lephart and Henry, 1996). Closed kinetic chain (CKC) activities with the distal segment fixed as motions occur proximally are advocated exercises for the upper extremity (Lear and Gross, 1998). The use of CKC exercises with progressive loading and proprioceptive (stability) challenges has become accepted practise during shoulder and scapula rehabilitation programmes (Pontillo et al., 2007). The press-up is a common upper extremity CKC rehabilitation and strength training exercise (Gouvali and Boudolos, 2005). Popularity of the exercise can be explained by the versatility of the press-up with variations including the wall, kneeling and box press-up. Within each variation there is the opportunity to add further changes that accommodate increased loading and stability challenges. Research suggests that the press-up exercise has not only resulted in muscular strength gain but also improvements in proprioception and neuromuscular control, promotion of co-activation of stabilising muscles, reduction in shear forces and equal joint compression distribution (Tucker et al., 2008; Lephart and Henry, 1996).

A common progression from the box press-up to the standard press-up is used in strengthening and rehabilitation programmes (Sandhu et al., 2008). Decker et al. (1999) and Ludewig et al. (2004) reported significantly higher serratus anterior activity in the standard press-up 'plus' when compared to the box press-up 'plus', the 'plus' representing movement of the scapula into full protraction.

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Much research has focussed on the use of the 'plus' phase due to the proposed low upper trapezius/high serratus anterior ratio the motion elicits (Ludewig et al., 2004; Lunden et al., 2010). Ludewig et al. (2004) reported the 'plus' phase of the press-up has shown serratus anterior activity to reach 120% versus 80% of maximal isometric voluntary contraction (MIVC) for the press-up and upper trapezius to be 20% in the push up and only 9% in the 'plus' phase (Ludewig et al., 2004). However caution in using the 'plus' phase in the press-up should be considered until further research into the scapula kinematics has been undertaken, as although it creates the desired increase in muscle activity it may not create appropriate muscle co-activation patterns (Ludewig and Cook, 2000). Lunden et al. (2010) examined the kinematics of the 'plus' phase which involves active scapula protraction at the top position of the press-up and noted that during the 'plus' phase the scapula exhibited increased internal rotation and decreased upward rotation with a possible decrease in subacromial space with the concomitant risk of subacromial impingement.

Previous research reporting on progressions from the box to the standard press-up which recorded activity from other muscles such as pectoralis major, infraspinatus and anterior deltoid, reported significantly greater muscle activity in all three muscles during the standard press-up compared to the box press-up (Uhl et al., 2003). The increase in muscle activity between the box and standard press-up may be as a result of increased forces through the shoulder as the centre of mass moves further away from the distal base of support (knees and feet) in the standard press-up (Suprak et al., 2011).

In order to explore progressions within the box and standard press-up a limited number of authors have researched the effect of progressing from bilateral support (two-armed) to unilateral support (one-armed) and found muscle activity increases in the one-armed press-up. Maenhout et al. (2010) reported serratus anterior activity to be significantly higher in the one-armed box press-up 'plus' (36.7% of maximum isometric contraction (MIVC) compared to the two-armed box press-up 'plus' (25.3%). No research has been found that explores progressions from two-armed to one-armed within the standard press-up without the 'plus' phase. Uhl et al. (2003), studied the press-up without the 'plus' phase for pectoralis major, anterior deltoid and infraspinatus EMG activity from bilateral to unilateral weight bearing. The authors reported significantly greater muscle activation occurred in the unilateral press-up for all muscles (Uhl et al., 2003).

Unstable surfaces are often used during rehabilitation in an attempt to improve proprioception and increase muscle activation. The reported changes in muscle activation have been conflicting. Lehman et al. (2008) examined muscle activation during the press-up on a Swiss ball compared to a stable base, pectoralis major and serratus anterior showed no significant differences in activity; Pontillo et al. (2007) reported significantly less serratus anterior activity during the box press-up on an unstable platform when compared to a stable platform. Pontillo et al. (2007) measured activity on a force platform in the static press-up position held for 20 s each time without randomly allocating the exercises. The authors suggested that muscle fatigue could have had an effect on the serratus anterior explaining the decrease in activation.

Sandhu et al. (2008) also reported significantly greater pectoralis major activation with the addition of the Swiss ball during the standard press-up, which is in contrast to Lehman et al. (2006). It is of note that Lehman et al. (2006) used subjects who routinely participated in strength training while Sandhu et al. (2008) used subjects with little strength training experience. Level of training could produce significantly different results due to neuromuscular adaptation.

Evidence supporting the use of press-up progressions as an appropriate rehabilitation exercise for the shoulder is limited. Authors have investigated a variety of press-up variations examining loading and stability progressions (Ekstrom et al., 2005; Lehman et al., 2006; Sandhu et al., 2008). However, none have researched rehabilitation progressions within the box press-up and standard press-up that has included progressive loading and stability challenges. Research has focused on individual aspects such as stability or loading without assessing the muscular activity within and between each aspect. Of the limited studies that have researched progressions few have speculated on where in the rehabilitation process these variations should be included.

The aim of this study is to explore isometric press-up variations and examine surface EMG (sEMG) activity within and between each exercise variations. The over-arching hypothesis of the study being that there will be greater muscle EMG activity as the nature of the exercise is changed, as loading is increased and stability decreased through the shoulder during press-up progressions it is expected EMG activity will increase.

2. Method

2.1. Participants

21 healthy, physically active subjects volunteered to participate (10 male and 11 females with a mean age of 22.8 (±1.4) years). The study was approved by the University ethics committee and all subjects gave written informed consent. All participants had no history of neck, shoulder, elbow wrist or hand injury/surgery within the previous six months.

2.2. Procedures

Testing was done using a KinePro Wireless EMG using KinePro EMG Triode Electrodes (Nickle-Plated Brass) with a 1 cm interelectrode distance. KinePro V.3.2 software was used for signal processing. Surface EMG (sEMG) was high and low pass filtered between 10 and 500 Hz, preamplified (×1000), and A/D converted at a rate of 1562 Hz using the KinePro wireless EMG system (Kine EHF, Reykjavík, Iceland). To determine the sEMG signal on/off, a computer aided algorithm was used to allow a threshold value to be calculated from 2 standard deviations above baseline, each trace was also visually inspected (Hodges and Bui, 1996). To quantify the sEMG amplitude, root mean square (RMS) was calculated, epochs were taken at 20 ms intervals and a mean value calculated for a standardised period (from onset for 9 s).

Participants were tested on their dominant side; the hand they wrote with. Electrodes were placed over selected muscles. Sites for electrode placement was prepared by shaving the area (where necessary), the skin exfoliated using Nuprep™ gel and swabbed with Cutisoft® wipes to ensure optimal electrode attachment and reduce skin impedance. Electrodes were placed in alignment with direction of muscle fibres.

2.2.1. Electrode placement position

Pectoralis major: 4–5 cm below the clavicle, medial to the anterior axillary border (Lehman et al., 2006). *Anterior Deltoid:* 4–5 cm inferior to acromion process (Pontillo et al., 2007). *Infraspinatus:* Mid distance between the scapula spine and inferior angle of scapula, 2 cm lateral from scapula medial border (Pontillo et al., 2007). *Serratus Anterior:* lower fibres of serratus anterior on the mid axillary line at rib level 6–8 with shoulder flexed at 90° (Ekstrom et al., 2005). *Latissimus dorsi:* 5 cm distal to the inferior angle of the scapula parallel to the lateral border of the scapula (Lehman et al., 2006).

2.3. Normalisation procedures

Maximal voluntary isometric contractions (MVIC) of each muscle were quantified for normalisation. Participants were seated, erect and unsupported (Ekstrom et al., 2005). All tests involved 10 s maximal contractions, the subjects being instructed and encouraged to maintain maximal effort for the whole 10 s. All normalisation tests took place with the subject seated with positions adapted from Boettcher et al. (2008). *Anterior Deltoid*; Shoulder abducted to 75° with shoulder slight flexion, elbow flexed at 90° with slight humeral lateral rotation. Participants resisted hand pressure on the anteromedial surface of the arm in the direction of adduction and slight extension. *Pectoralis major*: Shoulder abducted to 75°, elbow flexed to 90°. Participants performed maximal resisted hand press. *Infraspinatus*: Participants resisted lateral rotation of the arm with humerus at 90° abduction and 90° elbow flexion. *Serratus Anterior*: Participants resisted manual pressure applied above the elbow with elbow extended and shoulder flexed to 125°. *Latissimus dorsi*: Participants resisted humeral extension, adduction and medial rotation.

2.3.1. Testing procedure

Head position was neutral in all exercises with participants instructed to maintain a neutral spine position, 90° shoulder flexion and full elbow extension. Hands were placed shoulder width apart with the thumb vertically beneath the acromioclavicular joint. Thumb position was marked with two strips of tape on the floor mat. Hip position of 90° hip flexion was monitored during the box press-up position and extension of the hip and knees in the standard press up. Participants were not permitted to widen their feet beyond hip width and strips of tape were placed for each individual to ensure consistency. No rotation of the torso was permitted. Participants held each exercise position for 10 s. The exercise was repeated 3 times with a 30 s rest between each exercise attempt and a 2 min rest between each set of 3 exercises.

2.3.2. Exercises

Exercises (Fig. 1) were selected to gradually increase load to the dominant shoulder and are common to shoulder and scapula rehabilitation programs. Exercises were not randomised but followed the sequence of exercises 1–7 as shown in Fig. 1. The exercise sequence began with two arm box press up position, then one arm box press up position, followed with same activity on an Airex pad, standard press up followed by standard press up with hands on a swiss ball, one armed standard press up position and finally one armed press up with hand on an Airex pad.

2.4. Data analysis

Individual sEMG muscle mean RMS value (dependant variable) was calculated from the three attempts for each exercise (independent variable). The percentage of muscle effort was calculated by dividing the muscle RMS mean with the MIVC value and multiplying by 100. The study was a two-way, repeated measure design and was analysed using analysis of variance (ANOVA) with a post hoc test, a 5% level of confidence ($p \leqslant 0.05$) was used. Statistical analysis was undertaken SPSS V.20.0 for Windows (SPSS Science, Chicago, Illinios, USA). Post-hoc Pairwise comparison were made using Fisher's Least Significant Difference Test for a pairwise comparison of the overall muscle activation of each exercise. When investigating the main effect of exercise on individual muscle activation within each exercise and between exercises the non-parametric Friedman's Test, was used to identify significant differences for within exercise comparison for each muscle ranked by activation percentage and a between exercise comparison for each muscle ranked by muscle activation percentage. A Wilcoxon Post-hoc test (corrected for type 1 error with Bonferroni corrections) was used to establish where differences lay.

3. Results

The mean and standard deviation (SD) percentage MIVC for the group average activation for each exercise and muscle is depicted in Table 1.

3.1. Main effect of exercise on overall muscle activation

Fisher's Least Difference test examined the main effect of exercise on overall muscle activation. Significant differences were found between all exercises ($p < 0.05$) with the exception of the one-armed stable base box press-up and two-armed Swiss ball standard press-up ($p = 0.33$) and between one-armed Airex box press-up and two-armed Swiss ball standard press-up ($p = 0.07$).

3.2. Muscle activation within each exercise

The main effect on individual muscle activation within exercise showed significant differences ($p = 0.001$). Muscles were ranked in ascending order of median activation and Wilcoxon Post-hoc tests, corrected for type 1 error with Bonferroni corrections ($p = 0.005$), was undertaken to establish where differences lay. Fig. 2 illustrates the results of the post hoc analysis with any significant differences between the previous muscles listed.

Serratus anterior produced significantly greater activation ($p < 0.005$) than every other muscle in the two-armed stable base box press-up, the two-armed Swiss ball standard press-up, the one-armed Airex® standard press-up and the one-armed stable base standard press-up. Serratus anterior also showed greater activation in the one-armed Airex® box press-up than every other muscle ($p = 0.009$). In the one-armed Airex standard press-up and the one-armed stable base standard press-up infraspinatus produced significantly greater activity than the anterior deltoid latissimus dorsi and pectoralis major ($p < 0.005$). For both of these exercises latissimus dorsi also showed significantly greater activity than the pectoralis major ($p < 0.005$). During the two-armed stable base standard press-up pectoralis major produced significantly greater activity than infraspinatus, anterior deltoid and latissimus dorsi ($p < 0.005$). The anterior deltoid also showed significantly greater activity than the pectoralis major during in the one-armed stable base box press-up ($p < 0.005$). There were no other significant differences between muscle groups ($p > 0.005$).

3.3. Muscle activation between exercises

The non-parametric Friedman's Test, with a critical alpha level of $\alpha = 0.05$, was used to reveal significant differences of individual muscle activity between exercises. The main effect of exercise on individual muscle activation reported significant differences ($p = 0.001$). Exercises were ranked in ascending order of median muscle activation and Wilcoxon Post-hoc tests, corrected for type 1 error with Bonferroni corrections ($p = 0.002$), was undertaken to establish where differences lay. Fig. 3 illustrates the results of the post hoc analysis.

3.3.1. Pectoralis major

The one-armed Airex® standard press-up elicited significantly greater pectoralis major activation when compared with the one-armed Airex® box press-up ($p = 0.001$).

3.3.2. Latissimus dorsi

The one-armed Airex® box press-up elicited a significantly greater latissimus dorsi activation compared with the two-armed

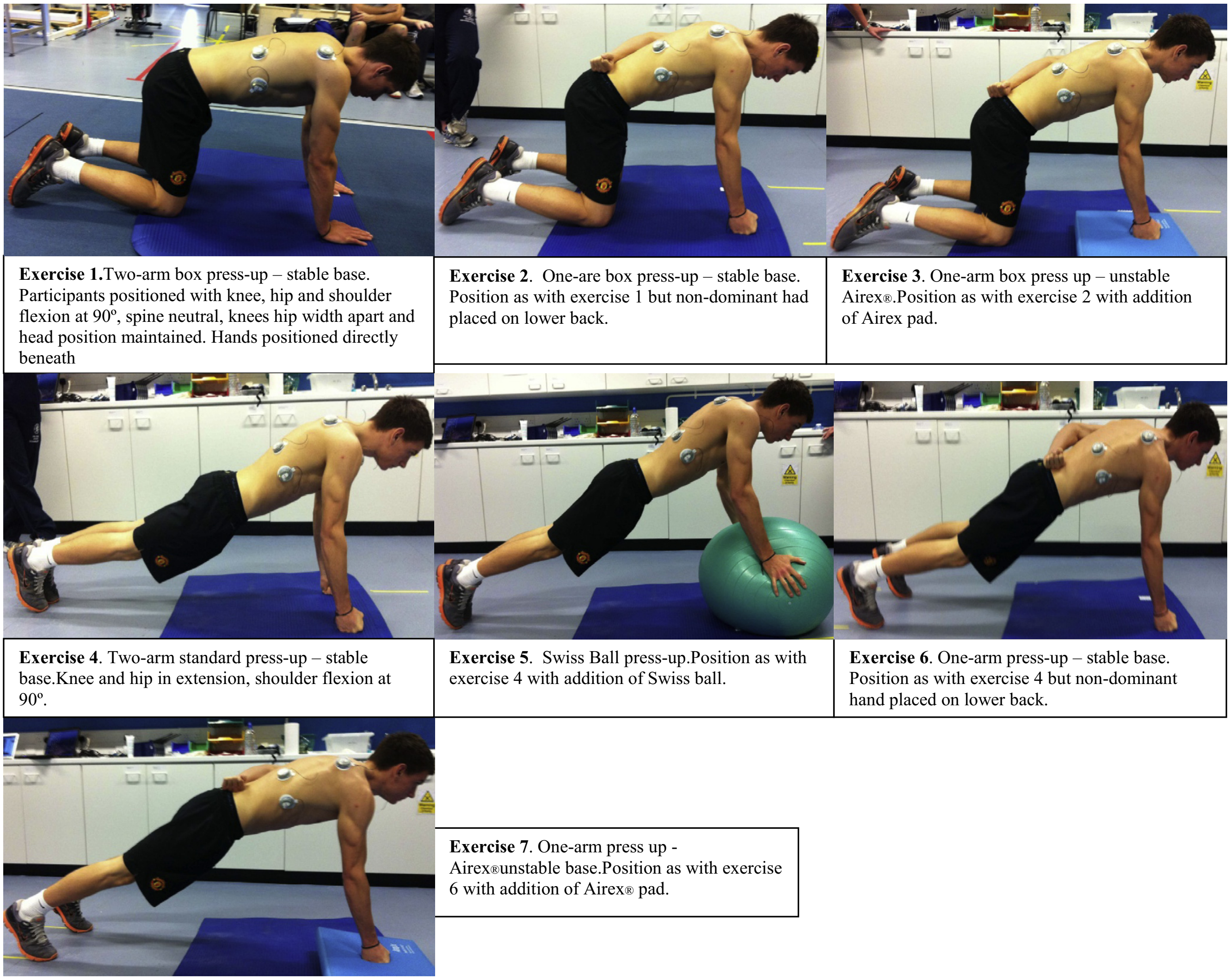

Fig. 1. Illustration of the exercise undertaken.

Table 1
Mean muscle activation results for exercise main effect (% of MVIC).

	Pectoralis major	Anterior deltoid	Infraspinatus	Serratus anterior	Latissimus dorsi
Ex 1	4.71 (±2.39)	6.84 (±4.57)	8.79 (±8.16)	19.68 (±15.65)	7.79 (±6.07)
Ex 2	6.13 (±5.40)	12.58 (±9.28)	26.62 (±21.45)	45.63 (±30.60)	17.32 (±14.71)
Ex 3	9.73 (±12.12)	10.95 (±11.34)	21.25 (±18.79)	38.17 (±29.60)	14.15 (±13.28)
Ex 4	19.77 (±8.46)	37.06 (±17.04)	31.86 (±23.50)	67.18 (±30.96)	24.94 (±19.49)
Ex 5	19.61 (±19.49)	16.93 (±9.67)	21.67 (±17.17)	48.59 (±33.12)	15.54 (±11.24)
Ex 6	20.98 (±13.40)	47.60 (±23.92)	77.03 (±50.05)	133.9 (±69.51)	47.39 (±38.00)
Ex 7	19.30 (±12.81)	45.65 (±23.56)	72.48 (±48.99)	118.51 (±59.05)	45.68 (±38.89)

Notes: Values are mean percentage ± SD. Refer to Fig. 1 for description of individual exercises.

stable base box press-up ($p = 0.001$). Additionally the one-armed stable base standard press-up was found to elicit significantly greater latissimus dorsi activation than the two-armed stable base standard press-up ($p = 0.002$).

3.3.3. Anterior deltoid

The one-armed stable base box press-up elicited a significantly greater anterior deltoid activation when compared with the two-armed stable base box press-up ($p = 0.001$). Additionally the two-armed stable base standard press-up was found to elicit significantly greater anterior deltoid activation than the two-armed Swiss ball standard press-up ($p = 0.001$).

3.3.4. Infraspinatus

The one-armed Airex® box press-up elicited a significantly greater infraspinatus activation compared with the two-armed stable base box press-up ($p = 0.001$). Additionally the two-armed stable base standard press-up was found to elicit significantly greater

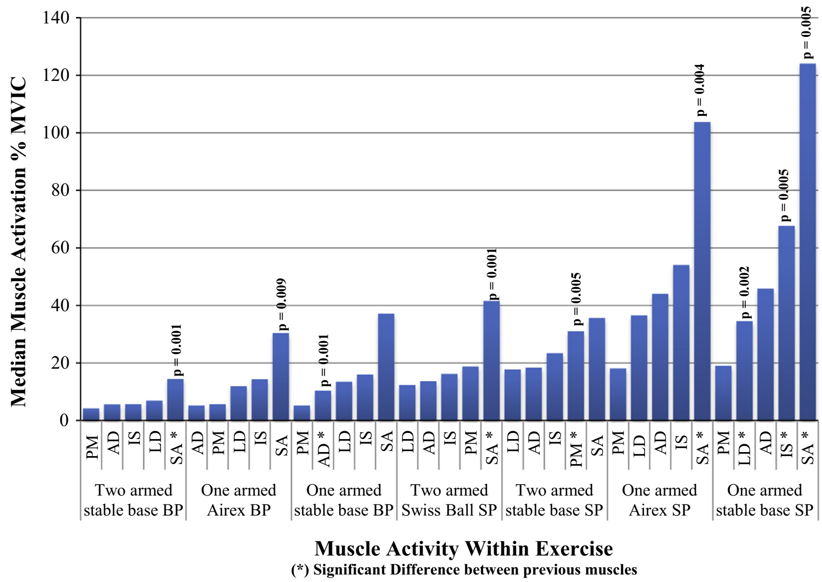

Fig. 2. Within exercise comparison of each muscle ranked by activation with significant differences (*) between the muscle and those previous and p value shown.

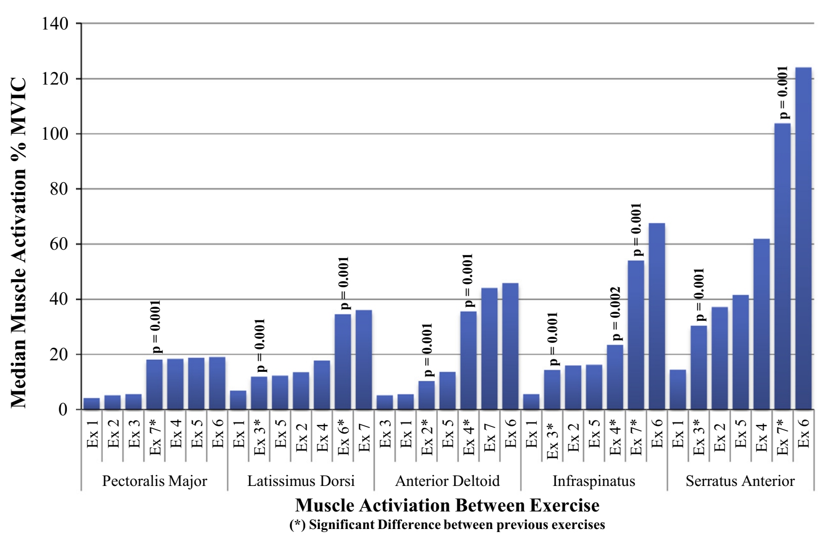

Fig. 3. Between exercise comparisons for each muscle, ranked by median activation (% MVIC) with significant differences (*) and p value shown.

infraspinatus activation than the two-armed Swiss ball standard press-up ($p = 0.002$). There was also significantly greater activation during the one-armed Airex® standard press-up when compared to the two-armed stable base standard press-up ($p = 0.001$).

3.3.5. Serratus anterior

The one-armed Airex® box press-up elicited a significantly greater serratus anterior activation level compared with the two-armed stable base box press-up ($p = 0.001$). Additionally the one-armed Airex® standard press-up was found to elicit significantly greater serratus anterior activation than the two-armed stable base standard press-up ($p = 0.001$).

The primary findings revealed that every muscle tested produced significantly higher activation during the two-armed standard press-up when compared to the two-armed box press-up. Significantly higher muscle activation in all muscles was also found when comparing the one-armed standard press-up compared to the one-armed box press-up. Therefore, the standard press-up requires significantly greater muscle activation than the box press-up. Latissimus dorsi, infraspinatus and the serratus anterior all produced significantly greater activation during the one-armed press-up compared to the two-armed press-up.

4. Discussion

The purpose of this study was to examine the effect of weight bearing static press-ups variations on sEMG activity of pectoralis major, anterior deltoid, infraspinatus, serratus anterior and latissimus dorsi muscles. This study assessed the standard press-up and the box press-up exploring the effect of increased body-weight load and stability challenges on selected muscles of the shoulder complex within each exercise and compared the activity of each muscle across exercises.

Increasing load through the shoulder complex created an increase in muscle activity. Previous studies have shown similar findings with progressive loading during press-up variations resulting in increases in muscle activation (Uhl et al., 2003) and this study is consistent with previous research showing CKC press-up with variations can produce progressively greater load to the shoulder (Pontillo et al., 2007).

Within and across exercises individual muscle activation levels varied which is consistent with findings of Uhl et al. (2003). Muscle recruitment has been placed into four categories based on sEMG activity: low (<20%), moderate (20–40%), high (41–60%) and very high (>60%) (Uhl et al., 2003). Moseley et al. (1992) stated that for an exercise to be classed as having optimal muscle activation it must be greater than or equal to 50% of maximal voluntary isometric contraction (MVIC). Moseley et al. (1992) stated further that any exercise creating activation below this level (50% MIVC) would result in no major effect on muscle strength development. In addition, Ludewig et al. (2004) noted that past authors have suggested that loads below 66% of MVIC will not increase strength even with numerous repetitions.

Examination of pectoralis major, anterior deltoid and latissimus dorsi activity demonstrated relatively small increases as progressions occurred with the maximum activation ranging between a 19% for pectoralis major to 46% MVIC for anterior deltoid (Table 1) and in accordance with Moseley et al. (1992) this indicates these exercises would not have a major effect on generating strength gains in these muscles. Uhl et al. (2003) reported similarly low activation levels for anterior deltoid and pectoralis major activity in the box press-up (6% and 10% respectively), the two-armed standard press-up (31% and 33%) and the one-armed standard press-up (46% and 44%). In contrast to Uhl et al. (2003) several authors have reported much greater activation for all three muscles in the standard press-up. Sandhu et al. (2008) found pectoralis major activation levels as high as 122%, while Decker et al. (1999) noted peak anterior deltoid activity of 185%. Decker et al. (2003) reported 65% MVIC activation for latissimus dorsi however these results were gained from dynamic standard press-up variations not static as this study investigated. It is therefore concluded that the static press-up is not sufficiently demanding to elicit a strength training stimulus on pectoralis major, latissimus dorsi and anterior deltoid. Further study is needed to examine dynamic press-up variations and progressions. Serratus anterior recorded the highest activation across all exercise conditions with a peak of 124% MVIC in the one-armed stable base standard press-up. Infraspinatus followed the same activation sequence with a peak of 68% MVIC.

The addition of an unstable platform did not produce a relative increase in muscle activation. Claims that the addition of an unstable platform results in an increase in muscle activation (Lehman et al., 2008) are not supported by this study. The Airex® pad and Swiss ball intervention activity levels from this study support previous studies where serratus anterior and infraspinatus activity decreased in the unstable variations (Pontillo et al., 2007). This may due to the increase in centre of pressure deviation produced by balancing on an unstable base being insufficient to induce increased muscle activation (Pontillo et al., 2007). The stable base condition findings from this study are in support of previous research for serratus anterior and infraspinatus, which show significantly greater muscle activation with increased body-weight loading to the shoulder. Maenhout et al. (2010) reporting serratus anterior had significantly greater activation in the one-armed box press-up compared to the two-armed box press-up. Uhl et al. (2003) reported an increase in infraspinatus activity in the one-armed press-up due to the increased demand to stabilise the upper body. With the increase in body-weight load serratus anterior would respond by increasing scapula stabilisation with an increase in activation (Tucker et al., 2008) while infraspinatus response would be to dynamically stabilise the humeral head against the glenoid while resisting humeral posterior translation/shear forces (Uhl et al., 2003).

While consistency with electrode placement and participant position was considered carefully inconsistencies may have transpired. Participant fatigue may have occurred as the exercises were not in random order and an order effect could have occurred, this is a potential limitation of the study. However adequate rest between attempts was given and participants were free to request more rest time if needed. Participants were convenience sampling and may not be a true representation of overall population.

5. Practical implications

This study has offered some understanding of muscle activation percentages of several muscles during the static press-up. This study has clearly shown is that increase in loading does result in greater levels of muscle activity however it has also been demonstrated that, in agreement with several other authors, an unstable base of support does not necessarily elicit greater muscle activation in all muscles. Progressions suggested by this study have been shown to be most suited to serratus anterior and infraspinatus activity. A more dynamic press-up could need to be considered for anterior deltoid, pectoralis major and latissimus dorsi activity. This study may be used as a guide to strengthening and rehabilitation practitioners when designing an exercise programme.

6. Conflict of interest

None.

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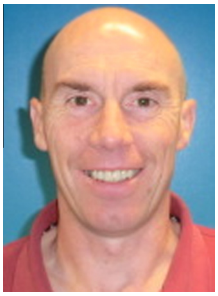

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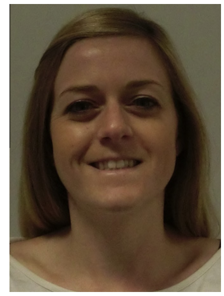

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