**Vibration as an adjunct to exercise: Its impact on shoulder muscle activation**

Michael J Grant1, David H Hawkes1,2, Jessica McMahon3, Ian Horsley4, Omid Khaiyat3

1 Specialty Registrar, Trauma and Orthopaedic Surgery, North West (Mersey) Deanery, Liverpool, UK

2 Musculoskeletal Science Research Group, Institute of Translational Medicine, University of Liverpool, Liverpool, UK

3 School of Health Sciences, Liverpool Hope University, Liverpool, UK

4 England Institute for Sport, Sports City, Manchester, UK

*Corresponding Author*:

Professor Omid Khaiyat

**Email:** alizado@hope.ac.uk

**Address**: School of Health Sciences, Liverpool Hope University, Hope Park, Liverpool L16 9JD

**Phone:** 0151 291 3262

**Abstract**

**Purpose**: There is an interest within elite sport in understanding the impact of a vibrating platform as an adjunct to exercise in the training and rehabilitation of throwing athletes. However, there has been no comprehensive evaluation of its impact on the rotator cuff muscles or its effect on the timing of shoulder muscle recruitment more globally.

**Methods**: Twenty healthy participants were recruited with EMG recorded from 15 shoulder girdle muscles. Isometric shoulder flexion at 25% maximal voluntary contraction was performed in 3 testing scenarios (no vibration (NV); whole body vibration (WBV) and arm vibration (AV)). A press up and triceps dips with and without vibration were also performed. Muscular recruitment was assessed pre- and post-vibration exposure as participants initiated forward flexion.

**Results**: Activation of the anterior deltoid (p=0.002), serratus anterior (p=0.004) and rotator cuff muscles (p=0.004-0.022) occurred significantly earlier following exposure to vibration. Significantly greater activation was seen in the anterior, middle and posterior deltoid, upper, middle and lower trapezius, serratus anterior, teres major, latissimus dorsi, supraspinatus and infraspinatus when the isometric contraction was performed with either WBV and/or AV (p=<0.001-0.040). Similarly, increased activation was also demonstrated during the press up and triceps dips when performed with vibration.

**Conclusion**: The use of vibration as an adjunct to exercise provokes a near global increase in shoulder muscle activation level. Further, exposure to vibration alters muscular recruitment improving readiness for movement. This has potential implications within elite sport for both training and game preparation, however further longitudinal work is required.

**Key Words**: EMG; Muscle Activity; Shoulder; Vibration; Muscle Recruitment

**Abbreviations**

|  |  |
| --- | --- |
|  |  |
| AD | Anterior deltoid |
| ANOVA | Analysis of variance |
| AV | Arm vibration |
| BB | Biceps brachii |
| ISP | Infraspinatus |
| LDL  | Latissimus dorsi lower part |
| LDU | Latissimus dorsi upper part |
| LT | Lower trapezius |
| MD | Middle deltoid |
| MT | Middle trapezius |
| MVC | Maximum voluntary contraction |
| NV | No vibration |
| PD | Posterior deltoid |
| PM | Pectoralis major |
| SA | Serratus anterior |
| SSP | Supraspinatus |
| SUBS | Subscapularis |
| TM | Teres major |
| UT | Upper trapezius |
| WBV | Whole body vibration |

**Introduction**

The maximisation of training gains is an important concept in elite sport. Recently, there is interest in the use of a vibrating platform to enhance muscle activation during the training and rehabilitation of high-level throwing athletes. Whole body vibration (WBV) is widely purported to increase muscle activation when used as a supplement to exercise. However, this potential benefit has predominantly been demonstrated in the lower limb (Hazell et al. 2010; Marin et al. 2011), with only a paucity of studies evaluating the upper limb (Ashnagar et al. 2016). Further, its effect on the rotator cuff muscles has not been described. Additional evidence is therefore required, not least owing to the multiple stakeholders involved in elite sport.

The anatomy of the rotator cuff dictates that contraction generates a compressive force across the glenohumeral joint. This effectively stiffens the joint preventing excessive translation of the humeral head on the glenoid fossa (Lugo et al. 2008). EMG is an accepted form of assessing muscular activation and has been used to investigate muscular activity in the shoulder, during flexion, abduction, extension and internal and external rotation (Kronberg et al. 1990; David et al. 2000; Wickham et al. 2009). The investigation of shoulder muscle activation has led to the understanding that co-ordinated, sustained and coupled activity is necessary for normal function (Hawkes et al. 2011). Importantly, coordinated muscle activity requires control of both the level of activation and also the temporal characteristics of that activation. David et al demonstrated that during shoulder rotational movements the rotator cuff muscles were active prior to the deltoid and pectoralis group (David et al. 2000). This rotator cuff ‘pre-setting’ creates a stable glenohumeral joint before movement progression.

The impact of vibration on the recruitment and timing of shoulder muscles has not been reported. It is proposed that exposure to vibration might enhance the ‘pre-setting’ of the rotator cuff owing to the instability within the shoulder created by the vibrating platform. If this hypothesis is correct it could perhaps advocate the role of the vibrating platform within athletes warm up. Indeed, scapular co-ordination training and rotator cuff strengthening exercises can help protect against injury (Tovin 2006). A recent systematic review has highlighted the deficiencies within the current evidence base, with the majority of recommendations being based on expert opinion or case studies (Wright et al. 2018). Clearly, further work is required.

The aim of this study was therefore to firstly define the impact of vibration exposure on the timing of shoulder muscle recruitment. Secondly, to study the effect of WBV and AV on muscle activation during isometric and isotonic upper limb exercises.

**Methods**

*Participants*

The study had Local Research Ethics Committee approval and informed consent was obtained from all subjects. Twenty healthy participants (10 females and 10 males) with no history of shoulder pathology and a normal clinical examination were recruited. The dominant arm was tested in all subjects. The mean age was 25.5.5±7.5yrs, mean mass 72.8±11.3kgs and mean height 172.0±9.1cm. The study group was the same as that reported in a previous study (Hawkes et al. 2018). The participants were predominantly university post-graduate students, all of whom regularly engaged in recreational sporting activity but none competed within an elite environment. The study design was observational.

*Strength Measurement*

A Nottingham Mecmesin Myometer (Mecmesin Ltd., UK) was used to measure maximal isometric shoulder flexion strength. The myometer was fixed securely to a work bench. Subjects were tested while standing with their feet shoulder width apart; shoulder elevated to 90o in the sagittal plane; elbow extended; and forearm and wrist in neutral. Participants exerted a maximal effort over a 3 second period via a strap connected to the myometer. Three trials were performed with the mean then taken as the maximum voluntary contraction (MVC). Participants were provided with verbal encouragement and challenged to improve on previous efforts (Baratta et al. 1998).

*EMG Measurement*

EMG signals were acquired using a Telemyo DTS system (Noraxon Inc., USA) and subsequent analysis was performed off-line using the accompanying MR3 software (Noraxon Inc., USA). Fifteen shoulder girdle muscles were included in the study. The activity of the anterior deltoid (AD), middle deltoid (MD), posterior deltoid (PD), upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), serratus anterior (SA), teres major (TM), latissimus dorsi upper part (LDU), latissimus dorsi lower part (LDL), pectoralis major (PM) and biceps brachii (BB) was measured using surface electrodes. The surface electrodes were disposable, pre-gelled Ag/AgCl bipolar electrodes with a conducting area of 10mm diameter and inter-electrode distance of 20mm (Noraxon Inc., USA). The electrodes were placed parallel to the muscle fibres in anatomical locations previously described within the literature (Cram et al. 1998; Prakash et al. 2006; Steenbrink et al. 2006). The judicious placement of appropriately sized electrodes limited the impact of cross talk. The activity of the supraspinatus (SSP), infraspinatus (ISP) and subscapularis (SUBS) was measured using bipolar disposable hook wire electrodes (SPES Medica s.r.l. Battipaglia, Italy) (Kadaba et al. 1992; Rudroff T 2008). Electrodes were inserted aseptically into the muscle bellies via a single hypodermic needle. All EMG signals were differentially amplified, digitised at a sampling rate of 3000 Hz and band-pass filtered ([10–500]Hz for surface electrodes and [10–1500]Hz for fine wire electrodes). Manual muscle testing was performed for each muscle to confirm electrode placement and enable a visual check of signal quality.

*EMG Testing Protocol*

EMG data were recorded during a number of different movement protocols described below. The movements enable both the timing and amplitude of muscle activation to be investigated. Muscle activation was measured during both isometric and isotonic exercises. Figure1 provides a schematic overview of the testing protocol. Testing was conducted within a Biomechanics Laboratory with the ambient temperature controlled at 21oC.

*Timing Analysis*

EMG was recorded as subjects initiated a shoulder movement into forward flexion. Each subject was instructed to stand with a relaxed posture, feet a shoulder width apart with their arms resting by their sides in neutral rotation. The illumination of a light bulb was the trigger for subjects to start the movement. Participants were instructed to move their arm in a prompt but smooth manner into shoulder flexion through a full range of motion as soon as they observed the light bulb illuminating. The light bulb was controlled by a separate trigger which illuminated after a random period of time. This acted to prevent any anticipated muscle pre-activation. The onset of movement itself was defined using a 3-axis accelerometer fixed to the subject’s arm. Muscles were defined as being active when their amplitude increased to 3 standard deviations above baseline (Di Fabio 1987). Reaction time was defined as the time between light bulb illumination and movement initiation. Muscle onset time was defined as the difference in time between movement onset and muscle activation. Negative times indicate a muscle was active prior to movement progression. Two trials were performed: before and after exposure to vibration. The vibration exposure consisted of the exercises described below. A number of trials were undertaken prior to the testing to limit any bias from learnt movement patterns.

*Amplitude Analysis*

EMG amplitude was evaluated during both isometric and isotonic exercises. The isotonic exercises included a modified press up and triceps dips. Initially subjects undertook a forward flexion isometric contraction, at 25% MVC. The testing position replicated that used to measure shoulder flexion MVC strength as described above. Participants were provided with feedback to ensure the correct intensity of contraction was maintained. Vibration was delivered using a vibrating platform and associated handle (Power Plate, Performance Health Systems). The Power Plate was set to “High Intensity” with a frequency of 35Hz. These settings were chosen as it has previously been advocated that a combination of a high frequency and a high platform displacement provokes the greatest increase in muscle activation (Lienhard et al. 2014). The Power Plate delivered vertical vibration.

Three testing scenarios were employed: no vibration (NV) (subjects stood on Power Plate with system switched off); whole body vibration (WBV) (subjects stood on Power Plate with system switched on); and arm vibration (AV) (vibration delivered though the handle of Power Plate but subjects not stood on platform) (Figure2). Three trials were performed in each testing scenario and the mean calculated. The sequence of testing scenarios were randomised between subjects to ensure no bias due to cumulative fatigue effect.

Subjects subsequently undertook a modified press up and triceps dips both with and without vibration. The press up was performed with subjects kneeling (to ensure it could be completed by all participants) and hands on the edge of the vibrating platform. Standard triceps dips were performed with subjects placing their hands on the edge of the vibrating platform (Figure3). Ten cycles of each exercise were performed both with and without vibration. The sequence of testing scenarios were again randomised between subjects.

*Data Management and Statistical Analysis*

An adaptive cancelation algorithm, pre-loaded within the MR3 software, was used to remove ECG contamination from affected signals. Signals were smoothed using the root-mean-square (window 100 ms). Amplitude normalisation was performed with respect to the MVC (Lehman and McGill 1999). The time of muscle onset or mean signal amplitude were compared between testing scenarios using a paired samples t-test or repeated measures analysis of variance (ANOVA) with Bonferroni correction as appropriate. A p-value of ≤0.05 was accepted as significant.

**Results**

All subjects were able to complete all elements of the testing protocol. Mean shoulder flexion strength was 84.9±29.8N.

*Timing*

There was no significant difference in reaction time for movement initiation in the pre- and post-vibration exposure tests (0.612s and 0.633s respectively; p=0.834). However, activation of the AD (p=0.002), SA (p=0.004), SSP (p=0.004), ISP (p=0.009) and SUBS (p=0.022) occurred significantly earlier following vibration exposure (Table1).

*Activation: Isometric Exercise*

Significantly greater activity was seen in the MD, PD, UT, MT, SA, LD-U, LD-L, SSP and ISP during AV and WBV as compared to NV (Table2 and Figure4). Significantly greater activity was seen in the AD for AV as compared to NV (p=0.005). Significantly greater activation was seen in WBV as compared to NV for the LT (p=0.005) and TM (p=0.048). There were no significant differences when comparing activation during WBV and AV for any muscle studied. PM and BB showed no differences in activation level between the different testing scenarios.

*Activation: Isotonic Exercises*

Table3 shows muscle activation for the press up and triceps dips with and without vibration. Significantly higher activation was seen when the press up was performed with the addition of vibration for the AD (p=<0.001), MD (p=<0.001), PD (p=0.003), TM (p=0.003), LD-L (p=0.036), PM (p=0.003) and BB (p=0.001). Muscle activation was significantly higher when the triceps dips were performed with vibration for the AD (p=<0.001), MD (p=<0.001), PD (p=0.001), UT (p=0.004), MT (p=0.045), TM (p=0.014), PM (p=0.005) and ISP (p=0.012). No muscles demonstrated higher activation without vibration for either of the exercises.

**Discussion**

Injury prevention whilst maximising training gains are of fundamental importance within elite sport. The role of the vibrating platform for overhead athletes has not previously been defined. Therefore, the aim of this work was to study the effect of a vibrating platform on both shoulder muscle recruitment and activation. To our knowledge this is the first study to investigate the impact of vibration on the entire shoulder girdle, in particular the rotator cuff muscles. The results are discussed below, firstly with regard to muscle recruitment and secondly muscle activation.

*Muscle Recruitment*

Translation of the humeral head on the glenoid fossa, in response to contraction of the powerful shoulder girdle muscles, occurs due to the limited osseous congruity of the shoulder (Bey et al. 2008). Therefore, coordinated muscle activation is necessary to maintain joint stability, ensuring normal function without symptom generation. The temporal characteristics, as well as absolute activation levels, is an important component of coordinated muscle function. Indeed, aberrant timing of rotator cuff activation has been implicated in shoulder instability (Barden et al. 2005). The importance of neuromuscular control for normal movement has also been described in disorders such as low back pain and patellofemoral dysfunction (Cowan et al. 2001; Hodges and Richardson 1996).

In this study, in the pre-vibration scenario, the AD, SA and SSP were active prior to the initiation of forward flexion. This was expected given the accepted function of the AD as a prime move of the shoulder in forward flexion and the wide acceptance of the stabilising role of SSP (Kronberg et al. 1990). The SA elevates and upwardly rotates the scapula, its activation prior to movement initiation creates proximal stability as a basis for arm movement (McQuade et al. 1998). Wickham described the temporal characterises of shoulder activation during abduction finding that SSP, MD and MT were active prior to movement initiation (Wickham et al. 2009). Whilst the plane of movement was different to this study, the results are comparable with the rotator cuff and periscapular muscles creating a stable base before movement. Similarly, Ricci et al has described early activation of the periscapular muscles, in order to achieve proximal stability, during a functional task (Ricci et al. 2015). A number of studies have reported on the timing of rotator cuff activation during both rotational exercises and external rotation perturbation, highlighting the role of the rotator cuff in ‘pre-setting’ prior to movement progression (David et al. 2000; Hess et al. 2005; Day et al. 2012).

After vibration exposure, the AD, SA, SSP, ISP and SUBS were all active significantly earlier as compared to the pre-vibration test. This suggests an increased readiness for movement after the vibration exposure. A possible explanation is that the vibrating platform creates micro-moments of instabilit­­­y for which the shoulder is required to find adaptive stabilising strategies. Earlier activation of the rotator cuff and SA therefore being akin to the ‘pre-setting’ for movement previously described within the introduction. There were no differences in the reaction time between the pre- and post-vibration test. This indicates that earlier recruitment of the was a strategy to improve stability prior to movement progression.

*Muscle Activation*

The physiological signals detected by EMG electrodes are the necessary prerequisites for a muscle contraction. It is therefore accepted that there is a high correlation between EMG amplitude and muscular force generation (Lawrence and De Luca 1983). Exercises which demonstrate increased EMG amplitude can therefore be postulated to improve training efficiency and maximise training gains.

A vibrating platform transfers energy to the whole body or a specific body part (Cochrane 2011). Traditionally the tonic-vibration-reflex has been used to describe the increased muscle activation in association with vibration. Mechanical vibrations induce length changes in muscle spindles activating afferent feedback loops which subsequently initiate muscle contraction through reflex arcs (Cardinale and Bosco 2003). However, more recently muscle tuning and alterations in central motor command have also been purported to have a role in governing the increased muscle activity seen in response to vibration (Cochrane 2011).

In this study there was almost a global increase in activation of the shoulder girdle muscles during an isometric flexion contraction with the addition of vibration. Activation of the MD, PD, UT, MT, SA, LD-U, LD-L, SSP and ISP was significantly higher when the contraction was performed with the addition of AV and WBV as compared to NV. Further, AD was significantly more active with AV as compared to NV and LT and TM during WBV as compared to NV. There were no significant differences between activation levels when comparing WBV and AV for any of the muscles studied. This later finding is consistent with a study by Pamukoff et al who found no differences in activation between WBV and local muscle vibration on quadriceps function (Pamukoff et al. 2016).

Similar results were seen during the isotonic exercises. Activation of the AD, MD, PD, TM, LD-L, PM and BB was significantly higher during a press up with the addition of vibration. In the triceps dips the AD, MD, PD, UT, MT, TM, PM and ISP were significantly more active when the exercise was performed with vibration. The results therefore demonstrate that the addition of vibration to a dynamic exercise increases activation levels in a number of muscles. The activation levels for the press up without vibration were highest for the SA, PM and SUSB. Herrington et al presents similar results, although only a limited number of muscles were studied. In their study the highest activity was seen in the SA. Lower activation was seen in the PM than is described here, but this probably reflects a subtle difference between the press up positions used (Herrington et al. 2015).

Previous literature has focused predominantly on the impact of vibration exercises on lower limb muscles with a number of authors having demonstrated increased muscle activity when WBV was added to various exercises (Hazell et al. 2010; Marin et al. 2011). Beneficial effects have also been demonstrated in deconditioned muscle following prolong periods of bed rest (Blottner et al. 2006). However, there is only a paucity of evidence evaluating the upper limb and we are not aware of any previous studies that have comprehensively evaluated the rotator cuff muscles. This is a particular deficiency within the literature given the reliance of the shoulder on coordinated muscle activity. Ashnagar, in a limited selection of muscles, studied muscle activity levels during a modified press up with and without vibration finding increased activity in the UT, SA, BB and triceps brachii when the press up was performed with vibration (Ashnagar et al. 2016).

*Practical Application*

It has been postulated that improving neuromuscular control of the rotator cuff can enhance stability of the glenohumeral joint. This might have the effect of limiting glenohumeral instability, which can develop following overhead sporting activity, and even protect against secondary injury. Indeed, neuromuscular training in professional rugby league athletes was found to have a protective effect against the rate of major shoulder injury (Chandnani et al. 1992). While it is clearly not possible to draw any such direct conclusions from this current study it would be interesting to evaluate the effect of a vibrating platform to an athlete’s warm-up. Further prospective longitudinal work would be required to study any effect of vibration on injury prevention.

The maximisation of training gains is an important concept within elite sport. This study demonstrates a near global increase in shoulder muscle activity when vibration is used as an adjunct to upper limb exercises. The results therefore offer valuable information to coaches, athletes and researches within sports and exercise physiology. However, it needs to be cautioned that additional research is required to evaluate these potential theoretical training benefits.

The limitations of this study are acknowledged. The isometric exercise was limited to a single plane of shoulder movement, which represents only a limited portion of the entire range of motion possible. However, the evidence base evaluating the impact of vibration on the upper limb is currently extremely limited. Single planar isometric movements are simpler to evaluate than complex multiplanar movements, especially when synchronously recording the activity of 15 shoulder girdle muscle. This study is therefore proposed to be a useful first step in an area of limited evidence. Further work is undoubtedly required evaluating exercises more representative of the training programmes within elite sport.

**Conclusion**

This is the first comprehensive analysis of the impact of vibration on shoulder muscle activation and recruitment when used as an adjunct to exercises. The use of either WBV or AV provokes a global increase in shoulder muscle activation levels. Further, exposure to vibration alters the timing of shoulder muscle recruitment with the effect of improving readiness for movement. The potential implication for elite sport is the maximisation of training gains while limiting injury risk, however, further work is required.

**References**

Ashnagar Z, Shadmehr A, Hadian M, Talebian S, Jalaei S (2016) The effects of whole body vibration on EMG activity of the upper extremity muscles in static modified push up position. J Back Musculoskelet 29(3):557-563.

Baratta RV, Solomonow M, Zhou BH, Zhu M (1998) Methods to reduce the variability of EMG power spectrum estimates. J Electromyogr Kines 8(5):279-285.

Barden JM, Balyk R, Raso VJ, Moreau M, Bagnall K (2005) Atypical shoulder muscle activation in multidirectional instability. Clin Neurophysiol 116(8):1846-1857.

Bey MJ, Kline SK, Zauel R, Lock TR, Kolowich PA (2008) Measuring dynamic in-vivo glenohumeral joint kinematics: technique and preliminary results. J Biomech 41(3):711-714.

Blottner D, Salanova M, Püttmann B, Schiffl G, Felsenberg D, Buehring B, Rittweger J (2006). Human skeletal muscle structure and function preserved by vibration muscle exercise following 55 days of bed rest. Eur J Appl Physiol. 2006 Jun;97(3):261-71

Cardinale M, Bosco C (2003) The use of vibration as an exercise intervention. Exerc Sport Sci Rev 31(1):3-7.

Chandnani V, Ho C, Gerharter J, Neumann C, Kursunoglu-Brahme S, Sartoris DJ, Resnick D (1992) MR findings in asymptomatic shoulders: a blind analysis using symptomatic shoulders as controls. Clin Imaging 16(1):25-30.

Cochrane DJ (2011) The Potential Neural Mechanisms of Acute Indirect Vibration. J Sports Sci Med 10(1):19-30.

Cowan SM, Bennell KL, Hodges PW, Crossley KM, McConnell J (2001) Delayed onset of electromyographic activity of vastus medialis obliquus relative to vastus lateralis in subjects with patellofemoral pain syndrome. Arch Phys Med Rehab 82(2):183-189.

Cram JR, Kasman GS, Holtz J (1998) Introduction to surface electromyography. Aspen Publishers, Gaithersburg, Md.

David G, Magarey ME, Jones MA, Dvir Z, Turker KS, Sharpe M (2000) EMG and strength correlates of selected shoulder muscles during rotations of the glenohumeral joint. Clin Biomec 15(2):95-102.

Day A, Taylor NF, Green RA (2012) The stabilizing role of the rotator cuff at the shoulder--responses to external perturbations. Clin Biomec 27(6):551-556.

Di Fabio RP (1987) Reliability of computerized surface electromyography for determining the onset of muscle activity. Phys Ther 67(1):43-48.

Hawkes D, Grant M, McMahon J, Horsley I, Khaiyat O (2018) Can grip strength be used as a surrogate marker to monitor recovery from shoulder fatigue? J Electromyogr Kines 41:139-146.

Hawkes DH, Alizadehkhaiyat O, Kemp GJ, Fisher AC, Roebuck MM, Frostick SP (2012) Shoulder muscle activation and coordination in patients with a massive rotator cuff tear: An electromyographic study. J Orthop Res 30(7):1140-6.

Hazell TJ, Kenno KA, Jakobi JM (2010) Evaluation of muscle activity for loaded and unloaded dynamic squats during vertical whole-body vibration. J Strength Cond Res 24(7):1860-1865.

Herrington L, Waterman R, Smith L (2015) Electromyographic analysis of shoulder muscles during press-up variations and progressions. J Electromyogr Kines 25(1):100-106.

Hess SA, Richardson C, Darnell R, Friis P, Lisle D, Myers P (2005) Timing of rotator cuff activation during shoulder external rotation in throwers with and without symptoms of pain. J Orthop Sports Phys Ther 35(12):812-820.

Hodges PW, Richardson CA (1996) Inefficient muscular stabilization of the lumbar spine associated with low back pain. Spine 21(22):2640-2650.

Kadaba MP, Cole A, Wootten ME, McCann P, Reid M, Mulford G, April E, Bigliani L (1992) Intramuscular wire electromyography of the subscapularis. J Orthop Res 10(3):394-397.

Kronberg M, Nemeth G, Brostrom LA (1990) Muscle activity and coordination in the normal shoulder. An electromyographic study. Clin Orthop Relat Res (257):76-85.

Lawrence JH, De Luca CJ (1983) Myoelectric signal versus force relationship in different human muscles. J Appl Physiol 54(6):1653-1659.

Lehman GJ, McGill SM (1999) The importance of normalization in the interpretation of surface electromyography: a proof of principle. J Manipulative Physiol Ther 22(7):444-446.

Lienhard K, Cabasson A, Meste O, Colson SS (2014) Determination of the optimal parameters maximizing muscle activity of the lower limbs during vertical synchronous whole-body vibration. Eur J Appl Physiol 114(7):1493-1501.

Lugo R, Kung P, Ma CB (2008) Shoulder biomechanics. Eur J Radiol 68(1):16-24.

Marin PJ, Santos-Lozano A, Santin-Medeiros F, Delecluse C, Garatachea N (2011) A comparison of training intensity between whole-body vibration and conventional squat exercise. J Electromyogr Kines. 2011;21(4):616-621.

McQuade KJ, Dawson J, Smidt GL (1998) Scapulothoracic muscle fatigue associated with alterations in scapulohumeral rhythm kinematics during maximum resistive shoulder elevation. J Orthop Sports Phys Ther 28(2):74-80.

Rudroff T (2008) Kinesiological Fine Wire EMG. A practical introduction to fine wire EMG applications. http://www.velamed.com/wp-content/uploads/Fine\_Wire\_EMG.pdf. Accessed July 2018

Pamukoff DN, Pietrosimone B, Lewek MD, Ryan ED, Weinhold PS, Lee DR, Blackburn JT (2016) Immediate effect of vibratory stimuli on quadriceps function in healthy adults. Muscle Nerve 54(3):469-478.

Prakash KM, Fook-Chong SM, Leoh TH, Dan YF, Nurjannah S, Tan YE, Lo YL (2006) The lower subscapular nerve conduction studies and utilisation in brachial plexopathy evaluation. J Neurol Sci 247(1):77-80.

Ricci FP, Santiago PR, Zampar AC, Pinola LN, Fonseca Mde C (2015) Upper extremity coordination strategies depending on task demand during a basic daily activity. Gait Posture 42(4):472-478.

Steenbrink F, de Groot JH, Veeger HE, Meskers CG, van de Sande MA, Rozing PM (2006) Pathological muscle activation patterns in patients with massive rotator cuff tears, with and without subacromial anaesthetics. Manual Ther 11(3):231-237.

Tovin BJ (2006) Prevention and Treatment of Swimmer's Shoulder. N Am J Sports Phys Ther 1(4):166-175.

Wickham J, Pizzari T, Stansfeld K, Burnside A, Watson L (2010) Quantifying 'normal' shoulder muscle activity during abduction. J Electromyogr Kines 20(2):212:222.

Wright AA, Hegedus EJ, Tarara DT, Ray SC, Dischiavi SL (2018) Exercise prescription for overhead athletes with shoulder pathology: a systematic review with best evidence synthesis. Brit J Sport Med 52(4):231-237.

**Figure Captions:**

**Fig1.** Flowchart illustrating the testing protocol

**Fig2.** Testing scenarios of isometric shoulder flexion.

**Fig3.** Testing positions for the press up and triceps dips

**Fig4.** Graphical representation of muscle activation levels during shoulder flexion at 25% MVC in the different testing scenarios

**Table Legends:**

**Table1.**Muscle activation onset times pre- and post-vibration exposure

**Table2.** A comparison of muscle activation during isometric shoulder flexion at 25% MVC in the different testing scenarios.

**Table3.**Muscle activation during press ups and triceps dips with and without vibration