ORIGINAL ARTICLE

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

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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 three testing scenarios [no vibration; 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. Furthermore, 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.

Keywords EMG · Muscle activity · Shoulder · Vibration · Muscle recruitment

Abbreviations

AD	Anterior deltoid
ANOVA	Analysis of variance
AV	Arm vibration
BB	Biceps brachii
ISP	Infraspinatus
LD-L	Latissimus dorsi lower part
LD-U	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

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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). Furthermore, 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 rotations (Kronberg et al. 1990; David et al. 2000; Wickham et al. 2010). The investigation of shoulder muscle activation has led to the understanding that coordinated, sustained, and coupled activity is necessary for normal function (Hawkes et al. 2012). 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 coordination 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, first to define the impact of vibration exposure on the timing of shoulder muscle recruitment and second, 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 $25.5.5 \pm 7.5$ years, mean mass 72.8 ± 11.3 kg, and mean height 172.0 ± 9.1 cm. 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 90° in the sagittal plane; elbow extended; and forearm and wrist in neutral. Participants exerted a maximal effort over a 3 s 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 the 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 offline 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 (LD-U), latissimus dorsi lower part (LD-L), pectoralis major (PM), and biceps brachii (BB) was measured using surface electrodes. The surface electrodes were disposable, pregelled Ag/AgCl bipolar electrodes with a conducting area of 10 mm diameter and inter-electrode distance of 20 mm (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 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. Figure 1 provides a schematic overview of the testing protocol. Testing was conducted within a Biomechanics Laboratory with the ambient temperature controlled at 21 ℃.

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 three 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

Fig. 1 Flowchart illustrating the testing protocol
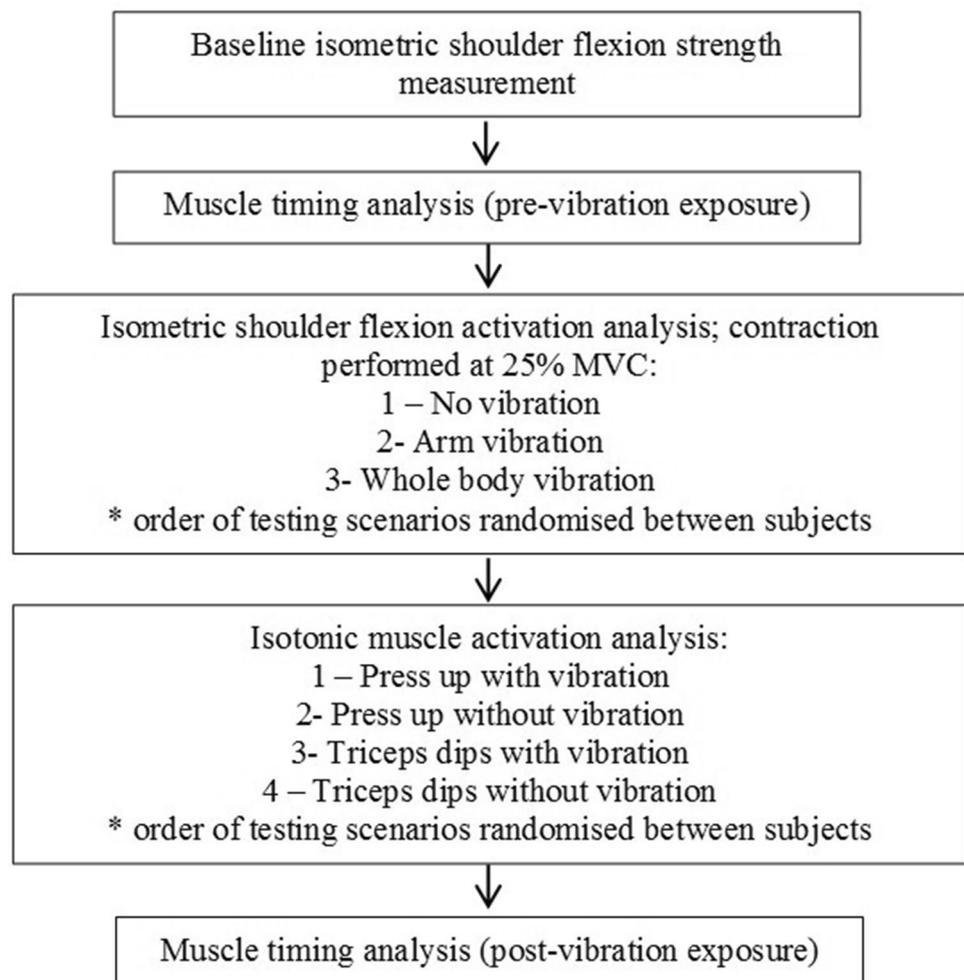
below. A number of trials were undertaken prior to the testing to limit any bias from learnt movement patterns.

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 35 Hz. 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) (Fig. 2). Three trials were performed in each testing scenario and the mean calculated. The sequence of testing scenarios was 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 that 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 (Fig. 3). Ten cycles of each exercise were performed both with and without vibration. The sequence of testing scenarios was 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 was 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 ± 29.8 N.

Timing

There was no significant difference in reaction time for movement initiation in the pre- and post-vibration exposure tests (0.612 s and 0.633 s, 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 (Table 1).
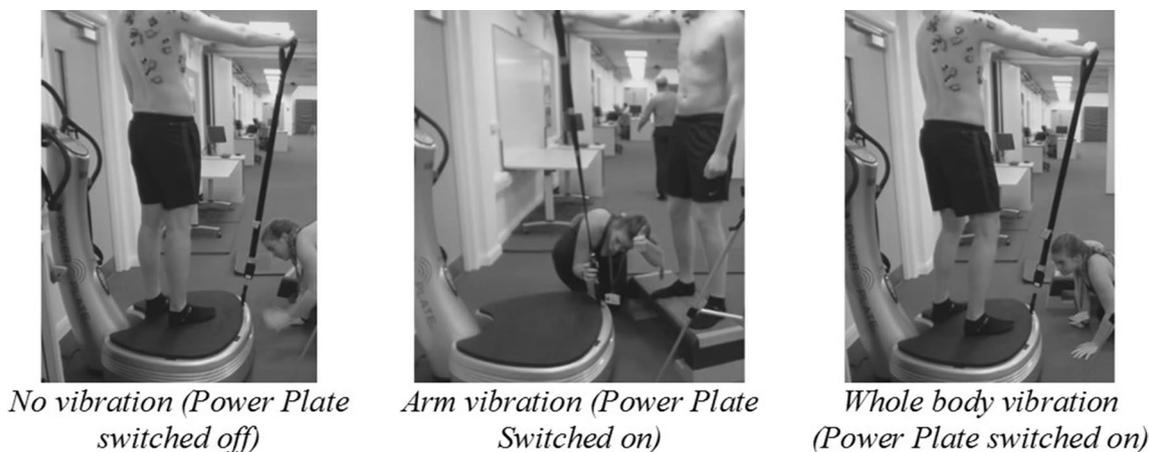

No vibration (Power Plate switched off)   *Arm vibration (Power Plate Switched on)*   *Whole body vibration (Power Plate switched on)*

Fig. 2 Testing scenarios of isometric shoulder flexion

Press-up (performed with Power Plate switched on and off)

Triceps-Dips (performed with Power Plate switched on and off)

Fig. 3 Testing positions for the press up and triceps dips

Table 1 Muscle activation onset times pre- and post-vibration exposures

	Pre-Vibration		Post-Vibration		Comparisons p value[†]
	Mean*	SEM	Mean*	SEM	
AD	− 0.085	0.066	− 0.162	0.075	**0.002**
MD	0.084	0.213	0.038	0.261	0.293
PD	0.254	0.271	0.173	0.331	0.991
UT	0.044	0.150	− 0.004	0.153	0.144
MT	0.126	0.193	0.053	0.191	0.079
LT	0.093	0.131	0.040	0.134	0.146
SA	− 0.075	0.085	− 0.138	0.114	**0.004**
TM	0.435	0.239	0.134	0.370	0.227
LD-U	0.327	0.439	− 0.015	0.507	0.284
LD-L	0.576	0.322	0.516	0.631	0.627
PM	0.110	0.294	0.036	0.211	0.157
BB	0.097	0.306	0.026	0.249	0.262
SSP	− 0.050	0.158	− 0.147	0.116	**0.004**
ISP	0.000	0.214	− 0.151	0.117	**0.009**
SUBS	0.394	0.368	− 0.064	0.231	**0.022**

Bold values indicate significant differences

*Values are time (s)

[†]Paired samples t test

Fig. 4 Graphical representation of muscle activation levels during shoulder flexion at 25% MVC in the different testing scenarios

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 (Table 2 and Fig. 4). 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 comparin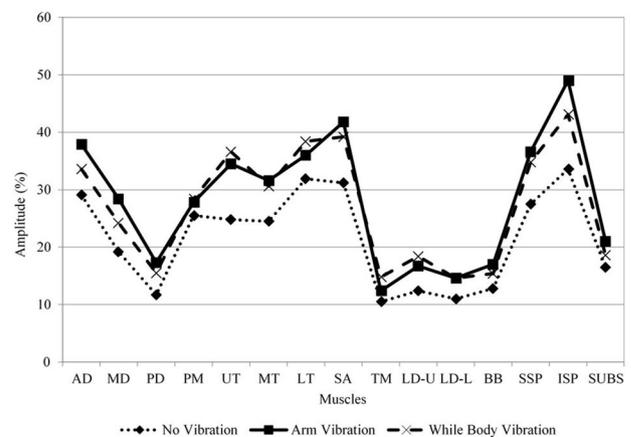g activation during WBV and AV for any muscle studied. PM and BB showed no differences in activation level between the different testing scenarios.

Activation: isotonic exercises

Table 3 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.

Table 2 Comparison of muscle activation during isometric shoulder flexion at 25% MVC in the different testing scenarios

	No vibration (NV)		Arm vibration (AV)		While body vibration (WBV)		Comparisons			
	Mean*	SEM	Mean*	SEM	Mean*	SEM	F	p value□	Scenario	p value△
AD	29.1	2.3	37.9	3.2	33.6	2.2	7.955	**0.002**	NV vs AV	**0.005**
									NV vs WBV	0.108
									AV vs WBV	0.208
MD	19.2	2.1	28.4	4.0	24.2	2.6	9.497	**0.003**	NV vs AV	**0.012**
									NV vs WBV	**0.008**
									AV vs WBV	0.100
PD	11.7	1.4	17.3	2.7	15.5	1.6	7.449	**0.005**	NV vs AV	**0.016**
									NV vs WBV	**0.002**
									AV vs WBV	0.834
UT	24.8	2.9	34.5	4.5	36.6	2.7	16.834	**< 0.001**	NV vs AV	**0.002**
									NV vs WBV	**< 0.001**
									AV vs WBV	1.000
MT	24.5	2.4	31.6	3.0	30.6	2.9	13.468	**< 0.001**	NV vs AV	**0.001**
									NV vs WBV	**0.001**
									AV vs WBV	1.000
LT	31.9	3.1	36.0	3.5	38.4	3.6	7.610	**0.002**	NV vs AV	0.067
									NV vs WBV	**0.005**
									AV vs WBV	0.464
SA	31.2	3.4	41.8	4.3	39.2	3.8	11.536	**< 0.001**	NV vs AV	**0.002**
									NV vs WBV	**0.009**
									AV vs WBV	0.632
TM	10.5	2.0	12.4	2.3	14.8	3.4	4.865	**0.027**	NV vs AV	0.076
									NV vs WBV	**0.048**
									AV vs WBV	0.428
LD-U	12.4	2.1	16.7	2.7	18.4	3.4	5.154	**0.024**	NV vs AV	**0.001**
									NV vs WBV	**0.040**
									AV vs WBV	1.000
LD-L	11.0	1.5	14.6	1.9	14.6	1.8	27.287	**< 0.001**	NV vs AV	**< 0.001**
									NV vs WBV	**< 0.001**
									AV vs WBV	1.000
PM	25.5	3.2	27.8	4.2	28.4	3.7	1.416	0.256	NV vs AV	N/A
									NV vs WBV	N/A
									AV vs WBV	N/A
BB	12.8	2.9	17.0	3.6	15.4	2.9	3.493	0.070	NV vs AV	N/A
									NV vs WBV	N/A
									AV vs WBV	N/A
SSP	27.5	4.6	36.6	5.2	34.8	4.5	7.542	**0.002**	NV vs AV	**0.011**
									NV vs WBV	**0.025**
									AV vs WBV	1.000
ISP	33.6	5.3	49.0	6.9	43.1	6.8	11.979	**0.001**	NV vs AV	**0.004**
									NV vs WBV	**0.012**
									AV vs WBV	0.522
SUBS	16.5	3.9	21.0	5.0	18.6	4.7	1.538	0.279	NV vs AV	0.704
									NV vs WBV	1.000
									AV vs WBV	1.000

Bold values indicate significant differences

*Values are mean amplitude (%)

□Repeated measures ANOVA comparing testing scenarios with relevant

△Bonferroni post-hoc testing

Table 3 Muscle activation during press ups and triceps dips with and without vibration

	Press ups			Triceps dips		
	No vibration	Vibration	Comparisons p value[†]	No vibration	Vibration	Comparisons p value[†]
	Mean*±SEM	Mean*±SEM		Mean*±SEM	Mean*±SEM	
AD	11.9±1.5	15.0±2.0	**<0.001**	6.8±1.3	9.3±1.7	**<0.001**
MD	5.5±1.1	6.6±1.2	**<0.001**	5.3±0.7	6.4±0.8	**<0.001**
PD	4.6±0.8	5.8±0.9	**0.003**	7.0±1.0	8.8±1.4	**0.001**
UT	14.6±1.8	15.2±2.1	0.104	5.1±1.0	6.6±1.4	**0.004**
MT	9.7±1.9	9.2±1.6	0.072	34.6±3.3	37.4±3.1	**0.045**
LT	7.7±1.3	8.3±1.0	0.212	49.3±5.0	52.2±4.9	0.054
SA	25.4±3.0	27.4±3.7	0.066	18.9±3.4	20.6±3.7	0.055
TM	6.2±0.9	7.4±1.2	**0.003**	30.1±3.8	35.9±5.2	**0.014**
LD-U	10.6±2.1	10.8±2.2	0.064	42.8±4.8	47.0±7.5	0.344
LD-L	11.1±1.9	11.4±1.9	**0.036**	46.1±6.1	55.2±9.0	0.275
PM	35.4±1.8	44.5±5.6	**0.003**	22.0±3.4	27.9±4.3	**0.005**
BB	4.2±0.8	5.6±1.0	**0.001**	7.4±2.0	9.3±3.0	0.125
SSP	15.2±4.3	14.2±2.0	0.240	22.0±7.3	27.2±6.7	0.091
ISP	12.3±2.0	17.4±3.4	0.586	20.4±3.0	29.8±4.7	**0.012**
SUBS	36.3±5.5	24.8±6.8	0.262	21.4±4.4	18.7±3.2	0.294

Bold values indicate significant differences

*Values are mean amplitude (%)

[†]Paired samples t test

Discussion

Injury prevention while maximising training gains is 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, first with regard to muscle recruitment and second 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, and 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. 2010). While 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. described the early activation of the periscapular muscles, 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 'presetting' 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 tests. This indicates that earlier recruitment 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. Furthermore, 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. present 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).

The 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 prolonged 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. Furthermore, 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.

Compliance with ethical standards

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