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Original Article

The effects of cervical high-velocity low-amplitude thrust manipulation on resting electromyographic activity of the biceps brachii muscle☆

James Dunning [a,b,*], Alison Rushton [b]

[a] Acupuncture, Spine & Headache Centre, Montgomery, AL, United States
[b] School of Health Sciences, University of Birmingham, Edgbaston, Birmingham, B15 2TT, United Kingdom

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ABSTRACT

There is a gap in the literature regarding the effects of spinal manipulation on extremity muscles that are unconnected to the vertebral column by an origin or insertion. This study investigated the effect of a right C5/6 high-velocity low-amplitude thrust (HVLAT) manipulation on resting electromyographic activity of the biceps brachii muscles bilaterally.

A placebo-controlled, single-blind, repeated measures design employed an asymptomatic convenience sample ($n = 54$) investigating three conditions: HVLAT, sham, and control.

HVLAT demonstrated an excitatory effect with increased EMG activity of 94.20% ($P = 0.0001$) and 80.05% ($P = 0.0001$) for the right and left biceps respectively. A one-way repeated measures ANOVA revealed a significant difference ($P = 0.0001$) in the mean percentage change of resting EMG activity, as did post hoc analyses ($P = 0.0001$) between all three conditions. Subjects not experiencing cavitation post HVLAT demonstrated greater EMG increases for both right ($P = 0.0001$) and left ($P = 0.014$) biceps than those experiencing cavitation. The magnitude of mean EMG change for the right biceps was significantly greater than the left ($P = 0.011$) post HVLAT.

This study demonstrates a single HVLAT to the right C5/6 zygapophyseal joint elicits an immediate increase in resting EMG activity of the biceps bilaterally, irrespective of whether or not cavitation occurs.

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1. Introduction

Spinal mobilisation and manipulation have been used for more than 2000 years in the treatment of neuromusculoskeletal disorders (Curtis, 1988). The effects of mobilisation and high-velocity low-amplitude thrust (HVLAT) manipulation have been an area of focus for recent research. Several studies have demonstrated that mobilisation and HVLAT of the cervical spine produce hypoalgesic effects through increased pressure pain thresholds in symptomatic and asymptomatic subjects (Cassidy et al., 1992; Vicenzino et al., 1995, 1998; Sterling et al., 2001; Fernandez-de-las-Penas et al., 2007). In addition, several studies have demonstrated mobilisation of the cervical spine in asymptomatic and symptomatic populations stimulates the peripheral sympathetic nervous system resulting in decreased blood flow and skin temperature, and increased skin conductance in the upper extremities (Petersen et al., 1993; Vicenzino et al., 1998; Sterling et al., 2001). However, there is conflicting evidence regarding the excitatory (Herzog et al., 1999; Suter et al., 1999; Keller and Colloca, 2000; Symons et al., 2000; Suter et al., 2000; Colloca and Keller, 2001; Dishman et al., 2002; Suter and McMorland, 2002) or inhibitory (Dishman and Bulbulian, 2000; Lehman and McGill, 2001; Lehman et al., 2001; DeVocht et al., 2005) nature of the neurophysiological response that occurs after HVLAT manipulation of the spine. The methodological quality of these studies is poor; with only three studies (Keller and Colloca, 2000; Suter et al., 2000; Dishman et al., 2002) utilising control or placebo groups. In addition, only two studies (Dishman and Bulbulian, 2000; Dishman et al., 2002) administered a single unilateral HVLAT manipulation to each subject; with the remaining studies administering multiple bilateral HVLAT manipulations, and in some studies to multiple spinal regions. Conclusions cannot therefore be made regarding the excitatory or inhibitory nature of reflexive muscular response post HVLAT.

HVLAT to segmentally associated zygapophyseal joints has demonstrated transient reflexic contractions of local paraspinal muscles using electromyography in asymptomatic (Herzog et al., 1999; Symons et al., 2000) and symptomatic subjects (Colloca and Keller, 2001). After lumbar HVLAT in LBP subjects, immediate increases in muscle strength of the erector spinae have been

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* Corresponding author. Acupuncture, Spine & Headache Centre, Montgomery, AL 36116, USA. Tel.: +1 334 356 1670; fax: +1 334 356 1690.
E-mail address: jamesdunning@hotmail.com (J. Dunning).

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demonstrated (Keller and Colloca, 2000). Equally, however, an immediate reduction in paraspinal electromyographic activity post HVLAT in asymptomatic (Dishman and Bulbulian, 2000) and LBP patients (Lehman and McGill, 2001; DeVocht et al., 2005) has been demonstrated and again it remains unclear whether HVLAT produces an excitatory or inhibitory effect on paraspinal muscle activity.

There is a gap in the literature regarding the effects of HVLAT on extremity muscles unconnected to the vertebral column by an origin or insertion. Herzog et al. (1999) assessed the effects of HVLAT to the spine on resting EMG activity of deltoid and found an ipsilateral reflex muscle contraction of deltoid post HVLAT. However, this was a limited study ($n = 10$) with no control or placebo, and each subject received 11 HVLAT manipulations to the cervical, thoracic, lumbar and pelvic regions. In addition, Herzog et al. (1999) did not report the magnitude of the response, only the percentage of positive responses occurring when the signal increased to at least three times the baseline value. Suter and McMorland (2002) demonstrated an immediate 7–10 N m increase in elbow flexor torque post HVLAT of the cervical spine; however, again the results must be interpreted cautiously because no control or placebo groups were utilised and multiple HVLAT manipulations were administered on all subjects.

Several authors (Indahl et al., 1997; Herzog et al., 1999; Symons et al., 2000; Pickar and Kang, 2006) have proposed that the neurophysiologic pathway of the observed electromyographic response following HVLAT involves activation of the mechanoreceptors in the zygapophyseal joint capsule, spinal ligaments, and intervertebral disc, the cutaneous receptors, and the muscle spindles and golgi tendon organs within the muscle belly and tendon of the associated muscles. Alteration in afferent discharge rates from the stimulation of these receptors following HVLAT manipulation is thought to cause changes in alpha motorneuron excitability levels with subsequent changes in muscle activity (Indahl et al., 1997; Dishman and Bulbulian, 2000; Suter et al., 2000; Symons et al., 2000). However, this proposal is not fully supported by their research (Herzog et al., 1999; Symons et al., 2000) as only Pickar and Kang (2006) directly measured mechanoreceptor or proprioceptor activity. Furthermore, Pickar and Kang (2006) only measured the muscle spindle discharge rates in non-human subjects.

There has been some debate in the literature surrounding the role of cavitation (an audible "pop" or "crack") during HVLAT and the observed effects. Herzog et al. (1993a) found reflex responses in the paravertebral muscles irrespective of whether cavitation was achieved. Likewise, Dishman and Bulbulian (2000) found similar reflexic responses in the lumbar spine following either mobilisation without cavitation or manipulation with cavitation, and proposed that the velocity dependent facet joint mechanoreceptors were not implicated in the neurophysiologic response. In contrast, Suter et al. (1994) were not able to elicit electromyographic reflex responses from non-cavitation thrust manipulations given at a low-velocity, i.e. at a rate greater than 1 s compared with 100–150 ms for high-velocity thrusts; however, no control or placebo conditions were employed and the findings cannot be attributed to the intervention. The question therefore remains whether the cavitation phenomenon is required to facilitate a neurophysiological response in resting muscle activity post HVLAT.

To date, no controlled study has investigated the effects of cervical HVLAT manipulation on resting muscle activity more distal than the deltoid (Herzog et al., 1999; Suter and McMorland, 2002) or on contralateral upper extremity muscle activity. The purpose of this study was to characterise the nature (excitatory or inhibitory) and the magnitude of any change in resting electromyographic activity of the biceps brachii muscle post C5/6 HVLAT ipsilaterally and contralaterally. In addition, the relationship to joint cavitation was explored. The biceps brachii muscle was selected as it is anatomically unconnected to the area of intervention through origin or insertion, but is segmentally linked from a neurophysiological perspective.

2. Methods

2.1. Subjects

A convenience sample of 54 asymptomatic undergraduate physiotherapy and nursing students (39 female and 15 male) with a mean age of 22.13 ± 4.68 years were recruited. Mean mass was 65.71 kg (SD 12.49) and mean height was 1.70 m (SD 0.091). Subjects were included if aged 18–40 years. Exclusion criteria included neck pain in the last 6 months; a history of trauma or surgery to the cervical spine or upper extremities; upper extremity referred pain, radiculopathy or peripheral neuropathy; or any contraindication to cervical HVLAT manipulation (Hartman, 2001; Gibbons and Tehan, 2003; Kerry and Taylor, 2006; Kerry et al., 2008). The most recent literature suggests that pre-manipulative cervical artery testing is unable to identify those individuals at risk of vascular complications from cervical HVLAT manipulation (Kerry and Taylor, 2005; Kerry et al., 2008), and any symptoms detected during pre-manipulative testing may be unrelated to changes in blood flow in the vertebral artery, so that a negative test neither predicts the absence of arterial pathology nor the propensity of the artery to be injured during cervical HVLAT, with testing neither sensitive or specific (Licht et al., 2000; Magarey et al., 2004; Kerry and Taylor, 2005; Kerry and Taylor, 2006; Kerry et al., 2008). Screening questions for cervical artery disease were negative, and pre-manipulative screening was not used. The study was approved by the Ethics Committee of the School of Health Sciences of The University of Birmingham, and written informed consent was obtained from all the subjects prior to testing.

2.2. Equipment

Resting electromyographic recordings of the biceps brachii muscle were made pre and post C5/6 HVLAT using the DelSys® Surface EMG system (DeLuca, 1997, 2002, 2003). Detection electrode surfaces were made of pure silver (>99.5%) in the form of parallel bars 10 mm long and 1 mm wide with an inter-detection surface spacing of 1.0 cm. This small electrode size and inter-detection surface spacing minimised cross-talk susceptibility from adjacent muscles (DeLuca, 1997, 2002). In addition, considering an average nerve conduction velocity of 4.0 m/s (Basmajian, 1985) and using the stated electrode size and inter-detection spacing, a bandwidth between 20 and 450 Hz was used to capture the full frequency spectrum of the biceps brachii EMG signal and suppress noise at higher frequencies (DeLuca, 1997, 2002).

2.3. Procedure

Each subject was positioned supine on a plinth with their lower limbs straight and head and neck in a neutral position on a single pillow. The subjects' arms rested on the plinth with the elbows bent at 90° and fingers interlocked over the abdomen to limit movement of the upper limbs during and between interventions. In order to minimise skin impedance between electrodes, the skin was wiped with alcohol swabs (DeLuca, 1997, 2002, 2003). Then 10 mm electrodes were placed on the longitudinal midline of the biceps brachii muscle bilaterally mid-way between the origin and insertion point (DeLuca, 2002). The short head of the biceps brachii originates from the apex of the coracoid process and the long head arises from the upper margin of the glenoid cavity; the two muscle bellies are closely applied to each other in the middle and lower brachium and

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insert as one tendon into the radial tuberosity (Gray, 1995). The electrode detection bars were aligned perpendicular to the length of the muscle fibres to allow intersection of most of the same muscle fibres by both detection bars and provide an EMG signal that reflected the activity of a fixed set of muscle fibres (DeLuca, 1997, 2002). The reference electrode (2 cm × 2 cm) was placed on the dorsum of the right hand (DeLuca, 2002). The DelSys® EMG software was set to collect data at a sampling rate of 2000 Hz per channel (Herzog et al., 1999; Symons et al., 2000; Suter and McMorland, 2002; DeVocht et al., 2005).

Prior to any data collection, subjects were instructed not to move any part of their body and to "relax as fully as possible". Before each condition was administered (control, sham or HVLAT), baseline resting EMG activity levels of the right and left biceps brachii muscles were recorded for a 'pre' 30 s segment, followed by a 1 min rest period (wherein the subject remained relaxed and supine with fingers interlocked over the abdomen), and then a 'post' 30 s segment ('during/after' = post) was initiated by a research assistant using a manual trigger on the computer to initiate EMG data collection at the moment the manipulative physiotherapist contacted the subjects head and neck region. During this 'post' 30 s data segment, one of the three experimental conditions was administered and all three conditions were applied to all 54 subjects.

The HVLAT manipulation to the right C5/6 segment (Hartman, 2001; Gibbons and Tehan, 2003) was performed by the manipulative physiotherapist placing the anterolateral aspect of the proximal phalanx of the right index finger over the posterolateral aspect of the articular pillar at the right C5/6 segment while the therapist's other hand cradled the subjects head on the left. Extension, ipsilateral side-bend, contralateral side-shift and contralateral rotation of C5 on C6 were introduced to engage the barrier—that is, until a firm crisp end-feel could be felt by the therapist—then an HVLAT was administered into left rotation in an arc towards the left eye. The head was then repositioned on the pillow into the same starting neutral position and all hand contact was removed for the remainder of the 'post' 30 s data collection interval. It was recorded if cavitation occurred. The sham manipulation to the right C5/6 segment was administered using the same 'set-up' as the HVLAT manipulation; however, once the barrier was engaged, the head was re-positioned to neutral with no thrust applied. The control condition consisted of no manual contact for 30 s.

Six sequencing orders were possible; and subjects, irrespective of gender, were randomly allocated to one of the sequencing orders (see Table 1).

In order to minimise any carry-over effect from one intervention to the next, an 8 min "wash-out" period was used between all conditions. DeVocht et al. (2005) found changes in resting electromyographic activity of the paravertebral muscles post spinal HVLAT to stabilise back to pre-treatment levels within several seconds to 4–5 min; and to date, although several studies have demonstrated immediate changes in EMG activity post spinal HVLAT (Herzog et al., 1999; Dishman and Bulbulian, 2000; Keller and Colloca, 2000; Suter et al., 2000; Symons et al., 2000; Colloca and Keller, 2001; Lehman and McGill, 2001; Lehman et al., 2001; Suter and McMorland, 2002; Colloca et al., 2003; Marshall and Murphy, 2006), there are no studies supporting the notion that changes in resting EMG activity of the paravertebral muscles post HVLAT last any longer than 4–5 min in duration (DeVocht et al., 2005). This informed an 8 min 'wash-out' period to minimise any carry-over effect between the control, sham and HVLAT conditions.

Table 1
Subject allocation to order of conditions.

	Order of conditions
Subjects 1–9	Control–Sham–HVLAT
Subjects 10–18	Sham–Control–HVLAT
Subjects 19–27	Sham–HVLAT–Control
Subjects 28–36	Control–HVLAT–Sham
Subjects 37–45	HVLAT–Control–Sham
Subjects 46–54	HVLAT–Sham–Control

2.4. Data and statistical analyses

DelSys® EMG Analysis software was used to rectify the raw bipolar signal to calculate the mean rectified absolute values, or average rectified value (ARV) for each 30 s data segment for both the right and left biceps brachii muscle in all three conditions for each subject. This process resulted in each subject having 12 ARV means (648 ARV means in total) encompassing a pre and post value for the control, sham, and HVLAT conditions contributing six means for the left and six means for the right biceps. The mean percentage of change (i.e. post-intervention minus pre-intervention, divided by pre-intervention, and multiplied by 100%) in resting EMG activity of the biceps brachii muscle was calculated. Data for both the right and left biceps was included in the analysis using SPSS 14.0.

A one-way repeated measures ANOVA tested for differences in the mean percentage change in resting EMG activity of the biceps brachii muscle between the three conditions. Post hoc analyses (Bonferroni pairwise comparisons) were subsequently performed. A paired *t*-test investigated ipsilateral and contralateral differences. An independent *t*-test investigated differences between those subjects who demonstrated cavitation and those that did not. The level of significance was set at 0.05 for all statistical procedures.

3. Results

3.1. Magnitude of EMG response

The mean percentage change of resting EMG activity of the right biceps brachii in the three conditions was −4.18% (control), 21.12% (sham), and 94.20% (HVLAT); and −2.16%, 17.15% and 80.04%, respectively, for the left. The error chart in Fig. 1 displays the means

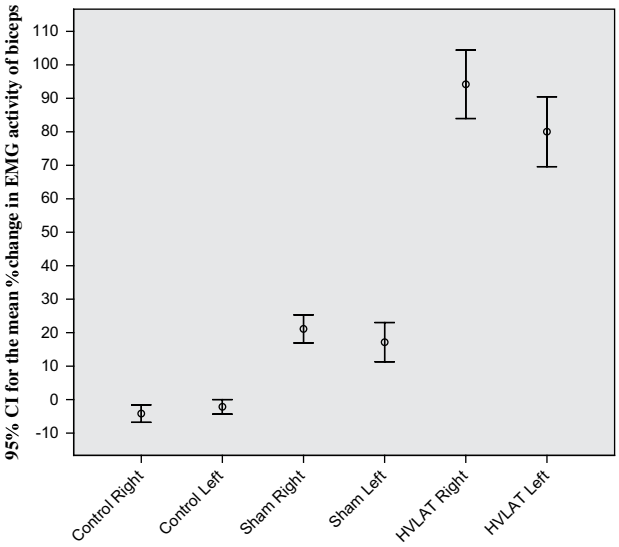

Fig. 1. Mean and 95% CI for the percentage of change in resting EMG activity of the right and left biceps brachii muscles following a control condition, a sham manipulation to the right C5/6 segment, and an HVLAT manipulation to the right C5/6 segment.

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and 95% confidence intervals for the percentage change in resting EMG activity for each condition, and Table 2 illustrates the parameter estimates post each condition.

Resting EMG activity of the biceps brachii muscle increased in 94% ($n = 51$) of subjects following a single HVLAT to the right C5/6 facet joint, with a slight decrease observed in 6% ($n = 3$) of subjects.

The one-way repeated measures ANOVA demonstrated a significant difference for mean percentage change of resting EMG activity of the biceps brachii muscle ($F = 223.28$, $P = 0.0001$). Bonferroni post hoc analyses demonstrated significant differences ($P = 0.0001$) between all three conditions. For the right biceps, mean percentage change and pairwise comparison between HVLAT and control conditions was 98.38% ($P = 0.0001$, 95% CI: 84.08–112.68), between sham and control conditions was 25.30% ($P = 0.0001$, 95% CI: 19.63–30.97), and between HVLAT and sham was 73.08% ($P = 0.0001$, 95% CI: 59.43–86.73). Similar trends were demonstrated for the left biceps brachii muscle, and pairwise comparison between HVLAT and control conditions was 82.19% ($P = 0.0001$, 95% CI: 67.06–97.33), between sham and control conditions was 19.31% ($P = 0.0001$, 95% CI: 10.10–28.52), and between HVLAT and sham was 62.89% ($P = 0.0001$, 95% CI: 49.18–76.59).

3.2. Ipsilateral and contralateral effect

The mean percentage change in resting EMG activity following HVLAT to the right C5/6 segment was 94.20% and 80.04% for the right and left biceps brachii muscles, respectively (see Fig. 2), with a mean difference of 14.16%. The right biceps brachii muscle therefore experienced a greater increase in resting muscle activity than the left. A paired t-test demonstrated this difference between the mean EMG change of the right and left biceps brachii muscles to be significant ($t = 2.645$, $P = 0.011$).

3.3. Cavitation effect

Thirty-two of the 54 subjects demonstrated joint cavitation following the HVLAT condition. The mean percentage change in resting EMG activity of the right biceps brachii muscle post HVLAT was 79.79% and 115.16% for the cavitation and no cavitation groups, respectively (see Fig. 3). Similarly, the mean percentage change for the left biceps brachii muscle post HVLAT was 69.61% and 95.20% for the cavitation and no cavitation groups, respectively. An independent t-test demonstrated a significant difference between the cavitation and no cavitation groups both on the right ($t = 3.817$, $P = 0.0001$) and on the left ($t = 2.744$, $P = 0.014$).

4. Discussion

The findings of this study provide support for previous studies demonstrating an excitatory effect of HVLAT on motor activity (Suter et al., 1999; Keller and Colloca, 2000; Suter et al., 2000; Symons et al., 2000; Colloca and Keller, 2001; Dishman et al., 2002), and more specifically on segmentally associated muscles of the upper limb (Herzog et al., 1999; Suter and McMorland, 2002). However, in both of these studies multiple HVLAT manipulations were administered on each subject, no control or placebo groups were employed, and small sample sizes of 10 (Herzog et al., 1999) and 16 subjects (Suter and McMorland, 2002) were used. Furthermore, Herzog et al. (1999) did not report the magnitude of the response in the deltoid muscle (only the percentage of positive responses), and Suter and McMorland (2002) measured elbow flexor torque and muscle inhibition changes during maximal voluntary contractions, rather than at rest. Therefore, this is the first controlled study to demonstrate an excitatory effect, and quantify its magnitude on the resting EMG activity of an upper limb muscle following a single HVLAT manipulation to the cervical spine.

It has been postulated that HVLAT manipulation activates mechanosensitive afferents (mechanoreceptors) in the intervertebral discs, zygapophyseal joints, spinal ligaments, paravertebral muscles (proprioceptors) and skin (Indahl et al., 1997; Herzog et al., 1999; Symons et al., 2000; Pickar and Kang, 2006). Alteration in afferent input from the stimulation of these receptors is thought to cause changes in alpha motorneuron excitability levels with subsequent increases in muscle activity (Dishman and Bulbulian, 2000; Suter et al., 2000). In this study, the increase in resting EMG

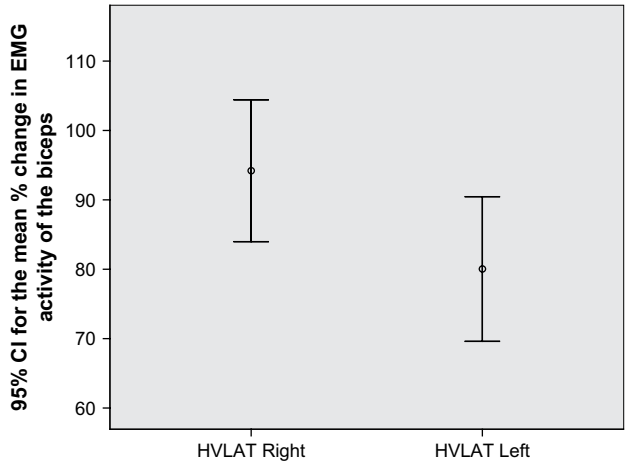

Fig. 2. Mean and 95% CI for the percentage of change in resting EMG activity of the right and left biceps brachii muscles following HVLAT manipulation to the right C5/6 facet joint.

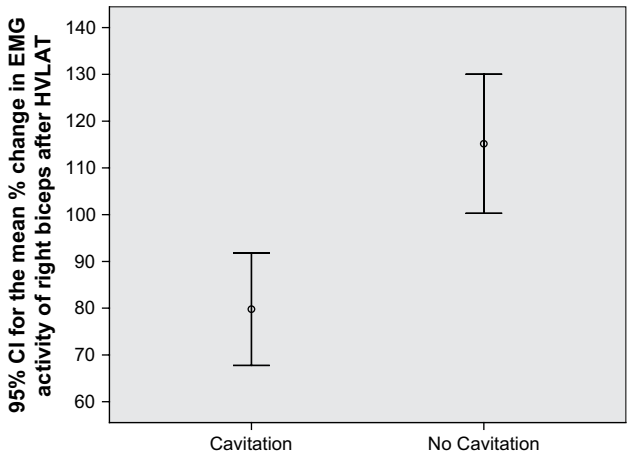

Fig. 3. Mean and 95% CI for the mean percentage of change in resting EMG activity of the right biceps brachii muscle following HVLAT manipulation of the right C5/6 facet joint between those subjects experiencing cavitation and those not experiencing cavitation.

Table 2
Parameter estimates.

Type of Manipulation	Mean	Std. error	95% Confidence interval	
			Lower bound	Upper bound
Control right	−4.18	1.31	−6.80	−1.56
Control left	−2.16	1.09	−4.34	0.02
Sham right	21.12	2.09	16.92	25.31
Sham left	17.15	2.92	11.29	23.01
HVLAT right	94.20	5.10	83.97	104.42
HVLAT left	80.04	5.20	69.61	90.47

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activity of the biceps brachii muscle occurred whether or not the C5/6 facet joint demonstrated the cavitation phenomenon. Therefore, in agreement with the findings of Herzog et al. (1999), this study supports the hypothesis that the neurophysiological reflexic increase in resting EMG activity of the biceps brachii muscle depends on the magnitude of force applied (Conway et al., 1993; Herzog et al., 1993b) and/or the rate of change in force application (acceleration) during the thrusting impulse (Colloca and Keller, 2001; Pickar and Kang, 2006), rather than the occurrence of the cavitation phenomenon itself.

The findings of this study demonstrate that HVLAT manipulation to the right C5/6 facet joint significantly increased the resting electromyographic activity of both the right and left biceps brachii muscles. This is consistent with the findings of Colloca and Keller (2001) who observed a contralateral neuromuscular reflex response in the lumbar erector spinae muscles following HVLAT manipulation to the lumbar spine. These findings are in contrast to Symons et al. (2000) who found the increase in resting EMG activity to always occur ipsilaterally and in muscles that had either their origin or insertion at the vertebral level that was manipulated. The results of this study demonstrate a non-local response and furthermore, an ipsilateral and contralateral response. The non-local response found in this study is in agreement with the findings of Herzog et al. (1999) that found increased EMG activity in the deltoid muscle.

The notion that muscle inhibition, or decreased motor activity, can occur in muscle groups that are not directly connected to the spine, such as the quadriceps or biceps muscles as a result of lumbopelvic or cervical joint dysfunction is increasingly supported within the literature (Suter et al., 1999, 2000; Suter and McMorland, 2002). Therefore, although this study examined the outcomes in a population of asymptomatic subjects, facilitation of resting motor activity in the elbow flexor muscles post HVLAT to the cervical spine as demonstrated in this study, may still have clinical implications for rehabilitation practitioners. The findings contribute to the suggestion that for optimal management of patients with cervical pain and upper extremity weakness suspected to be of an arthrogenic nature (Suter et al., 2000; Liebler et al., 2001; Sterling et al., 2001; Suter and McMorland, 2002), the application of HVLAT manipulation to the segmentally associated facet joints in the cervical spine may be a beneficial approach before traditional strength training is initiated. Previously, Suter and McMorland (2002) found, when compared with a normal sample, that most patients with chronic neck pain demonstrated more than 5% inhibition of the biceps brachii muscles; and furthermore muscle inhibition bilaterally was reduced to control levels following one treatment session of HVLAT to C5/6 and C6/7 levels. More specifically, Suter and McMorland (2002) reported an immediate increase in elbow flexor torque of 7–10 N m during maximal isometric contractions and a 4.3–11.1% decrease in elbow flexor muscle inhibition following a single session of HVLAT. However, Suter and McMorland (2002) did not report the side manipulated (right and/or left) or the number of HVLATs delivered to each patient; with no placebo or control groups employed.

There were several limitations to this study that need to be acknowledged. No verification existed to ensure that the actual motion segment that was manipulated was indeed the C5/6 level, and this is problematic as the literature reports poor levels of accuracy and specificity of many HVLAT manipulation procedures (Beffa and Mathews, 2004; Ross et al., 2004). In addition, the magnitude of the thrusting force of the HVLAT applied to the C5 vertebrae was not standardised between subjects, and exact replication of electrode placement within the centre of the longitudinal midline of the muscle (DeLuca, 2002, 2003) was not verified.

This study also highlights areas for further research. It would be useful to investigate longer duration recordings of electromyographic activity in order to elucidate the longer term effects of HVLAT. In addition to resting electromyographic activity, measurement of outcomes that represent immediate and longer term changes in the functional capacity of muscles post HVLAT should be investigated. In order to assess the actual clinical relevance of these findings, future studies should employ a symptomatic population with neck pain and/or upper limb dysfunction.

5. Conclusion

This study has demonstrated that a single HVLAT manipulation to the cervical spine elicits a measurable short term increase in resting electromyographic activity in a remote area not directly connected by any musculoskeletal structures to the cervical spine but segmentally and neuroanatomically associated. The results suggest that HVLAT to the cervical spine immediately increases the resting electromyographic activity of the biceps brachii muscle, but does not address the duration of this increase. In addition, HVLAT to the right C5/6 zygapophyseal joint immediately increased resting motor activity of both the right and left biceps brachii muscles, and this increase occurred irrespective of whether the cavitation phenomenon was present.

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