Human Movement Science 52 (2017) 67–73

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Full Length Article

Attentional focusing instructions influence quadriceps activity characteristics but not force production during isokinetic knee extensions

David C. Marchant *, Matt Greig

Dept. of Sport and Physical Activity, Edge Hill University, Ormskirk, Lancs L39 4QP, UK

ARTICLE INFO

Article history:
Received 24 February 2016
Revised 7 January 2017
Accepted 11 January 2017
Available online 28 January 2017

Keywords:
Focus of attention
Muscle activity
Motor control
Exercise

ABSTRACT

The attentional focus emphasised in verbal instruction influences movement and muscle recruitment characteristics, with an external focus (onto movement effects) typically benefiting performance. However, contrasting findings suggest either a selective isolation or spreading activation effect on associated muscles as a result of internally focused instruction (movement characteristics). In the present experiment, participants completed maximal isokinetic concentric leg extension exercise using internally (muscle specific: vastus medialis oblique) or externally (outcome specific) focused instructions. Integrated Electromyography (iEMG) of the vastus lateralis, vastus medialis oblique and rectus femoris muscles was obtained in addition to knee extensor torque. There were no differences in torque production between conditions. Externally focused instruction produced significantly lower iEMG magnitude across muscles, whereas an internal focus produced the greatest activity but with no evidence of a selective isolation effect of the vastus medialis oblique. The muscle-specific internal focus of attention resulted in a spreading activation effect, such that activity is elevated in muscles not within the focus of attention. Whilst an external focus did not improve performance, force was produced with lower muscular activity reflecting increased efficiency. The resultant noise in the motor system associated with an internal focus inhibits movement economy and attempts at selective activation.

1. Introduction

Recent studies demonstrate that the attentional focus emphasised through verbal instruction differentially impacts upon force production (see Marchant, Greig, Bullough, & Hitchen, 2011; Wulf & Lewthwaite, 2016). For example, when compared to internally focused attention (onto aspects of the movements being executed) an external focus of attention (onto movement outcomes) has improved performance on standing long jumps (Porter, Anton, Wikoff, & Ostrowski, 2013), discus throwing (Zarghami, Saemi, & Fathi, 2012), bench press and squat exercise endurance (Marchant et al., 2011), and finally accuracy in an isometric force production task (Lohse, Sherwood, & Healy, 2011). To investigate these effects, researchers have identified muscular activation characteristics measured through electromyography (EMG) as a significant mechanism (See Lohse, Wulf, & Lewthwaite, 2012). In those studies, instructions to adopt an external focus of attention have typically

* Corresponding author.
E-mail addresses: david.marchant@edgehill.ac.uk (D.C. Marchant), matt.greig@edgehill.ac.uk (M. Greig).

http://dx.doi.org/10.1016/j.humov.2017.01.007
0167-9457/

resulted in more efficient activation (See Wulf, 2013) when compared to an internal focus of attention. An external focus of attention is manipulated through instructions directing attention to the intended outcome of the movement. However, inducing an internal focus of attention has been achieved through different approaches; with some directing attention to movement mechanics (e.g., Zachry, Wulf, Mercer, & Bezodis, 2005) whilst others focus attention onto the muscles themselves (e.g., Marchant, Greig, & Scott, 2009; Vance, Wulf, Töllner, McNevin, & Mercer, 2004). Further emphasising these differences in instructional approaches, research that does not incorporate electromyography typically does not emphasise muscular activation as part of the internal focus manipulations. Rather they focus attention onto the movement of the limbs involved in the action (e.g., Lohse, Sherwood, & Healy, 2010).

In research examining instructionally manipulated attentional focus, an external focus of attention has typically facilitated efficient muscular activation. On the other hand, the conscious control associated with internally focused attention results in inefficient muscular activity, or "noise" in the motor system, which is subsequently detrimental to performance. For example, during force production or exercise type movements reduced muscular activation has been observed with an external versus internal focus during biceps curls type exercise (Marchant et al., 2009; Vance et al., 2004: focus on the movement of the curl bar vs focus on the muscles involved), sit up exercises (Neumann & Brown, 2015: "make your movements smooth/flow" vs "focus on or feel your stomach muscles") and vertical jump and reach tasks (Wulf, Dufek, Lozano, & Pettigrew, 2010: reach for the target vs reaching with your fingers). Lohse et al. (2011) found less accurate isometric force production with the foot as well as a higher degree of co-contractions of agonist (soleus) and antagonist (tibialis anterior) muscles with an internal focus onto the calf muscles compared to externally focused instructions emphasising the force platform. Interestingly, although internal instruction purposefully directed attention to the agonist muscle, significantly greater muscle activity was only observed in the antagonist muscle.

In many of the force production studies an internal focus of attention is induced through emphasising specific muscular activation. However, this is typically not an approach adopted in studies assessing skilled movements. For example, in a basketball free throw task Zachry et al. (2005) found that instructions to focus externally (the target hoop) compared to internally (movement of the wrist) resulted in greater accuracy and reduced EMG activity of the biceps and triceps brachii. Supporting this in a dart throwing task, Lohse et al. (2010) found that externally focused instructions (the flight of the dart) improved accuracy in addition to lowering EMG activity of the triceps muscle when compared to an internal focus (onto their arm). Such inconsistencies suggest potential differences in the conceptualisation of an internal focus and how it should be instructed depending upon the task being assessed.

One interesting observation is a "spreading" of influence where an internal focus of attention has a broader influence of movement efficiency and muscular activation. Specifically, an internal focus influences the activity of muscle groups that participants were focusing on, in addition to those that they were not specifically directed to focus on (e.g., Lohse et al., 2011; Vance et al., 2004; Wulf et al., 2010; Zachry et al., 2005). This spreading effect appears to be observed regardless of whether specific muscles or movement characteristics are emphasised in the internally focused instructions provided. This observation and the muscular activation findings to-date are in line with the constrained action hypothesis (McNevin, Shea, & Wulf, 2003; Wulf, McNevin, & Shea, 2001). When an external focus is adopted there is greater utilisation of the motor system's self-organising capabilities (e.g., Lohse, Jones, Healy, & Sherwood, 2014) and automatic control processes. This supports effective neuromuscular coordination and activation of agonist and antagonist muscle groups. An internal focus on the other hand promotes conscious control of movements through self-related processing (Wulf & Lewthwaite, 2010) which constrains the motor system resulting in unnecessary muscular activation and co-contractions. This "noise" in the motor system evidences reduced automatic control processes and increased conscious attempts to control movement. Although motor unit recruitment is not under conscious control (Lohse et al., 2012), these observations highlight that the attentional focus adopted influences the efficiency of the motor system, which in turn significantly impacts on neuromuscular coordination. Consequentially, the alterations in neuromuscular activity coincide with changes in outcome measures.

Contrasting this spreading effect, researchers have demonstrated that instructional approaches can selectively recruit muscles during exercise and rehabilitative movements. Muscle specific verbal instruction have resulted in selective activation of oblique and rectus abdominis muscles during trunk curl exercises (Karst & Willett, 2004), the latissimus dorsi during low-intensity lat pull-down exercise (Snyder & Leech, 2009), and pectoralis major and triceps brachii activity during bench press exercise and 50% of trained participants 1-repetition max (1RM), but not at 80% of 1RM (Snyder & Fry, 2012). Using a single legged dynamic landing movement Palmerud, Sporrong, Herberts, and Kadefors (1998) found selective reductions in upper trapezius activity during isometric shoulder abduction exercise (with corresponding increases in rhomboids major and minor and the transverse trapezius muscles) only when verbal cues were supported with EMG biofeedback. However, Cowling, Steele, and McNair (2003) found that instructions to specifically recruit the hamstring muscles during jump landing were unsuccessful. The instructions resulted in inefficient co-contraction of associated muscles such that landings posed a greater risk of injury. The internally focused nature of the instruction provided may have resulted in a spreading influence across associated muscles rather than the intended selective effect.

Given the evidence reviewed, it is clear that verbal instruction provided by coaches, physical therapists, and personal trainers has a measurable effect on muscle activation and force production during exercise movements. Attempts to isolate or promote muscular activation through verbal guidance may well be hindered by the "spreading" effect (e.g., Lohse et al., 2011) where the influence of internally focused instructions "spreads" to other muscle groups that participants were not specifically instructed to focus on. The present study aims to assess the influence of internally focused instructions emphasising specific muscular activity when compared to externally focused instructions that emphasise the movement outcome.

Verbal attentional focusing instructions will be provided for a maximal concentric isokinetic knee extension exercise at $60°\cdot s^{-1}$, whilst force and muscular activation characteristics are measured. Of particular interest in the present study was the relative activation between vastus medialis oblique (VMO) and vastus lateralis (VL) during these movements, and the VMO:VL ratio.

2. Method

2.1. Participants

20 (Male 16, Female 4) healthy and regularly training participants were recruited from an undergraduate student athlete population (mean age of 20.2 ± 1.47 years). Participants were intermittent team sport players with a minimum of three years' experience, not specifically strength trained but familiar with the tasks used in the present study as forming part of appropriate preparatory strength and conditioning for their sport. Training activities were equivalent to two training sessions plus one competitive match per week. Participants were naïve to the purpose of the study. The sample size was determined based on previous research and were from a convenience sample, recruited during a predetermined period of data collection. An institutional ethics review committee approved the methods, and informed consent was obtained prior to participation.

2.2. Design

Using a within-subjects design, the present study examined the acute effects of verbal attentional focusing instructions on kinetic and muscular characteristics during maximal concentric isokinetic knee extension. Instructional conditions were internally focused (a focus on muscular activation) and externally focused (onto the movement outcome). Instruction condition order was counterbalanced across participants. Force characteristics measured are Peak Torque (Tpk) and the time-averaged area under the torque curve (mean power output [MP]). Muscular variables include integrated and peak EMG (iEMG and pkEMG) of the vastus lateralis (VL), vastus medialis oblique (VMO) and rectus femoris (RF) muscles, and VMO: VL activation ratio. As the VMO is an important component of the quadriceps in stabilizing the patellofemoral joint, internal attentional focusing instructions will specifically target the work of the VMO. There were no data exclusions, all manipulations are reported and measures analysed, and data collection was completed before any analysis.

2.3. Task and measures

2.3.1. Isokinetic dynamometry

Participants performed one set of 10 isokinetic knee extension repetitions at $60°\ s^{-1}$ on a Biodex (System 3, Biodex Medical Systems, New York) isokinetic dynamometer (pre-calibrated according to manufacturer's guidelines) in each condition. Concentric extensions were performed through a range of approximately 90° of knee flexion. Each participant was seated on the dynamometer chair, which was individually adjusted for unilateral knee extension for the dominant leg (defined as the preferred kicking leg). The lateral epicondyle of the knee was visually aligned with the axis of the dynamometer lever arm. The range of movement was standardised to the participant-specific full range of movement. The length of the lever arm was adjusted for comfort, and restraints were applied across the shoulders, lap and thigh to minimise contribution of additional musculature and extraneous movement. To minimise muscular effort during the knee flexion phase, a passive knee flexor movement was used. Gravity-corrected net joint torque was used to quantify the peak knee extensor torque (Tpk) determined from the isokinetic phase of the movement (Biodex Advantage software). The time-averaged area under the torque-angle curve was calculated to provide a measure of mean power output (MP).

2.3.2. Electromyography

Muscular activation was obtained for the femoral quadriceps VMO, VL, and RF. The present study selected the VMO and VL due to the dynamic relationship on lateral pull (The VL causes a lateral pull which is counteracted by the medial pull the VMO exerts on the patella), and the RF as a further indication of quadriceps function with attentional focus manipulations. Despite the relationships observed in antagonist activation in attentional focus research (e.g., Lohse et al., 2011), the dynamometer setup on the present study precluded such measurement. Electrode preparation and placement followed the SENIAM group recommendations (e.g., Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). Pairs of disposable bi-polar silver-silver chloride passive surface electrodes (Medicotest, Denmark) were placed on the visual midpoint of the contracted muscle belly of the VMO, VL and RF (identified through palpation and functional observation) orientated parallel to the direction of the muscle fibre alignment. Electrodes were placed 20 mm apart (centre to centre) on the skin. A reference electrode positioned on a bony and inactive aspect of the knee established a threshold for computer signal processing. Prior to electrode placement, the skin was first dry-shaved and then cleaned with an alcohol swab. The pre-amplified electrode leads were connected to an 8-channel transmitter unit (Noraxon Telemyo 2400T) adjacent, but not connected to the participant. To avoid inter-experimenter variations, the same researcher applied the electrodes to all participants. The active EMG signal was pre-amplified (gain 500) and subjected to a 10–1000 Hz band-pass filter. A sampling frequency of 1500 Hz was used to collect the EMG signal, with data collection manually initiated prior to the first repetition and terminated following the final repetition. Processing of the EMG signal was conducted using Noraxon Software (MyoResearch XP Master). Signal processing of the raw EMG data was achieved using an EMG linear envelope, achieved using a combination of full-wave rectification to attain the absolute value, and the application of low- and high-pass bandwidth filters to attain a frequency spectrum of 10–300 Hz. For each muscle, from movement onset to offset integrated EMG (iEMG: representing the area under the EMG time-history curve) were calculated at each repetition. An index of VMO:VL co-contraction was calculated by taking the ratio of VMO iEMG divided by VL iEMG.

2.3.3. Attentional focusing instructions

Verbal instruction was provided by the same researcher prior to exercise initiation. The provision of complex instructions for simple motor tasks (e.g., golf putting; Poolton, Maxwell, Masters, & Raab, 2006) has been proposed as one reason why benefits of an external focus have been observed (Wulf, 2013). Therefore, simple instructions appropriate to the task being performed were developed. Each instruction contained a common and attentional focusing component. For the common instruction, all participants were first instructed to exert maximal effort on the extension phase and relax while returning to the starting position. This was followed by an attentional focusing cue. In the internal focus condition, after verbal and visual description of VMO location and function, instructions emphasised focusing on contracting the VMO whilst generating maximal effort. For the external condition, instructions emphasised focusing on pushing against the pad whilst generating maximal effort. For example, in combination the external instructions were; "Try to exert maximal effort during the movement whilst focusing on pushing against the pad". No verbal encouragement was given during the isokinetic exercise.

2.4. Procedure

Data collection was conducted within a well-controlled sport and exercise science laboratory. In the 24 h preceding testing participants continued normal diet and physical activity patterns, but refrained from strenuous exercise and consumption of caffeine or alcohol. Upon arrival participants were health screened for exercise participation. Following a standardised warm-up (submaximal cycling), Participants first completed a familiarisation session of three practice repetitions to become accustomed to the movements and velocities of the apparatus. Participants then performed both attentional focus conditions on the same day of testing, counterbalanced between participants, with a rest period of 15 min between trials. At the beginning of each trial the allocated verbal instructions were delivered by the same researcher, and participants were encouraged to use instructions throughout the trial. No visual or verbal feedback, nor verbal encouragement was provided and the researcher was the only individual present with the participant to control for social influences. Data collection was initiated when the participant was told to "go".

2.5. Data processing and analysis

The first and last repetitions in each set were excluded from analysis as they are qualitatively different from the other repetitions (Vance et al., 2004). Tpk and MP were analysed separately using 2 (Focus: Internal vs External) × 8 (Repetition) repeated measures ANOVA. Muscular activation was assessed using a 2 (Focus: Internal vs External) × 3 (Muscle: RF, VL, VMO) × 8 (Repetition) repeated measures ANOVA, whilst the VMO:VL iEMG co-contraction ratio was analysed using a 2 (Focus: Internal vs External) × 8 (Repetition) repeated measures ANOVA. An α-level of 0.05 was used for all analyses. Further, the purpose was not to measure or compare between subjects, in which case a maximal voluntary contraction (MVC) could have been used to normalize data. Results are presented as the mean ± standard error of the mean. The test-retest reliability of peak torque and iEMG were determined during familiarisation. The intraclass correlation coefficients for pk Torque were >0.90 representing excellent reliability, and for iEMG >0.75 representing good reliability based on the classifications of (Portney & Watkins, 1993).

3. Results

3.1. Force production

A 2 (Focus: Internal vs External) X 8 (Repetition) repeated measures ANOVA found that the instructed focus of attention did not significantly influence the level of force produced during the maximal efforts, both in terms of Tpk (Internal = 152.73 Nm, SE = 12.30 vs External = 153.39 Nm, SE = 11.19; $F(1,19) = 0.01$, $p = 0.92$, partial $\eta^2 = 0.001$, 95% CI [−12.20 to 13.50]) and MP (Internal = 114.68 Nm·s, SE = 8.10 vs External = 113.66 Nm·s, SD = 7.59; $F(1,19) = 0.07$, $p = 0.80$, partial $\eta^2 = 0.004$, 95% CI [−7.26 to 9.31]). No significant Focus X Repetition interaction were identified for either Tkp ($F(1,19) = 1.12$, $p = 0.35$, partial $\eta^2 = 0.06$) or MP ($F(1,19) = 0.96$, $p = 0.46$, partial $\eta^2 = 0.05$). A descriptive summary of data for all variables is shown in Table 1.

Table 1
Force and Electrophysiological data as function of attentional focus.

	Internal Focus		External Focus	
	Mean (SE)	95% CI	Mean (SE)	95% CI
Tpk Nm	152.73 (12.30)	[126.99, 178.48]	153.39 (11.19)	[129.97, 176.81]
MP Nm·s	114.68 (8.10)	[97.73, 131.63]	113.66 (7.59)	[97.77, 129.54]
VMO iEMG μV·s	158.94 (15.95)	[125.56, 192.33]	140.02 (13.74)	[111.27, 168.79]
VL iEMG μV·s	154.85 (18.09)	[116.98, 192.72]	141.95 (15.65)	[109.19, 174.71]
RF iEMG μV·s	132.74 (15.21)	[104.59, 152.70]	128.64 (11.49)	[104.59, 152.70]
VMO:VL	1.17 (0.12)	[0.93, 1.43]	1.11 (0.12)	[0.87, 1.35]
InRF%Ex	106.87 (6.41)	[93.45, 120.29]		
InVL%Ex	110.84% (4.25)	[101.94, 119.74]		
InVMO%Ex	117.81 (7.37)	[102.38, 133.23]		

Note. Cells show mean ± Standard Error for dependent variables as a function of attention focus. Dependent measures include Peak Torque (Tpk), mean power output (MP), the cocontraction ratio of vastus medialis to vastus lateralis activity (VMO:VL), and iEMG for the vastus medialis (VMO), vastus lateralis (VL) and rectus femoris (RF) activity. The internal focus iEMG is expressed as a percentage of external focus iEMG for each muscle (InRF%Ex, InVL%Ex, InVMO %Ex).

3.2. EMG measures

A 2 (Focus: Internal vs External) × 3 (Muscle: RF, VL, VMO) × 8 (Repetition) repeated measures ANOVA identified a significant main effect for focus, with less iEMG activity with an external focus (136.87 μV·s, SE = 11.05) than with an internal focus (148.84 μV·s, SE = 14.03) ($F(1, 19) = 5.06$, $p = 0.04$, partial $\eta^2 = 0.21$, 95% CI [0.84–23.10]). No significant main effect for muscle ($F(2, 38) = 1.18$, p = 0.32, partial $\eta^2 = 0.06$) or Focus × Muscle interaction ($F(2, 38) = 1.21$, $p = 0.431$, partial $\eta^2 = 0.06$) were evident (See Fig. 1). A 2 (Focus) × 8 (Repetition) repeated measures ANOVA revealed no difference in the VMO:VL iEMG co-contraction ratio between attentional focus conditions (external = 1.11, SE = 0.12 vs Internal = 1.17, SD = 0.12; ($F(1, 19) = 1.06$, $p = 0.32$, *partial* $\eta^2 = 0.05$, 95% CI [-0.06 to 1.78]).

To further assess proportional changes in muscular activation, internal focus iEMG was expressed as a percentage of external focus iEMG given that the latter is typically observed to result in lower muscular activity (e.g., see Lohse et al., 2012). Despite a relatively larger increase in VM activation when internally focused instructions were provided, a 3 (Muscle) X 8 (Repetition) repeated measures ANOVA did not identify a significant difference in proportional percentage changes for RF (106.87%, SE = 6.41), VL (110.84%, SE = 4.25) or VM (117.81%, SE = 7.37); F (1.34, 25.52) = 0.78, p = 0.47, partial $\eta^2 = 0.04$ (with greenhouse-geisser corrections).

4. Discussion

Contrasting research perspectives suggest that an internal focus of attention on bodily movement components results in a generalised increase in muscular activation through a "spreading" effect (e.g., see Lohse et al., 2012); whereas an internal focus onto the activation of specific muscles during movement can have a selective activation effect (e.g., Karst & Willett, 2004). This research attempted to examine the effects of muscular specific (internal focus) vs movement outcome (external focus) instructions on force production and muscular activation during maximal efforts. The use of the knee extensor musculature enabled a muscular specific focus on the VMO within the co-contracting quadriceps.

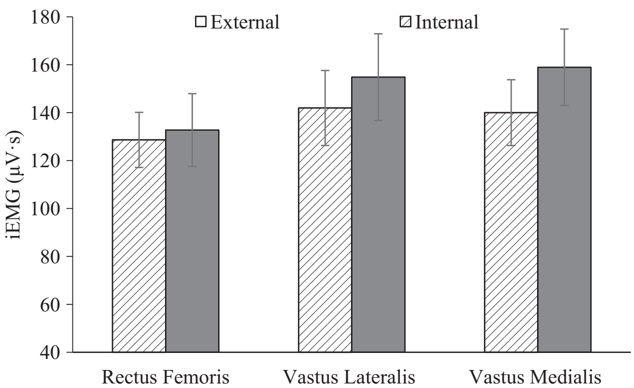

Fig. 1. Means ± standard error. Differences in iEMG in RF (rectus femoris), VL (vastus lateralis), VMO (vastus medialis oblique) under the Internal and External attentional focusing instruction conditions.

The results show that verbal instruction can influence trained subjects' recruitment of muscles during resistance exercise movement. However, the potential for an isolating effect appears limited. Externally focused instructions resulted in significantly lower activation during the exercise task for each measured muscle. No selective effects were observed for individual muscles, nor did the VMO:VL co-contraction ratio indicate any such effect. Therefore, these findings support the observation that focusing attention internally can result in a spreading effect where the increase in activity is seen in muscle groups that the participants were not specifically instructed to focus on (e.g., Lohse et al., 2011; Vance et al., 2004; Wulf et al., 2010; Zachry et al., 2005). As the internally focused instructions used here were muscular specific (VMO) these findings support studies failing to induce selective activation through similar instructional approaches (e.g., Cowling et al., 2003; Snyder & Leech, 2009). It appears that conscious attempts to selectively activate muscles during exercise movements reduces the efficiency of the muscular activation utilised, in line with theories such as the constrained action hypothesis that suggest an internal focus results in increased noise in the motor system during online motor control. This noise hampers attempts to consciously control the targeted muscle.

In contrast to similar earlier studies (e.g., Marchant et al., 2009) the results demonstrated that the two attentional focusing instruction types did not differentially impact upon force production characteristics. In their attempt to isolate muscular activation during bench press movement, Snyder and Fry (2012) also observe a similar effect. In that study subjects performed the same resistance exercise at the same speed, but with different muscular activation profiles depending upon which instruction was provided. Despite no differences in output in the present study, similar maximal force production can be achieved with improved muscular efficiency when externally versus muscular specific internally focused instructions are provided; no additional force was created as a result of the additional muscular activity resulting from the internal focus.

In combination, the findings suggest that directing attention to specific muscles appears to neither result in benefited output nor a localised activation effect. The resulting spreading effect has not limited performance, but performance has been achieved with greater muscular effort. In line with the constrained action hypothesis, the muscular specific internal focus results in significant "noise" in the motor system. With selective activation appearing to be beyond conscious control in this acute setting, the subsequent spreading effect is similar to that observed when both muscular and bodily characteristics are emphasised in internally focused instructions (e.g., Vance et al., 2004; Wulf et al., 2010), suggesting that an internal focus constrains associated components of a movement not simply the action of the body part or muscle being focused on (e.g., Zachry et al., 2005). Further, these findings suggest that an internal focus induces generalised constraints in the motor system (Wulf & Lewthwaite, 2010).

The present research has a number of limitations to consider. Firstly, the study's acute design; selective activation may not be possible after such a brief intervention, but could potentially occur with further training. Indeed, Basmajian demonstrated in 1963 that with training individuals could selectively activate single motor units while inhibiting others. In this case, providing a short description of the muscle location and function may not be enough to direction attention appropriately, only serving to exaggerate a spreading effect. Furthermore, the acute design limits observations of adaptation. Given the consistent observation of such acute effects of attentional focus on force production, it appears logical for research to test Ives and Shelley's (2003) proposal that the attentional focus adopted during training would influence the physical adaptations to that training. Would the differences in efficiency result in long-term adaptations? The design also did not include a non-muscular specific internal focus for comparison, for example focusing attention onto the movement of the leg rather than the VMO. Such a condition would have allowed for comparisons between types of internal focus in terms of potentially different effects. The measurement of additional and antagonist muscle activity was limited through experimental setup, but could be an important component of attentional focus associated effects on co-contractions within a movement's associated musculature (e.g., Lohse et al., 2011). Therefore, it is not clear whether the internal focus instructions assisted in the isolation of the quadriceps themselves, whilst the external focus may have resulted in activation of additional muscles to perform the task. An important limitation is the nature of the task itself. A maximal effort task may well limit individuals' efforts to selectively activate muscles during action. Finally, it is possible that isolation of muscles during exercise movements requires greater support than through simple verbal instruction. For example instructions supplemented with EMG biofeedback can enhance isolation of specific muscles during exercise (e.g., Holtermann, Mork, Andersen, Olsen, & Sogaard, 2010; Holtermann et al., 2009). Future research should examine training effects supported through instruction and biofeedback that directs attention both internally and externally.

From an applied perspective, verbal instructions from coaches, trainers, and physical therapists influence muscle involvement during exercise movements, and the efficiency with which output is produced. Instruction to isolate muscles during exercise appears to be limited through the general spreading activation effect caused by an internal focus of attention. Furthermore, the internal focus results in a generalised disruption of neuromuscular efficiency during movement. This is an important consideration given research suggesting that coaches and physical therapists typically provide internally focused instructions in practice (Durham, Van Vliet, Badger, & Sackley, 2009; Porter, Wu, & Partridge, 2010). To promote efficiency during movement, instructions that direct attention externally towards the movement outcomes are more efficient than internally focused muscle-specific instruction. It is also worth noting the potential implications of increasing general muscular activity through the use of internally focused instruction, for example in rehabilitative settings.

In conclusion, the present study demonstrated that internally focused instructions emphasising the activation of a specific muscle did not result in its selective activation, with elevated activation observed across other muscles associated with the movement. No force production benefits were found for an external focus of attention when compared to the internal focus, suggests that an external focus resulted in more efficient production of similar forces. The findings question the utility of instructions designed to activate specific muscles and support the observation of spreading effects in muscular activation as a result of an internal focus, inducing a generalised rather than localised constraint across the motor system. Researchers and practitioners should be aware of the effects that subtle differences in instructional emphasis can have, as they may have unintended influence. The findings support the established evidence that promoting an external focus towards action effects benefits movement efficiency at a muscular level.

References

Basmajian, J. V. (1963). Control and training of individual motor units. *Science, 141*(3579), 440–441.

Cowling, E. J., Steele, J. R., & McNair, P. J. (2003). Effect of verbal instructions on muscle activity and risk of injury to the anterior cruciate ligament during landing. *British Journal of Sports Medicine, 37*(2), 126–130.

Durham, K., Van Vliet, P. M., Badger, F., & Sackley, C. (2009). Use of information feedback and attentional focus of feedback in treating the person with a hemiplegic arm. *Physiotherapy Research International, 14*(2), 77–90.

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography Kinesiology, 10*, 361–374.

Holtermann, A., Mork, P. J., Andersen, L. L., Olsen, H. B., & Sogaard, K. (2010). The use of EMG biofeedback for learning of selective activation of intra-muscular parts within the serratus anterior muscle: A novel approach for rehabilitation of scapular muscle imbalance. *Journal of Electromyography and Kinesiology, 20*, 359–365.

Holtermann, A., Roeleveld, K., Mork, P. J., Grönlund, C., Karlsson, J. S., Andersen, L. L., ... Søgaard, K. (2009). Selective activation of neuromuscular compartments within the human trapezius muscle. *Journal of Electromyography and Kinesiology, 19*, 896–902.

Ives, J. C., & Shelley, G. A. (2003). Psychophysics in functional strength and power training: Review and implementation framework. *The Journal of Strength & Conditioning Research, 17*(1), 177–186.

Karst, G. M., & Willett, G. M. (2004). Effects of specific exercise instructions on abdominal muscle activity during trunk curl exercises. *Journal of Orthopaedic & Sports Physical Therapy, 34*(1), 4–12.

Lohse, K. R., Jones, M., Healy, A. F., & Sherwood, D. E. (2014). The role of attention in motor control. *Journal of Experimental Psychology: General, 143*, 930–948.

Lohse, K. R., Sherwood, D. E., & Healy, A. F. (2010). How changing the focus of attention affects performance, kinematics, and electromyography in dart throwing. *Human Movement Science, 29*(4), 542–555.

Lohse, K. R., Sherwood, D. E., & Healy, A. F. (2011). Neuromuscular effects of shifting the focus of attention in a simple force production task. *Journal of Motor Behavior, 43*(2), 173–184.

Lohse, K. R., Wulf, G., & Lewthwaite, R. (2012). Attentional focus affects movement efficiency. In N. J. Hodges & A. M. Williams (Eds.), *Skill acquisition in sport: Research, theory & practice* (2nd ed.. New York, NY: Routledge.

Marchant, D. C., Greig, M., & Scott, C. (2009). Attentional focusing instructions influence force production and muscular activity during isokinetic elbow flexions. *The Journal of Strength & Conditioning Research, 23*(8), 2358–2366.

Marchant, D. C., Greig, M., Bullough, J., & Hitchen, D. (2011). Instructions to adopt an external focus enhance muscular endurance. *Research Quarterly for Exercise and Sport, 82*(3), 466–473.

McNevin, N. H., Shea, C. H., & Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. *Psychological Research Psychologische Forschung, 67*(1), 22–29.

Neumann, D. L., & Brown, J. (2015). The effect of attentional focus strategy on physiological and motor performance during a sit-up exercise. *Journal of Psychophysiology*.

Palmerud, G., Sporrong, H., Herberts, P., & Kadefors, R. (1998). Consequences of trapezius relaxation on the distribution of shoulder muscle forces: an electromyographic study. *Journal of Electromyography and Kinesiology, 8*(3), 185–193.

Poolton, J. M., Maxwell, J. P., Masters, R. S. W., & Raab, M. (2006). Benefits of an external focus of attention: Common coding or conscious processing? *Journal of Sports Sciences, 24*(1), 89–99.

Porter, J. M., Anton, P. M., Wikoff, N. M., & Ostrowski, J. B. (2013). Instructing skilled athletes to focus their attention externally at greater distances enhances jumping performance. *The Journal of Strength & Conditioning Research, 27*(8), 2073–2078.

Porter, J., Wu, W., & Partridge, J. (2010). Focus of attention and verbal instructions: Strategies of elite track and field coaches and athletes. *Sport Science Review, 19*(3–4), 77–89.

Portney, L., & Watkins, M. (1993). Statistical measures in reliability. In L. Portney & M. Watkins (Eds.), *Foundation of clinical research, application to practice* (pp. 505–528). East Norwalk: Appleton and Lange.

Snyder, B. J., & Fry, W. R. (2012). Effect of verbal instruction on muscle activity during the bench press exercise. *The Journal of Strength & Conditioning Research, 26*(9), 2394–2400.

Snyder, B. J., & Leech, J. R. (2009). Voluntary increase in latissimus dorsi muscle activity during the lat pull-down following expert instruction. *The Journal of Strength & Conditioning Research, 23*(8), 2204–2209.

Vance, J., Wulf, G., Töllner, T., McNevin, N., & Mercer, J. (2004). EMG activity as a function of the performer's focus of attention. *Journal of Motor Behavior, 36*(4), 450–459.

Wulf, G. (2013). Attentional focus and motor learning: A review of 15 years. *International Review of Sport and Exercise Psychology, 6*(1), 77–104.

Wulf, G., Dufek, J. S., Lozano, L., & Pettigrew, C. (2010). Increased jump height and reduced EMG activity with an external focus. *Human Movement Science, 29*(3), 440–448.

Wulf, G., & Lewthwaite, R. (2010). Effortless motor learning? An external focus of attention enhances movement effectiveness and efficiency. In B. Bruya (Ed.), *Effortless attention: A new perspective in attention and action* (pp. 75–101). Cambridge, MA: MIT Press.

Wulf, G., & Lewthwaite, R. (2016). Optimizing performance through intrinsic motivation and attention for learning: The OPTIMAL theory of motor learning. *Psychonomic Bulletin & Review*, 1–33.

Wulf, G., McNevin, N., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology: Section A, 54*(4), 1143–1154.

Zachry, T., Wulf, G., Mercer, J., & Bezodis, N. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin, 67*(4), 304–309.

Zarghami, M., Saemi, E., & Fathi, I. (2012). External focus of attention enhances discus throwing performance. *Kinesiology, 44*(1), 47–51.