

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

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4 Running Head: Attentional focus and muscle activation

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## 25 **Abstract**

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

43 **Keywords:** Focus of attention, muscle activity, motor control, exercise

44

## 45 **Highlights**

- 46 • Attentional focusing instructions did not impact on leg torque production.
- 47 • Muscle focused internal focus resulted in elevated muscular activation compared to an  
48 external focus.
- 49 • No selective activation effects were observed for muscle specific internal focus  
50 instructions.
- 51 • An external focus resulted in similar force production but with more efficient muscle  
52 activation.

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

56 1.1 Introduction

57 Recent studies demonstrate that the attentional focus emphasised through verbal instruction  
58 differentially impacts upon force production (see Marchant, 2011; Wulf & Lewthwaite,  
59 2016). For example, when compared to internally focused attention (onto aspects of the  
60 movements being executed) an external focus of attention (onto movement outcomes) has  
61 improved performance on standing long jumps (Porter, Anton, Wikoff, & Ostrowski, 2013),  
62 discus throwing (Zarghami, Saemi, & Fathi, 2012), bench press and squat exercise endurance  
63 (Marchant, Greig, Bullough, & Hitchen, 2011), and finally accuracy in an isometric force  
64 production task (Lohse, Sherwood, & Healy, 2011). To investigate these effects, researchers  
65 have identified muscular activation characteristics measured through electromyography  
66 (EMG) as a significant mechanism (See Lohse, Wulf & Lewthwaite, 2012). In those studies,  
67 instructions to adopt an external focus of attention have typically resulted in more efficient  
68 activation (See Wulf, 2013) when compared to an internal focus of attention. An external  
69 focus of attention is manipulated through instructions directing attention to the intended  
70 outcome of the movement. However, inducing an internal focus of attention has been  
71 achieved through different approaches; with some directing attention to movement mechanics  
72 (e.g., Zachry, Wulf, Mercer, & Bezodis, 2005) whilst others focus attention onto the muscles  
73 themselves (e.g., Vance, Wulf, Töllner, McNevin, & Mercer 2004; Marchant, Greig, & Scott,  
74 2009). Further emphasising these differences in instructional approaches, research that does  
75 not incorporate electromyography typically does not emphasise muscular activation as part of  
76 the internal focus manipulations. Rather they focus attention onto the movement of the limbs  
77 involved in the action (e.g., Lohse et al., 2010).

78 In research examining instructionally manipulated attentional focus, an external focus of  
79 attention has typically facilitated efficient muscular activation. On the other hand, the  
80 conscious control associated with internally focused attention results in inefficient muscular  
81 activity, or “noise” in the motor system, which is subsequently detrimental to performance.  
82 For example, during force production or exercise type movements reduced muscular  
83 activation has been observed with an external versus internal focus during biceps curls type  
84 exercise (Vance et al., 2004; Marchant et al., 2009: focus on the movement of the curl bar vs  
85 focus on the muscles involved), sit up exercises (Neumann & Brown, 2015: “make your

86 movements smooth/flow” vs “focus on or feel your stomach muscles”) and vertical jump and  
87 reach tasks (Wulf, Dufek, Lozano, & Pettigrew, 2010: reach for the target vs reaching with  
88 your fingers). Lohse et al. (2011) found less accurate isometric force production with the  
89 foot as well as a higher degree of co-contractions of agonist (soleus) and antagonist (tibialis  
90 anterior) muscles with an internal focus onto the calf muscles compared to externally focused  
91 instructions emphasising the force platform. Interestingly, although internal instruction  
92 purposefully directed attention to the agonist muscle, significantly greater muscle activity  
93 was only observed in the antagonist muscle.

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

104 One interesting observation is a “spreading” of influence where an internal focus of attention  
105 has a broader influence of movement efficiency and muscular activation. Specifically, an  
106 internal focus influences the activity of muscle groups that participants were focusing on, in  
107 addition to those that they were not specifically directed to focus on (e.g., Zachry et al., 2005;  
108 Lohse et al., 2011; Vance et al., 2004; Wulf, et al., 2010). This spreading effect appears to be  
109 observed regardless of whether specific muscles or movement characteristics are emphasised  
110 in the internally focused instructions provided. This observation and the muscular activation  
111 findings to-date are in line with the constrained action hypothesis (McNevin, Shea, & Wulf,  
112 2003; Wulf, McNevin, Shea, 2001). When an external focus is adopted there is greater  
113 utilisation of the motor system’s self-organising capabilities (e.g., Lohse, Jones, Healy, &  
114 Sherwood, 2014) and automatic control processes. This supports effective neuromuscular  
115 coordination and activation of agonist and antagonist muscle groups. An internal focus on the  
116 other hand promotes conscious control of movements through self-related processing (Wulf  
117 & Lewthwaite, 2010) which constrains the motor system resulting in unnecessary muscular  
118 activation and co-contractions. This “noise” in the motor system evidences reduced automatic

119 control processes and increased conscious attempts to control movement. Although motor  
120 unit recruitment is not under conscious control (Lohse et al., 2012), these observations  
121 highlight that the attentional focus adopted influences the efficiency of the motor system,  
122 which in turn significantly impacts on neuromuscular coordination. Consequentially, the  
123 alterations in neuromuscular activity coincide with changes in outcome measures.

124 Contrasting this spreading effect, researchers have demonstrated that instructional approaches  
125 can selectively recruit muscles during exercise and rehabilitative movements. Muscle specific  
126 verbal instruction have resulted in selective activation of oblique and rectus abdominis  
127 muscles during trunk curl exercises (Karst & Willett, 2004), the latissimus dorsi during low-  
128 intensity lat pull-down exercise (Snyder & Leech, 2009), and pectoralis major and triceps  
129 brachii activity during bench press exercise and 50% of trained participants 1-repetition max  
130 (1RM), but not at 80% of 1RM (Snyder & Fry, 2012). Using a single legged dynamic landing  
131 movement Palmerud et al. (1998) found selective reductions in upper trapezius activity  
132 during isometric shoulder abduction exercise (with corresponding increases in rhomboids  
133 major and minor and the transverse trapezius muscles) only when verbal cues were supported  
134 with EMG biofeedback. However, Cowling, Steele, and McNair (2003) found that  
135 instructions to specifically recruit the hamstring muscles during jump landing were  
136 unsuccessful. The instructions resulted in inefficient co-contraction of associated muscles  
137 such that landings posed a greater risk of injury. The internally focused nature of the  
138 instruction provided may have resulted in a spreading influence across associated muscles  
139 rather than the intended selective effect.

140 Given the evidence reviewed, it is clear that verbal instruction provided by coaches, physical  
141 therapists, and personal trainers has a measurable effect on muscle activation and force  
142 production during exercise movements. Attempts to isolate or promote muscular activation  
143 through verbal guidance may well be hindered by the “spreading” effect (e.g., Lohse et al.,  
144 2011) where the influence of internally focused instructions “spreads” to other muscle groups  
145 that participants were not specifically instructed to focus on. The present study aims to assess  
146 the influence of internally focused instructions emphasising specific muscular activity when  
147 compared to externally focused instructions that emphasise the movement outcome. Verbal  
148 attentional focusing instructions will be provided for a maximal concentric isokinetic knee  
149 extension exercise at  $60^{\circ}\cdot s^{-1}$ , whilst force and muscular activation characteristics are  
150 measured. Of particular interest in the present study was the relative activation between

151 vastus medialis oblique (VMO) and vastus lateralis (VL) during these movements, and the  
152 VMO:VL ratio.

## 153 **2.1 Method**

### 154 ***2.1.1 Participants***

155 20 (Male 16, Female 4) healthy and regularly training participants were recruited from an  
156 undergraduate student athlete population (mean age of  $20.2 \pm 1.47$  years). Participants were  
157 intermittent team sport players with a minimum of three years' experience, not specifically  
158 strength trained but familiar with the tasks used in the present study as forming part of  
159 appropriate preparatory strength and conditioning for their sport. Training activities were  
160 equivalent to two training sessions plus one competitive match per week. Participants were  
161 naïve to the purpose of the study. The sample size was determined based on previous research  
162 and were from a convenience sample, recruited during a predetermined period of data  
163 collection. An institutional ethics review committee approved the methods, and informed  
164 consent was obtained prior to participation.

### 165 ***2.1.2 Design***

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

### 178 ***2.1.3 Task and Measures***

#### 179 ***2.1.3.1 Isokinetic Dynamometry:***

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

#### 195 *2.1.3.2 Electromyography:*

196 Muscular activation was obtained for the femoral quadriceps VMO, VL, and RF. The present  
197 study selected the VMO and VL due to the dynamic relationship on lateral pull (The VL causes  
198 a lateral pull which is counteracted by the medial pull the VMO exerts on the patella), and the  
199 RF as a further indication of quadriceps function with attentional focus manipulations. Despite  
200 the relationships observed in antagonist activation in attentional focus research (e.g., Lohse et  
201 al., 2011), the dynamometer setup on the present study precluded such measurement. Electrode  
202 preparation and placement followed the SENIAM group recommendations (e.g., Hermens,  
203 Freriks, Disselhorst-Klug, Rau, 2000). Pairs of disposable bi-polar silver-silver chloride  
204 passive surface electrodes (Medicotest, Denmark) were placed on the visual midpoint of the  
205 contracted muscle belly of the VMO, VL and RF (identified through palpation and functional  
206 observation) orientated parallel to the direction of the muscle fibre alignment. Electrodes were  
207 placed 20mm apart (centre to centre) on the skin. A reference electrode positioned on a bony  
208 and inactive aspect of the knee established a threshold for computer signal processing. Prior to  
209 electrode placement, the skin was first dry-shaved and then cleaned with an alcohol swab. The  
210 pre-amplified electrode leads were connected to an 8-channel transmitter unit (Noraxon  
211 Telemetry 2400T) adjacent, but not connected to the participant. To avoid inter-experimenter  
212 variations, the same researcher applied the electrodes to all participants. The active EMG



213 signal was pre-amplified (gain 500) and subjected to a 10-1000 Hz band-pass filter. A sampling  
214 frequency of 1500 Hz was used to collect the EMG signal, with data collection manually  
215 initiated prior to the first repetition and terminated following the final repetition. Processing of  
216 the EMG signal was conducted using Noraxon Software (MyoResearch XP Master). Signal  
217 processing of the raw EMG data was achieved using an EMG linear envelope, achieved using  
218 a combination of full-wave rectification to attain the absolute value, and the application of low-  
219 and high-pass bandwidth filters to attain a frequency spectrum of 10-300Hz. For each muscle,  
220 from movement onset to offset integrated EMG (iEMG: representing the area under the EMG  
221 time-history curve) were calculated at each repetition. An index of VMO:VL co-contraction  
222 was calculated by taking the ratio of VMO iEMG divided by VL iEMG.

### 223 *2.1.3.3 Attentional Focusing Instructions*

224 Verbal instruction was provided by the same researcher prior to exercise initiation. The  
225 provision of complex instructions for simple motor tasks (e.g., golf putting; Poolton et al.,  
226 2006) has been proposed as one reason why benefits of an external focus have been observed  
227 (Wulf, 2013). Therefore, simple instructions appropriate to the task being performed were  
228 developed. Each instruction contained a common and attentional focusing component. For  
229 the common instruction, all participants were first instructed to exert maximal effort on the  
230 extension phase and relax while returning to the starting position. This was followed by an  
231 attentional focusing cue. In the internal focus condition, after verbal and visual description of  
232 VMO location and function, instructions emphasised focusing on contracting the VMO whilst  
233 generating maximal effort. For the external condition, instructions emphasised focusing on  
234 pushing against the pad whilst generating maximal effort. For example, in combination the  
235 external instructions were; “Try to exert maximal effort during the movement whilst focusing  
236 on pushing against the pad”. No verbal encouragement was given during the isokinetic  
237 exercise.

### 238 *2.1.4 Procedure*

239 Data collection was conducted within a well-controlled sport and exercise science laboratory.  
240 In the 24 hours preceding testing participants continued normal diet and physical activity  
241 patterns, but refrained from strenuous exercise and consumption of caffeine or alcohol. Upon  
242 arrival participants were health screened for exercise participation. Following a standardised  
243 warm-up (submaximal cycling), Participants first completed a familiarisation session of three  
244 practice repetitions to become accustomed to the movements and velocities of the apparatus.

245 Participants then performed both attentional focus conditions on the same day of testing,  
246 counterbalanced between participants, with a rest period of 15 minutes between trials. At the  
247 beginning of each trial the allocated verbal instructions were delivered by the same researcher,  
248 and participants were encouraged to use instructions throughout the trial. No visual or verbal  
249 feedback, nor verbal encouragement was provided and the researcher was the only individual  
250 present with the participant to control for social influences. Data collection was initiated when  
251 the participant was told to “go”.

### 252 **2.1.5 Data Processing and Analysis**

253 The first and last repetitions in each set were excluded from analysis as they are qualitatively  
254 different from the other repetitions (Vance et al., 2004). Tpk and MP were analysed separately  
255 using 2 (Focus: Internal vs External) X 8 (Repetition) repeated measures ANOVA. Muscular  
256 activation was assessed using a 2 (Focus: Internal vs External) X 3 (Muscle: RF, VL, VMO) X  
257 8 (Repetition) repeated measures ANOVA, whilst the VMO:VL iEMG co-contraction ratio  
258 was analysed using a 2 (Focus: Internal vs External) X 8 (Repetition) repeated measures  
259 ANOVA. An  $\alpha$ -level of .05 was used for all analyses. Further, the purpose was not to measure  
260 or compare between subjects, in which case a maximal voluntary contraction (MVC) could  
261 have been used to normalize data. Results are presented as the mean  $\pm$  standard error of the  
262 mean. The test-retest reliability of peak torque and iEMG were determined during  
263 familiarisation. The intraclass correlation coefficients for pk Torque were  $>0.90$  representing  
264 excellent reliability, and for iEMG  $>0.75$  representing good reliability based on the  
265 classifications of (Portney & Watkins, 1993).

## 266 **3.1. Results**

### 267 **3.1.1 Force Production**

268 A 2 (Focus: Internal vs External) X 8 (Repetition) repeated measures ANOVA found that the  
269 instructed focus of attention did not significantly influence the level of force produced during  
270 the maximal efforts, both in terms of Tpk (Internal = 152.73 Nm, SE = 12.30 vs External =  
271 153.39 Nm, SE = 11.19;  $F(1,19) = 0.01$ ,  $p = 0.92$ , partial  $\eta^2 = .001$ , 95% CI [-12.20 to 13.50])  
272 and MP (Internal = 114.68 Nm·s, SE = 8.10 vs External = 113.66 Nm·s, SD = 7.59;  $F(1,19) =$   
273  $0.07$ ,  $p = 0.80$ , partial  $\eta^2 = .004$ , 95% CI [-7.26 to 9.31]). No significant Focus X Repetition  
274 interaction were identified for either Tkp ( $F(1,19) = 1.12$ ,  $p = 0.35$ , partial  $\eta^2 = .06$ ) or MP  
275 ( $F(1,19) = 0.96$ ,  $p = 0.46$ , partial  $\eta^2 = .05$ ). A descriptive summary of data for all variables is  
276 shown in Table 1.

277 -- Table 1 - - - -

### 278 3.1.2 EMG measures

279 A 2 (Focus: Internal vs External) X 3 (Muscle: RF, VL, VMO) X 8 (Repetition) repeated  
280 measures ANOVA identified a significant main effect for focus, with less iEMG activity with  
281 an external focus (136.87  $\mu\text{V}\cdot\text{s}$ , SE = 11.05) than with an internal focus (148.84  $\mu\text{V}\cdot\text{s}$ , SE =  
282 14.03) ( $F(1, 19) = 5.06$ ,  $p = .04$ , partial  $\eta^2 = .21$ , 95% CI [0.84 to 23.10]). No significant main  
283 effect for muscle ( $F(2, 38) = 1.18$ ,  $p = .32$ , partial  $\eta^2 = .06$ ) or Focus X Muscle interaction  
284 ( $F(2, 38) = 1.21$ ,  $p = .431$ , partial  $\eta^2 = .06$ ) were evident (See Figure 1). A 2 (Focus) X 8  
285 (Repetition) repeated measures ANOVA revealed no difference in the VMO:VL iEMG co-  
286 contraction ratio between attentional focus conditions (external = 1.11, SE = 0.12 vs Internal  
287 = 1.17, SD = 0.12; ( $F(1, 19) = 1.06$ ,  $p = .32$ , partial  $\eta^2 = .05$ , 95% CI [-0.06 to 1.78]).

288 -- Figure 1 - - - -

289 To further assess proportional changes in muscular activation, internal focus iEMG was  
290 expressed as a percentage of external focus iEMG given that the latter is typically observed to  
291 result in lower muscular activity (e.g., see Lohse et al., 2012). Despite a relatively larger  
292 increase in VM activation when internally focused instructions were provided, a 3 (Muscle) X  
293 8 (Repetition) repeated measures ANOVA did not identify a significant difference in  
294 proportional percentage changes for RF (106.87%, SE = 6.41), VL (110.84%, SE = 4.25) or  
295 VM (117.81%, SE = 7.37);  $F(1.34, 25.52) = 0.78$ ,  $p = 0.47$ , partial  $\eta^2 = .04$  (with greenhouse-  
296 geisser corrections).

297

## 298 4.1 Discussion

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

307 The results show that verbal instruction can influence trained subjects' recruitment of muscles  
308 during resistance exercise movement. However, the potential for an isolating effect appears  
309 limited. Externally focused instructions resulted in significantly lower activation during the  
310 exercise task for each measured muscle. No selective effects were observed for individual  
311 muscles, nor did the VMO:VL co-contraction ratio indicate any such effect. Therefore, these  
312 findings support the observation that focusing attention internally can result in a spreading  
313 effect where the increase in activity is seen in muscle groups that the participants were not  
314 specifically instructed to focus on (e.g., Zachry et al.'s 2005; Lohse et al., 2011; Vance et al.,  
315 2004; Wulf et al., 2010). As the internally focused instructions used here were muscular  
316 specific (VMO) these findings support studies failing to induce selective activation through  
317 similar instructional approaches (e.g., Cowling et al., 2003; Snyder & Leech, 2009). It appears  
318 that conscious attempts to selectively activate muscles during exercise movements reduces the  
319 efficiency of the muscular activation utilised, in line with theories such as the constrained  
320 action hypothesis that suggest an internal focus results in increased noise in the motor system  
321 during online motor control. This noise hampers attempts to consciously control the targeted  
322 muscle.

323 In contrast to similar earlier studies (e.g., Marchant et al., 2009) the results demonstrated that  
324 the two attentional focusing instruction types did not differentially impact upon force  
325 production characteristics. In their attempt to isolate muscular activation during bench press  
326 movement, Snyder and Fry (2010) also observe a similar effect. In that study subjects  
327 performed the same resistance exercise at the same speed, but with different muscular  
328 activation profiles depending upon which instruction was provided. Despite no differences in  
329 output in the present study, similar maximal force production can be achieved with improved  
330 muscular efficiency when externally versus muscular specific internally focused instructions  
331 are provided; no additional force was created as a result of the additional muscular activity  
332 resulting from the internal focus.

333 In combination, the findings suggest that directing attention to specific muscles appears to  
334 neither result in benefited output nor a localised activation effect. The resulting spreading  
335 effect has not limited performance, but performance has been achieved with greater muscular  
336 effort. In line with the constrained action hypothesis, the muscular specific internal focus  
337 results in significant "noise" in the motor system. With selective activation appearing to be  
338 beyond conscious control in this acute setting, the subsequent spreading effect is similar to that  
339 observed when both muscular and bodily characteristics are emphasised in internally focused

340 instructions (e.g., Vance et al., 2004; Wulf et al., 2010), suggesting that an internal focus  
341 constrains associated components of a movement not simply the action of the body part or  
342 muscle being focused on (e.g., Zachry, et al. 2005). Further, these findings suggest that an  
343 internal focus induces generalised constraints in the motor system (Wulf and Lewthwaite,  
344 2010).

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

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

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

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

	<i>Internal Focus</i>		<i>External Focus</i>	
	<i>Mean (SE)</i>	<i>95% CI</i>	<i>Mean (SE)</i>	<i>95% CI</i>
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 $\mu\text{V}\cdot\text{s}$	158.94 (15.95)	[125.56, 192.33]	140.02 (13.74)	[111.27, 168.79]
VL iEMG $\mu\text{V}\cdot\text{s}$	154.85 (18.09)	[116.98, 192.72]	141.95 (15.65)	[109.19, 174.71]
RF iEMG $\mu\text{V}\cdot\text{s}$	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]		

500

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

507

### Figure Captions

508 Figure 1. Means  $\pm$  standard error. Differences in iEMG in RF (rectus femoris), VL (vastus  
509 lateralis), VMO (vastus medialis oblique) under the Internal and External attentional focusing  
510 instruction conditions.