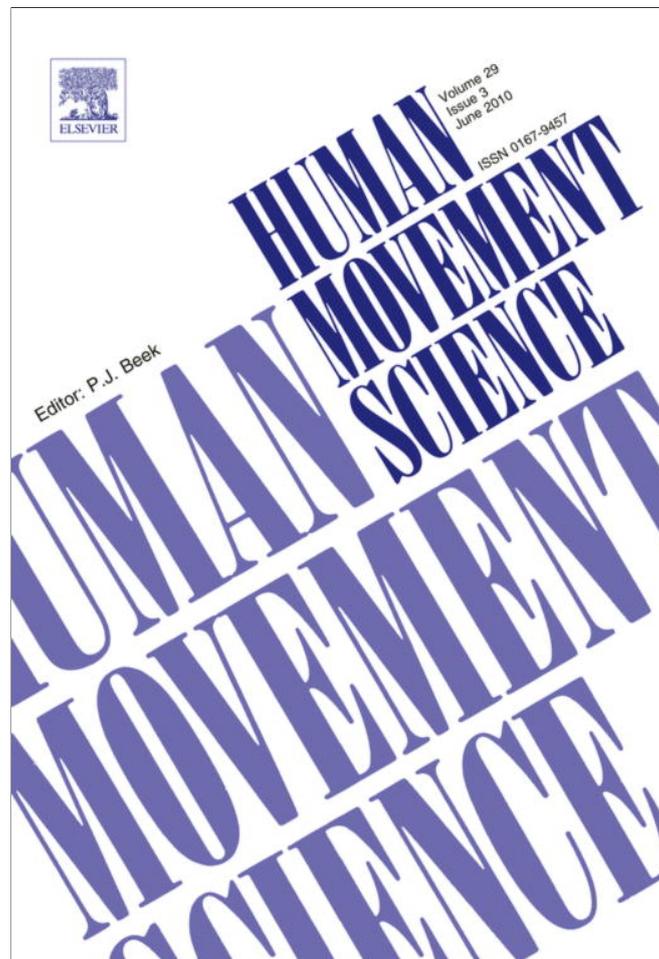


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## Increased jump height and reduced EMG activity with an external focus

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### ABSTRACT

Jump height is increased when performers are given external focus instructions, relative to an internal focus or no focus instructions (Wulf & Dufek, 2009; Wulf, Zachry, Granados, & Dufek, 2007). The purpose of present study was to examine possible underlying neurophysiological mechanisms of this effect by using electromyography (EMG). Participants performed a vertical jump-and-reach task under two conditions in a counterbalanced order: external focus (i.e., focus on the rungs of the measurement device) and internal focus (i.e., focus on the fingers with which the rungs were to be touched). EMG activity of various muscles (anterior tibialis, biceps femoris, vastus lateralis, rectus femoris, gastrocnemius) was measured during jumps. Jump height was greater with an external compared to an internal focus. While there were no differences in muscle onset times between attentional focus conditions, EMG activity was generally lower with an external focus. These results suggest that neuromuscular coordination is enhanced by an external focus of attention. The present findings add to the evidence that an external focus facilitates the production of effective and efficient movement patterns.

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### 1. Introduction

Over the past decade or so, numerous studies have shown that the focus of attention an individual adopts during the execution of a motor skill influences performance – and, perhaps more importantly, skill learning (for reviews, see Wulf, 2007a, 2007b). In particular, if attention is focused on the

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movement effect, or outcome, one is attempting to achieve (external focus) as compared to attention focused on one's body movements (internal focus), the result is typically greater movement effectiveness. This has been demonstrated for a variety of (complex) laboratory and sport skills, including those performed in golf (e.g., Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007), basketball (Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002; Zachry, Wulf, Mercer, & Bezodis, 2005), soccer (e.g., Wulf, McConnel, Gärtner, & Schwarz, 2002, Experiment 2), volleyball (Wulf et al., 2002, Experiment 1), dart throwing (Marchant, Clough, & Crawshaw, 2007), as well as for various balance skills (e.g., Totsika & Wulf, 2003; Wulf, Höß, & Prinz, 1998). The benefits of adopting an external focus are not only seen relative to internal focus conditions, but also in comparison to control conditions without specific focus instructions (e.g., Landers, Wulf, Wallmann, & Guadagnoli, 2005; Marchant, Greig, Scott, & Clough, 2006; Wulf, Landers, Lewthwaite, & Töllner, 2009; Wulf & McNevin, 2003; Wulf, Weigelt, Poulter, & McNevin, 2003; Wulf et al., 1998). This suggests that an external focus *enhances* performance and learning, presumably because individuals are inclined to adopt an internal focus even when they are not explicitly instructed to do so.

The majority of studies on attentional focus have used various measures of movement accuracy (e.g., deviation from a target) or balance (e.g., postural sway) to assess movement effectiveness (see Wulf, 2007a, 2007b, for reviews). Recent studies have demonstrated that force production is also influenced by the performer's focus of attention. In the first study to examine this issue, Vance, Wulf, Töllner, McNevin, and Mercer (2004) used a biceps-curl task, with performers being instructed to focus either on the movements of the curl bar (external focus) or of their arms (internal focus). The results showed that muscular activity (i.e., as measured by electromyography, EMG) was significantly reduced in the external relative to the internal focus condition. Given that the weight lifted was identical under both conditions, this finding indicated that movements were performed more efficiently with an external attentional focus. Marchant and colleagues (Marchant, Greig, & Scott, 2009a, 2009b; Marchant et al., 2006) extended those findings. In one study, Marchant et al. (2006) demonstrated that an external focus in a series of repetitions on a biceps-curl task resulted in less EMG activity not only compared to an internal focus, but also compared to no focus instructions (control condition). In another study, Marchant et al. (2009a) found beneficial effects of an external focus on maximum force production. Using an isokinetic dynamometer, these researchers had participants produce maximum voluntary contractions of the elbow flexors under internal focus (i.e., arm muscles) or external focus (i.e., crank hand-bar) conditions. The results showed that participants produced significantly greater peak joint torque when they focused externally – and that this was achieved with significantly less muscular (EMG) activity.

In another series of studies, Wulf and Dufek (2009) and Wulf, Zachry, Granados, and Dufek (2007) used a task that required whole-body coordination to produce maximum force, namely, a vertical jump-and-reach task. Using a Vertec™ measurement device, participants performed the task under each of two conditions: focus on the rungs that were to be touched (external focus) or focus on the finger with which the rungs were to be touched (internal focus). Jump height and vertical center-of-mass (COM) displacement were greater in the external than internal focus condition (Wulf et al., 2007). In addition, impulse and lower extremity joint moments were greater with an external focus as well (Wulf & Dufek, 2009) – indicating that individuals jumped higher by producing greater forces.

Findings showing that an external focus enables individuals to lift the same weight (Marchant et al., 2006; Vance et al., 2004), and to produce greater impulses, joint moments (Wulf & Dufek, 2009), as well as peak forces with less muscular activity (Marchant et al., 2009a) provide converging evidence that movements are produced more efficiently when attention is directed to the desired movement effect. But how is motor control optimized by an external focus? The predominant explanation for the attentional focus effects centers on the idea that an internal focus induces conscious control and constrains the motor system, whereas an external focus promotes automaticity in movement control (“constrained action hypothesis”; Wulf, McNevin, & Shea, 2001). Support for this notion has been provided in previous studies (e.g., McNevin, Shea, & Wulf, 2003; Wulf, Shea, & Park, 2001). This assumption implies that an external focus leads to a more advanced stage of learning sooner – in which performance is not only more effective, but in which movement efficiency is enhanced as well (Wulf, 2007b). In line with this view, Vanezis and Lees (2005) who compared “good” and “poor” jumpers found that, while there were no major differences with regard to the technique used, the two

groups showed significant differences in the amount of force produced – similar to what participants in the [Wulf and Dufek \(2009\)](#) study showed when they were instructed to use an external rather than internal focus.

Still, an interesting question is: How is the motor system able to increase force production when the individual adopts an external focus (or becomes more skilled)? More specifically, what are the underlying mechanisms that allow individuals to jump higher? One possibility is that motor unit activation is coordinated more effectively with an external focus. The result of more effective motor unit recruitment might be not only an increase in output (e.g., jump height), but also a generally lower level of muscular activity. This would be similar to what is seen, for example, in the early phases of a weight lifting program (e.g., [Conley, Stone, Nimmons, & Dudley, 1997](#); [Häkkinen & Komi, 1983](#)). In those studies, it was found that, after a relatively short period of resistance training, less muscle area was used to lift the same weight – strongly suggesting that neural adaptations (i.e., learning processes) were responsible for this effect ([Ploutz, Tesch, Biro, & Dudley, 1994](#)). It has been argued that giving learners external focus instructions speeds the learning process so that a more advanced level of performance is achieved sooner ([Wulf, 2007b](#)). Given that a higher skill level is typically associated with greater movement effectiveness and efficiency, one would expect to see increased jump height and reduced muscular activity with an external relative to an internal focus. In addition to enhanced intra-muscular coordination, another possibility is that an external focus optimizes the coordination among the muscles, which may be reflected in different timing patterns in the onset of the different muscles involved. We addressed these questions in present study. Specifically, we used the vertical jump-and-reach task used in previous studies ([Wulf & Dufek, 2009](#); [Wulf et al., 2007](#)), with participants being instructed to focus either on the rungs of the measurement device (external focus), or on the fingers with which the rungs were to be struck (internal focus). We hypothesized that, in addition to increased jump height, EMG activity in the lower extremity muscles, expressed as root-mean-square error (RMSE), would be reduced in the external compared to the internal focus condition. We also examined the onset (timing) of the same muscles as a function of attentional focus.

## 2. Methods

### 2.1. Participants

Eight healthy, physically active undergraduate university students (five female, three male), with a mean age of 22.6 years (*SD*: 2.50), participated in the study. They were not aware of the specific study purpose. Informed consent was obtained from all participants before the beginning of the experiment.

### 2.2. Apparatus and task

A Vertec™ measurement device was used to record vertical jump-and-reach height. It consisted of a series of horizontal plastic rungs incrementally spaced (0.5 in. or 1.3 cm) at different heights, which participants reached for during maximum counter-movement jumps. The participants were asked to stand with their dominant hand closest to the Vertec™. From a standing position, the subject reached up with their dominant hand, along the spine of the measurement device. The height of the device was then adjusted so that the lowest rung was 12 in. from the extended fingertips of the participant. To measure vertical ground reaction forces (vGRF), kinetic data were obtained using a force platform (Kistler, Model # 8600B, 40 × 60 cm). Muscle activation during the jump was obtained with EMG surface electrodes (Noraxon, Inc., 2.5 cm center-to-center distance). Force and EMG data were synchronized through an external square wave via a Kistler 16 channel, 16 bit (Type 5605A) A/D board and BioWare (version 3.21) software, sampling at 1080 Hz.

### 2.3. Procedure

Participants were instructed to jump straight up and touch the highest rung they could reach with the tips of the fingers of their dominant hand. Participants were allowed to warm up and

**Table 1**

Anatomical function of muscles evaluated.

Muscle	Action(s)
Anterior tibialis (AT)	Ankle dorsiflexion, inversion
Biceps femoris (BF)	Hip joint extension, knee joint flexion
Vastus lateralis (VL)	Knee joint extension
Rectus femoris (RF)	Hip joint flexion, knee joint extension
Lateral gastrocnemius (LG)	Knee joint flexion, ankle plantar flexion

practice sub-maximally until they felt comfortable with the equipment, protocol, and technique. Following practice and instruction, participants were instrumented with EMG electrodes. Standard EMG skin preparation methods were utilized including shaving and lightly abrading the skin with alcohol to reduce electrical impedance. The electrodes were positioned to record the activity of five right lower extremity muscles including: rectus femoris (RF), biceps femoris (BF), vastus lateralis (VL), lateral gastrocnemius (LG), and the anterior tibialis (AT). The electrodes were positioned using anatomic surface landmarks and palpation in accordance with methods recommended in the literature (Konrad, 2005). Anatomical function of each of the five muscles selected for evaluation is given in Table 1.

Each participant performed 10 jumping trials under each of the internal and external focus conditions, with the general instruction to reach as high as possible during each jump. Condition order was counterbalanced among participants. In internal focus conditions, participants were instructed to concentrate on the tips of their fingers, whereas under external focus conditions, they were instructed to concentrate on the rungs. Attentional focus reminders were given before each trial. At the start of a trial, the participant was instructed to step onto two force platforms, with one foot on each platform, and to stand still. After the attentional focus reminder, the participant jumped when he or she was ready.

#### 2.4. Dependent variables and data analysis

For each jump, the experimenter recorded the highest rung that was touched and displaced. The vGRF time-history was used to define the jump phase and identify the simultaneous EMG profile associated with each jump. The initiation of the jump was defined as that point in the vGRF profile when the jumper initiated unloading (vertical GRF less than 50% bodyweight) and terminated when vGRF was equal to zero (take-off). Take-off was used as a normalizing characteristic among jumps and was set to time = 0 s. Therefore, jump phase EMG temporal values carried a negative value (some time prior to take-off). EMG amplitude was first corrected by removing DC-bias from the signal. The RMSE of the EMG signal during the jump phase was calculated for each muscle and trial. The onset of muscle activation was then determined by starting at 1.0 s prior to take-off and identifying the point in the EMG time-history when activation reached two standard deviations greater than the baseline value (Foster, Sveistrup, & Woollacott, 1996), lasting for at least 10 ms.

Jump-and-reach height (converted into cm), EMG RMSE, and muscles onset times were averaged across the 10 trials. Jump height was analyzed in an one-way analysis of variance (ANOVA). EMG RMSE and muscles onset times were analyzed in 2 (Attentional Focus: internal, external)  $\times$  5 (Muscles: AT, BF, VL, RF, LG) ANOVAs with repeated measures on the first factor.

### 3. Results

#### 3.1. Jump-and-reach height

Jump-and-reach height was greater when participants adopted an external focus (32.4 cm, SE = 3.05) relative to an internal focus (31.0 cm, SE = 3.18) (see Fig. 1). The main effect of attentional focus was significant, with  $F(1, 7) = 6.36$ ,  $p < .05$ ,  $\eta^2 = .49$ .

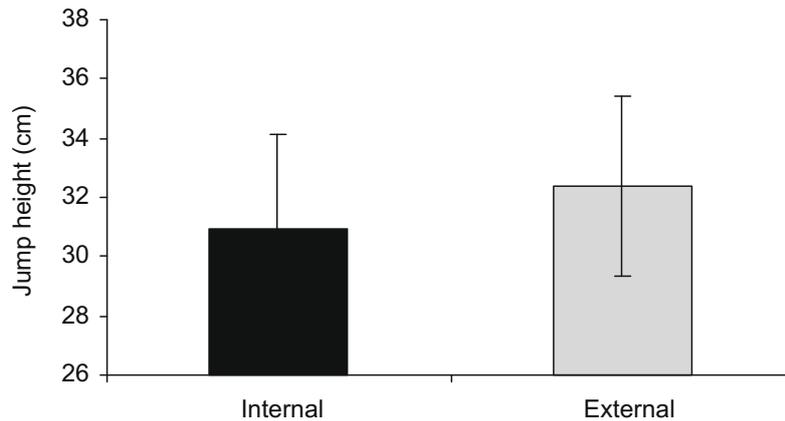


Fig. 1. Jump-and-reach height as a function of internal versus external focus.

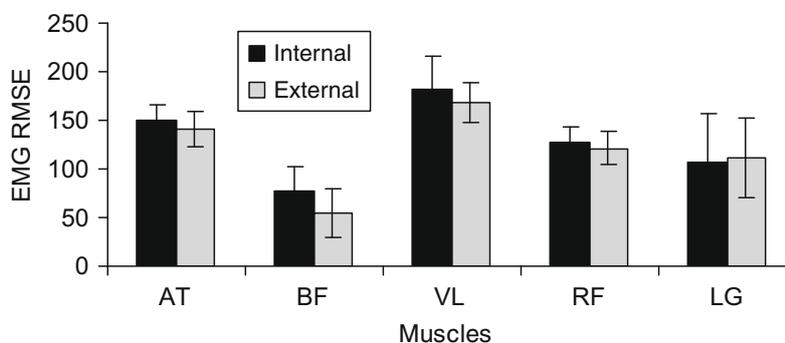


Fig. 2. EMG root-mean-square error (RMSE), from muscle onset to takeoff, for the various muscles as a function of internal versus external focus (AT = tibialis anterior; BF = biceps femoris; VL = vastus lateralis; RF = rectus femoris; LG = lateral gastrocnemius).

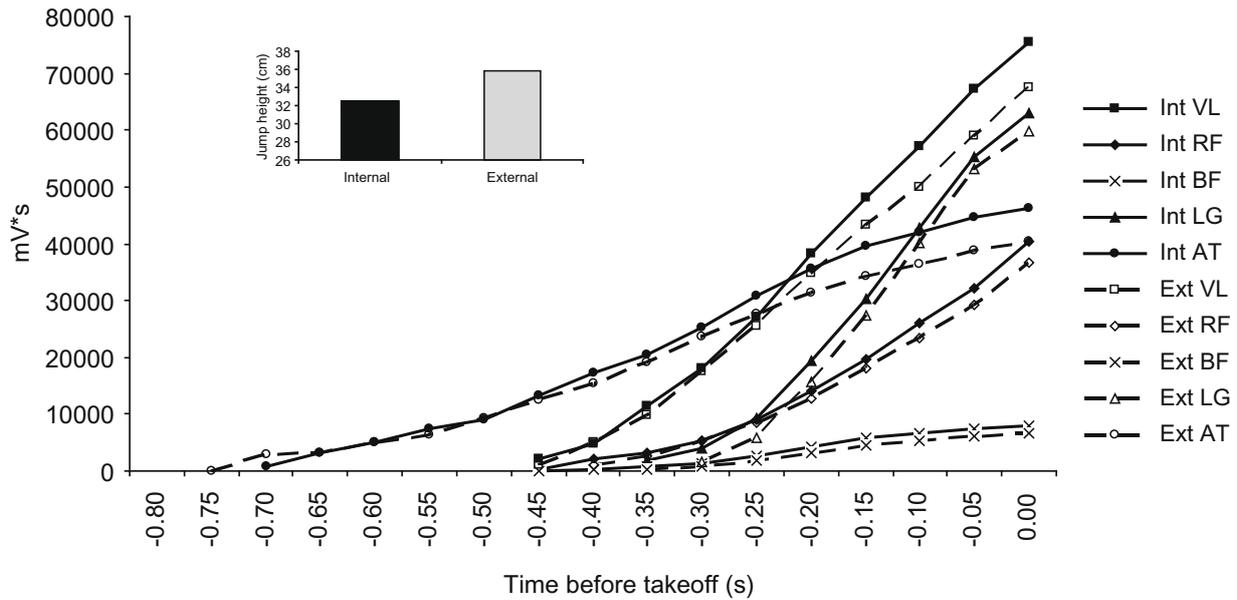
### 3.2. EMG RMSE

EMG activity was generally lower under the external compared to the internal focus condition (see Fig. 2). The main effect of attentional focus was significant,  $F(1, 7) = 5.76$ ,  $p < .05$ ,  $\eta^2 = .49$ . Also, not surprisingly, the various muscles differed in the extent of muscular activity. In particular, VL produced the greatest amount of EMG activity. Also, because of its early onset (see below), AT had a relatively large RMSE. The Muscle main effect was significant,  $F(4, 28) = 2.76$ ,  $p < .05$ ,  $\eta^2 = .28$ . Post-hoc tests (LSD) showed that VL had significantly larger RMSE than BF, RF, and LG, but did not differ from AT. None of the other differences were significant. There was no interaction of focus and muscle,  $F(4, 28) = 1.19$ ,  $p = .34$ ,  $\eta^2 = .15$ .

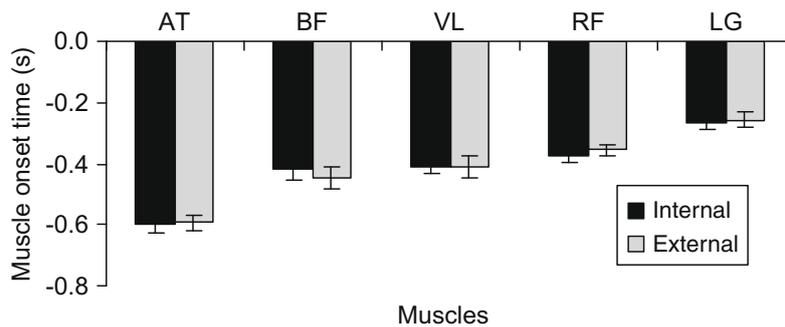
Fig. 3 shows, for one representative participant, the EMG activity of the various muscles as a function of time before take-off (0 s). This participant, who jumped higher under the external (35.9 cm) than the internal focus condition (32.5 cm), showed generally lower EMG activity with an external focus. Yet, there did not appear to be a difference in the timing of muscle activation between focus conditions.

### 3.3. Muscle onset times

As can be seen from Fig. 4, muscle onset times were generally similar for the internal and external focus conditions (see Fig. 4). The main effect of attentional focus was not significant,  $F(1, 7) = .055$ ,  $p = .822$ ,  $\eta^2 = .01$ . AT was activated about 0.60 s before takeoff, followed by BF (0.43 s) and VL (0.41 s), then RF (0.36), and finally LG (0.26 s). The main effect of muscle was significant,  $F(4, 28) = 39.73$ ,  $p < .001$ ,  $\eta^2 = .85$ . Post-hoc tests AT and LG differed from each other and all other muscles



**Fig. 3.** Jump height and EMG activity, averaged across 10 trials in each of the internal and external focus conditions, for one representative participant from muscle onset to takeoff (AT = m. tibialis anterior; BF = m. biceps femoris; VL = m. vastus lateralis; RF = m. rectus femoris; LG = lateral m. gastrocnemius).



**Fig. 4.** Muscle onset times before takeoff for the various muscles as a function of internal versus external focus (AT = m. tibialis anterior; BF = m. biceps femoris; VL = m. vastus lateralis; RF = m. rectus femoris; LG = lateral m. gastrocnemius).

in their onset times ( $p < .005$ ; significant after Bonferroni adjustment for multiple comparisons). The interaction of attentional focus and muscle was not significant,  $F(4, 28) = 1.50, p = .229, \eta^2 = .18$ .

#### 4. Discussion

Numerous previous studies, using movement outcome measures, have provided indirect evidence for enhanced movement coordination when performers adopt an external rather than an internal focus of attention (see Wulf, 2007a, 2007b). Those measures included, for example, movement accuracy (e.g., Wulf & Su, 2007), speed (e.g., Totsika & Wulf, 2003), deviations of a balance platform from the horizontal (e.g., Wulf et al., 1998), or maximum force production (e.g., Marchant et al., 2006). Our goal in the present study was to examine more directly how movements might be controlled differently as a function of the performer's attentional focus. We used the vertical jump-and-reach task for which previous studies have demonstrated increases in jump height, vertical COM displacement, impulse, and joint moments with an external focus (Wulf & Dufek, 2009; Wulf et al., 2007). Consistent with those previous results, we again found greater jump heights in the external relative to the internal focus condition. Our main interest in the present study, however, was to examine possible differences

between attentional foci in the amount of muscular activity within muscles (i.e., EMG RMSE) and the coordination pattern among different muscles (i.e., muscle onset).

Both aspects, intra-muscular and inter-muscular coordination (Hollmann & Hettinger, 2000), need to be optimized in tasks that require the generation of maximum forces, such as jumping as high as possible. For one, the timing of the contributing forces needs to occur in an optimal sequence. The lower extremity muscle sequencing for participants in the present study followed a general proximal-to-distal sequence of activation (i.e., hip, knee, ankle sequencing), reported as biomechanically efficient (Putnam, 1993). Independent of whether or not muscle onset was indeed optimal, there were no differences between focus conditions in the onset of the various muscles. That is, all muscles were activated at similar times before take-off in the external and internal focus conditions. Thus, there was no evidence that differences in jump height were due to differences in the coordination among muscle groups. This finding may not be too surprising, considering that most young active adults presumably have this skill in their repertoire. Thus, substantial changes in the technique as a function of attentional focus would probably not be expected.

Yet, there were significant differences in the amount of muscular activity between focus conditions. When participants were instructed to focus on the rungs (external focus) instead of their fingers (internal focus), EMG activity was generally lower. Interestingly, jump height was significantly increased at the same time. Findings showing reduced EMG activity, combined with more effective outcomes, as a result of an external focus (see also Lohse, Sherwood, & Healy, 2009; Marchant et al., 2006) provide converging evidence that the coordination within muscles is optimized by the external focus. Enhanced movement effectiveness and efficiency are typically associated with higher levels of expertise, or a more advanced stage of learning, but it has been suggested that giving learners external focus instructions speeds the learning process so that a more advanced level of performance is achieved sooner (Wulf, 2007b). The present findings corroborate this view.

How can the learning process be expedited by the adoption of a specific attentional focus? We believe that an (external) focus on the desired outcome results in neuromuscular activation patterns that are similar to those seen in more experienced performers (who presumably tend to adopt an external focus, instead of focusing internally (see Wulf, 2008)). It is well known that strength gains occur, as a function of practice or experience, in early weight training that cannot be explained by hypertrophy (e.g., Conley et al., 1997; Häkkinen & Komi, 1983; Moritani & deVries, 1979; Ploutz et al., 1994). There are also reports of decreased EMG activity associated with lifting the same load after training (Häkkinen, Alén, & Komi, 1985; Moritani & deVries, 1979), suggesting that movement production may become more efficient with practice. Furthermore, greater force production and increased jump heights as a function of expertise have been reported that could not be explained by differences in age, height, weight, or technique (Vanezis & Lees, 2005). It is generally believed that changes in neural adaptations are the underlying cause of these phenomena. Motor units are generally assumed to be recruited according to the size principle (Henneman, Somjen, & Carpenter, 1965a, 1965b), according to which faster motor units are recruited after slower (and more fatigue-resistant) motor units and are also the first to be deactivated. However, for a high intensity task such as jumping, faster (and faster fatiguing) motor units are recruited earlier to produce the high forces needed for a short period of time. Also, various other factors such as task demands, auditory or visual feedback, and afferent influences from the spinal and brain levels have been shown to influence recruitment patterns. According to a recent review by Hodson-Tole and Wakeling (2009), the complex interactions between factors influencing motor unit recruitment are currently not well understood. In any event, it appears that the performer's attentional focus needs to be added to the list of factors influencing neuromuscular activation patterns.

Studies using magnetic resonance imaging (MRI) have also demonstrated increased efficiency in muscle recruitment as a function of practice (e.g., Conley et al., 1997; Green & Wilson, 2000; Ploutz et al., 1994). Ploutz and colleagues (1994) showed that short-term resistance training resulted in less muscle area being used to lift the same weight. This was seen in both trained and contralateral untrained muscles (quadriceps femoris), suggesting that alterations in neuromuscular activation were responsible for this effect. Similarly, Conley et al. (1997) found a de-recruitment of previously utilized muscles for a given load after resistance training. Interestingly, recent brain imaging studies have shown what appear to be corresponding effects. Several studies have examined differences in brain

activation as skills become more automatic through practice (e.g., Poldrack et al., 2005; Wu, Chan, & Hallett, 2008; Wu, Kansaku, & Hallett, 2004). Even though the physiology of automaticity is not yet well understood, these studies have demonstrated that, when individuals practice a motor task (e.g., pressing a series of keys), brain activation is reduced after a certain practice period. That is, when performers become more skilled, brain activity is seen in the same brain regions (e.g., cerebellum, pre-motor area, parietal cortex, prefrontal cortex) as in early practice, but to a lesser extent (Wu et al., 2004, 2008). Moreover, the interaction of central motor networks is strengthened with practice. “With automaticity, brain regions become less active, but some of them increase their effective connectivity. More efficient connectivity may indicate an increased efficacy of connections, which presumably allows the brain to function more efficiently in a given task, even with a reduced level of activation” (Wu et al., 2008, p. 4302).

Thus, there is consistent evidence – from studies using a variety of paradigms and methods – that, when skill execution becomes automatized through practice, movement outcome (e.g., weight lifted) is enhanced, and at the same time movements are produced more efficiently (e.g., with less neuromuscular activity). In several ways, these findings parallel those seen when performers are instructed to adopt an external focus of attention. Along with demonstrations of greater automaticity (e.g., McNevin et al., 2003; Wulf et al., 2001), an external focus has reliably been shown to result in more effective outcomes and increased movement efficiency (for reviews, see Wulf, 2007a, 2007b). The present results show that performance of a whole-body, maximum-effort motor skill can be enhanced in both respects (i.e., effectiveness and efficiency) by a simple change in the individual's focus of attention – paralleling what is typically seen in more advanced performers. It would be interesting to see whether external and internal foci have effects on the effective connectivity between various brain areas, for example, similar to the changes observed across practice (Wu et al., 2008). Some recent MRI studies have already shown that external and internal foci have different neural correlates (e.g., greater activation of the medial [external focus] versus lateral [internal focus] rostral prefrontal cortex) with concomitant differential effects on motor performance (Wenkeler et al., 2009; see also Zentgraf et al., 2009).

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