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Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention

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Abstract

The performance and learning of motor skills has been shown to be enhanced if the performer adopts an external focus of attention (focus on the movement effect) compared to an internal focus (focus on the movements themselves) [G. Wulf, W. Prinz, Directing attention to movement effects enhances learning: a review, Psychon. Bull. Rev. 8 (2001) 648–660]. While most previous studies examining attentional focus effects have exclusively used performance outcome (e.g., accuracy) measures, in the present study electromyography (EMG) was used to determine neuromuscular correlates of external versus internal focus differences in movement outcome. Participants performed basketball free throws under both internal focus (wrist motion) and external focus (basket) conditions. EMG activity was recorded for m. flexor carpi radialis, m. biceps brachii, m. triceps triceps brachii, and m. deltoid of each participant's shooting arm. The results showed that free throw accuracy was greater when participants adopted an external compared to an internal focus. In addition, EMG activity of the biceps and triceps muscles was lower with an external relative to an internal focus. This suggests that an external focus of attention enhances movement economy, and presumably reduces "noise" in the motor system that hampers fine movement control and makes the outcome of the movement less reliable.

Keywords: Focus of attention; Electromyography; Basketball; Free throw

In the past few years, a number of studies have shown that an individual's focus of attention can have an important influence on motor performance and learning [25]. Specifically, focusing on one's body movements, that is, adopting a so-called *internal* focus, during the execution of a motor skill has been found to be relatively ineffective. In contrast, focusing on the effects that one's movements have on the environment (e.g., an apparatus or implement), or adopting an *external* focus, has been demonstrated to result in more effective performance and learning [3,8,9,12,18,27,29]. For example, wording the instructions given to learners in a way that they direct attention to the movement effect, rather than to their movements, has been found to enhance the accuracy of golf shots [19], volleyball serves [20], soccer kicks [20,28], and basketball free throws [1]. In addition, numerous studies have shown enhanced balance performance when individuals adopt an external focus, e.g., [6,8,9,12,18]. Interestingly, in studies that included control conditions without attentional focus instructions [6,18,21,29], external focus instructions resulted in more effective learning than both internal focus and no instructions, with no difference between the latter two. This suggests that an external focus of attention *enhances* learning (rather than an internal focus degrading learning).

Wulf et al. [8,23,27] proposed a constrained action hypothesis to explain these attentional focus effects. According to this view, individuals consciously try to control their movements when they are asked to adopt an internal focus (and perhaps also when they are not given attentional focus instructions). As a consequence, they tend to constrain their motor system and inadvertently disrupt automatic control processes. In contrast, focusing on the movement effect, or adopting an external focus, allows unconscious or automatic processes to control their movements—resulting in

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more effective performance and learning. Support for this notion comes from a variety of studies. For instance, in the study by Wulf et al. [23], probe reaction times (RTs) were measured to assess the attentional demands of balancing on a stabilometer under internal (feet) or external focus (markers on the balance platform) conditions. External focus participants demonstrated shorter probe RTs than internal focus participants—indicating reduced attentional demands and a greater degree of automaticity under the external focus conditions. In addition, the frequency characteristics (mean power frequency) of the platform movements showed higher-frequency adjustments for external than for internal focus participants (see also refs. [8,27]). A high frequency of movement adjustments is viewed as an indication of a more automatic, reflex-type mode of control that is based on faster and more finely tuned integrated movement responses [14]. Finally, a recent study by Vance et al. [16], using electromyography (EMG), demonstrated reduced EMG activity when participants adopted an external relative to an internal focus. Specifically, participants performing biceps curls were either instructed to focus on the curl bar (external focus) or on their biceps muscles (internal focus). Under the external focus condition, integrated EMG activity was significantly reduced compared to the internal focus condition. This suggests that the adoption of an external focus not only results in movements that are controlled more automatically, but also in movement patterns that are more efficient or economical.

Most studies examining attentional focus effects have used performance "outcome" measures [7,11], such as movement amplitude (on a ski-simulator) [18], movement accuracy [19,20], or postural sway [9,24]. Yet, performance "production" measures, such as EMG, have the advantage that they provide insight into how motor control is organized by the nervous system when individuals adopt different attentional foci. The Vance et al. study [16] was the first to demonstrate external–internal focus differences in EMG activity. However, one might ask whether more efficient muscle activation patterns (e.g., more discriminate motor unit recruitment) can explain attentional focus differences in movement accuracy, for example [1,19,20,29]. The biceps curl task used in the Vance et al. study with a given weight and a prescribed movement amplitude and frequency did not have an "outcome", which would allow performance to be described as more or less effective. The purpose of the present study was, therefore, to examine whether external–internal focus differences in EMG activity would also be found in tasks that have a clear goal and measurable outcome, such as movement accuracy relative to the goal. If EMG differences were found for those tasks as well, this might shed more light on the mechanisms responsible for external relative to internal focus advantages in movement outcome. For example, greater EMG activity under internal focus conditions might add "noise" to the motor system that could act to constrain the system and hamper movement effectiveness (e.g., degrade movement accuracy). Furthermore, it would be interesting to see whether this increased EMG activity, if any, would also be observed in muscle groups that the performer does not directly focus on. In the Vance et al. study, participants in the internal focus condition were instructed to focus on their biceps muscles, which were also the main agonists for that task. If EMG differences were found for muscle groups that are not directly in performer's focus of attention, it would strengthen the view that interference, or noise, in the motor system could be responsible for external–internal focus differences in movement effectiveness.

The present study examined these issues. In a within-subject design, participants were required to perform basketball free throws while focusing either on their wrist motion (internal focus) or the basket (external focus). EMG activity was recorded for various muscle groups of the shooting arm (m. deltoid, m. biceps brachii, m. triceps brachii, m. flexor carpi radialis). If a greater throwing accuracy under the external relative to the internal focus condition, if any, were accompanied by decreased EMG activity, this would provide more direct evidence for the view that performance benefits of an external focus are due to the utilization of more effective and efficient motor control processes.

1. Method

1.1. Participants

Participants were 14 university students (6 females and 8 males; mean age: 26.2 years; mean height: 1.77 m). All participants had at least 1 year of basketball experience at the physical education class and/or high school team level. Informed consent was obtained prior to participation in compliance with the University's Institutional Review Board.

1.2. Apparatus, task, and procedure

Even though participants had basketball-related experience, instructions regarding the correct free throw technique [4,13] were given before data collection began (see Table 1). Participants were also instructed to "get set" in a still position, ready to shoot (i.e., knees and waist bent, hands in position), with the ball held at about waist level. Data collection was then initiated, and the participant was told to "go". The first movement on video after the "go" signal was considered onset of movement and was used as the starting point for movement analysis. All trials were completed with an official women's basketball, which was deflated (for the purposes of protecting laboratory equipment). Shots were taken on a portable basketball hoop set (Lifetime Products Inc., Clearfield, UT) to a regulation height of 10 ft and from a distance of 15 ft. Before the beginning of data collection, participants were allowed to practice until they were comfortable with the equipment and technique.

Participants then performed the free throw task under both internal and external focus conditions. They were informed that they would have to perform two sets of 10 trials under

Table 1
General free throw instructions given to participants

Stance	
(1)	Square yourself to the basket—your shoulders and torso face the basket.
(2)	Place your feet about shoulder-width apart.
(3)	Bend the knees and waist slightly.
Grip	
(4)	Place your shooting hand (dominant) behind the ball, fingers spread almost to maximum.
(5)	Use the other (non-dominant) hand to stabilize the ball from the side.
(6)	The ball should rest on the pads of the fingers and hand, not the palm.
Shot	
(7)	Get set by ensuring the knees and waist are slightly bent.
(8)	Shoot the ball by releasing the guide hand (non-dominant) and extending the knees and arms together.
(9)	Follow through with the shot by fully extending the elbow and letting the ball roll off the fingers—the wrist should snap toward the basket and the hand should hang when complete.

each condition. For the internal focus condition, participants were instructed to concentrate on the "snapping" motion of their wrist during the follow-through of the free throw shot. For the external focus condition, they were instructed to concentrate on the center of the rear of the basketball hoop. Reminders regarding the focus of attention (internal or external) were given after every trial for the first three trials of each condition, and after every other trial after that. Also, before the start of each condition, participants were informed (reminded) that accuracy of their shots would be scored within a range of 1–5 points, with 5 being awarded for a made shot.

Electromyographic (EMG) data were recorded using Noraxon™ MyoResearch 2 software and sampled at a frequency of 1080 Hz. EMG data were captured using a Noraxon™ MyoSystem 2000 unit. Participants were fitted with Blue Sensor™ brand juvenile EMG electrodes (model N-00-S). EMG electrodes were placed on the surface of the skin in pairs directly over the medial biceps brachii, the long head of the medial triceps brachii, the medial deltoid, and the medial flexor carpi radialis of each participant's shooting (preferred) arm [2]. The distance between electrodes in each pair was 3 cm. A ninth electrode was mounted to the opposite (non-preferred) acromion process to serve as an "electrical common" for data recording. An elastic bandage was wrapped around the EMG electrodes to secure the devices from extraneous movement while not impeding muscular function or movement about the shoulder and elbow joints.

Movements were also captured with a Panasonic video recorder, and recorded with Vicon™ Motion Analysis system software (Version 4.6, Oxford Metrics, Oxford, UK) at 30 Hz for purposes of determining onset of movement and ball release. The camera was positioned to the participant's right side, perpendicular to the sagittal plane such that the movement was fully visible throughout the entire shot. Vicon™ Motion Analysis system software and Noraxon MyoResearch 2 software were synchronized using a low-voltage square wave connected to both systems, which allowed frames to be synchronized based on the onset of the firing of the square wave.

All participants performed two sets of 10 trials of the free throw task under each of the two attentional focus conditions, resulting in a total of 40 trials. The order of attentional focus conditions was counterbalanced between participants. They were given rest periods of at least 30 s between each shot and at least 1 min between each set. Scores were awarded for the accuracy of the free throws [26]. Specifically, 5 points were awarded if the ball went through the hoop, 3 points for the ball touching the hoop, 2 points for the ball touching the board and the hoop, and 1 point for the ball touching the board. A missed shot was given a score of 0.

1.3. Data analysis

Raw biceps and triceps EMG data were removed of dc-bias and full-waved rectified using custom laboratory software (MatLab Version 6.5, The MathWorks Inc.). From these data, the root-mean-square (RMS) of the EMG signal was calculated [10] for the period between onset of movement and ball release plus three video frames (30 Hz). This amounted to 108 frames of EMG data and was done in order to incorporate the follow-through of the free throw. Movement accuracy was analyzed in a paired *t*-test, as numerous previous studies have shown external compared to internal focus benefits for outcome measures. EMG activity (RMS) for each muscle group was analyzed for the first and last trial of each 10-trial block under each attentional focus condition, resulting in a 2(focus of attention: internal versus external) × 2(block) × 2(trial) analyses of variance (ANOVA) with repeated measures on all factors.

2. Results

2.1. Free throw accuracy

When participants were instructed to adopt an external focus their accuracy was higher compared to when they adopted an internal focus (see Fig. 1). The average accuracy score was 2.56 for the external focus condition and 2.09 for the internal focus condition. A paired *t*-test revealed that this difference was significant, $t(13) = 1.78$, $p < .05$, confirming the external focus benefits in terms of movement outcome found in several previous studies [25].

2.2. EMG

2.2.1. Flexor carpi radialis

Average EMG activity for flexor carpi radialis (see Fig. 2, left) did not differ significantly between the external and internal focus conditions, $F(1, 13) = 1.16$, $p > .05$. Also, there were

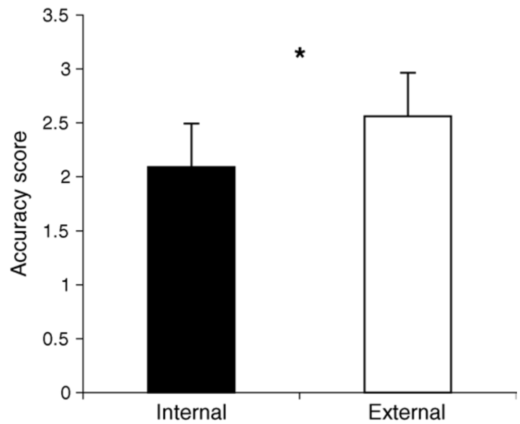

Fig. 1. Average free throw accuracy scores of the internal and external focus groups.

no main effects of block or trial, Fs (1, 13) < 1, or any interaction effects.

2.2.2. Biceps brachii

For biceps, EMG activity was clearly lower under the external relative to the internal focus condition (see Fig. 2, second from left). This was confirmed by a significant main effect of attentional focus, F (1, 13) = 4.94, $p < .05$. The main effects of block and trial were not significant, Fs < 1. Also, there were no significant interactions.

2.2.3. Triceps brachii

Similar to biceps, there was significantly less EMG activity for triceps when participants adopted an external compared to an internal focus (see Fig. 2, second from right), F (1, 13) = 5.92, $p < .05$. There were no significant main effects of block, F (1, 13) = 1.28, $p > .05$, or trial, F (1, 13) = 1.21, $p > .05$. Furthermore, none of the interaction effects were significant.

2.2.4. Deltoid

For deltoid activity, there was no significant difference between the external and internal focus condition (see Fig. 2, right), F (1, 13) < 1. Also, there were no significant effects of block, F (1, 13) = 2.00, $p > .05$, or trial, F (1, 13) = 2.76, $p > .05$, or any interaction effects.

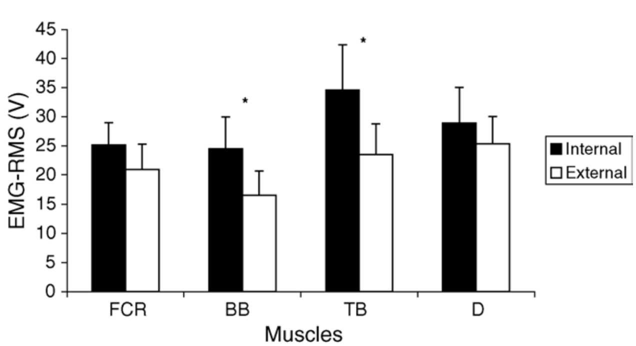

Fig. 2. EMG root mean square errors (RMSE) of the internal and external focus groups for the four muscle groups (FCR = flexor carpi radialis, BB = biceps brachii, TB = triceps brachii, D = deltoid).

3. Discussion

While there is considerable evidence that focusing on the movement effect (i.e., adopting an external focus of attention) is more effective for motor performance and learning than focusing on one's movements (i.e., adopting an internal focus), this evidence comes almost exclusively from studies using performance outcome measures [25]. The only study that examined external versus internal focus differences at a neurophysiological level was the study by Vance et al. [16]. Yet, the task used by Vance and colleagues (biceps curls) had no measurable movement outcome in terms of movement accuracy. Thus, the degree of goal achievement as a function of attentional focus could not be determined. In addition, under the internal focus condition, participants' attention was directed to the muscle group (m. biceps) that was the main agonist for that task. The present study followed up on the Vance et al. study and sought to extend those findings. In contrast to Vance et al., we used a task that had a clearly defined goal, so that external focus advantages in movement outcome could (hopefully) be replicated. In addition, we measured EMG activity in various muscle groups, including ones that participants were not specifically instructed to focus on.

The present results confirm and extend previous findings. First, the greater movement accuracy (i.e., higher scores) in free throw shooting seen under the external relative to the internal focus condition is in line with previous studies showing external focus advantages in movement outcome [15,18–21]; for a review, see ref. [25]. Many of those previous studies used learning designs, where different groups of participants practiced a task under either internal or external focus conditions (or control conditions), and where learning was assessed in retention or transfer tests. In contrast, the present study used a within-participant design, in which all participants performed under both internal and external focus conditions; see also refs. [9,16,24]. The fact that attentional focus effects occur not only in learning studies, but even when within-participant designs are used (and despite the fact that participants had task-related experience), suggests that the type of focus has relatively strong and immediate effect on performance.

Importantly, the greater movement accuracy seen under the external focus condition was accompanied by reduced EMG activity in the shooting arm, compared to the internal focus condition. Even though there was no significant attentional focus difference in EMG activity for flexor carpi radialis or deltoid, biceps and triceps activities were significantly lower when participants focused externally. As participants were instructed to focus their attention on the flexion of their wrist under the internal focus condition, one might have expected to see greater EMG differences between focus conditions for flexor carpi radialis, the muscle responsible for wrist flexion. It is possible, however, that, because the wrist action is an important component of the free throw technique, EMG activity was generally relatively high for this muscle, and that differences between conditions were attenuated by a ceiling effect. Interestingly, though, EMG activity was clearly lower for biceps and triceps under the external compared to the internal focus condition. This reduced EMG activity when participants adopted an external focus might be viewed as reflecting a greater economy in movement production. Adopting an internal focus (wrist motion), on the other hand, presumably acted to constrain the motor system and led to a "freezing" of the neuromuscular degrees of freedom [17,23].

It should also be pointed out that the biceps counteracts the triceps during the shooting motion, and therefore biceps activity should be low to facilitate the effectiveness and efficiency of triceps activity. The fact that this was achieved to a greater extent with an external focus suggests that movement economy was enhanced, at least in part, through a more effective coordination between agonist and antagonist muscle groups. This finding is similar to the results of Vance et al. [16], who also found greater EMG activity in both biceps and triceps muscles with an internal compared to an external focus.

In addition to replicating that aspect of the Vance et al. results, the present findings extend their findings in two ways. First, in the present study, attentional focus differences in EMG occurred in muscle groups that participants were not specifically instructed to focus on. This suggests that the effects of attentional focus on the motor system are rather general in nature, in that they "spread" to muscle groups that are not in the performer's focus of attention. This is reminiscent of findings showing that the type of attentional focus on a "supra-postural" task affects postural control. For example, if the supra-postural task requires an individual to hold an object still, focusing on the object (external focus) has been shown to result in greater postural stability, that is, reduced postural sway, than focusing on one's hands (internal focus) [9,24,29]. The commonality between those findings and the ones of the present study seems to be that the focus on a certain part of the body (e.g., hand) not only has an influence on the control of its movement, but on the control of other parts of the motor system as well. In other words, an internal focus appears to constrain not only the action of the body part that the individual focuses on, but also the action of other parts, and perhaps even the whole motor system.

The results of the present study also extend those of Vance et al. [16] in another way: They show that the reduced EMG activity observed under the external focus condition was accompanied by greater movement accuracy (i.e., free throw accuracy), compared to the internal focus condition. Presumably, the increased noise in the motor system (i.e., increased EMG activity) that resulted from the internal focus hampered fine movement control and made the outcome less reliable. This might also explain the findings of other studies showing external relative to internal focus advantages, for example, in the accuracy of golf shots [19], volleyball serves [20], or soccer kicks [20,28]. The present results, together with those of Vance et al. [16], suggest that focusing one's attention on the movement effect (external focus), rather than on the movements required to achieve this effect (internal focus), results in an effective and efficient movement pattern. As a consequence, movement accuracy is enhanced.

Overall, the findings of the present study add another important piece to the mosaic of how an external focus of attention functions to enhance motor performance and learning. They demonstrate that, when individuals adopt an external focus, reduced neuromuscular activity is associated with increased movement accuracy. The reduced EMG activity, and presumably more discriminate motor unit recruitment, might explain the increase in movement accuracy seen in the present study. In fact, it might also have contributed to the greater movement speed [15] and movement amplitude [18] observed in previous studies. More efficient motor unit recruitment patterns could also be advantageous for tasks that require maximum force production (e.g., discus throwing, shot put, high jump) or endurance (running, swimming, cross-country skiing). Both would benefit from an effective recruitment of muscle fibers within a muscle (intra-muscular coordination) [5] and enhanced coordination between muscles (inter-muscular coordination) [5], such that the appropriate (e.g., maximum) forces are generated at the appropriate time and in the right direction. In addition, activities requiring endurance should benefit from relatively low neuromuscular activity for a given output, so that energy is preserved or a given activity level maintained for a longer period of time. Further studies will be needed to examine these issues. At any rate, the effects of attentional focus on motor performance not only provide interesting insights into the effectiveness of automatic control capabilities of the motor system, but they also have important implications for performance improvements in applied settings.

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