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EMG Activity as a Function of the Performer's Focus of Attention

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ABSTRACT. In previous studies of attentional focus effects, investigators have measured performance outcome. Here, however, the authors used electromyography (EMG) to determine whether differences between external and internal foci would also be manifested at the neuromuscular level. In 2 experiments, participants ($N = 11$, Experiment 1; $N = 12$, Experiment 2) performed biceps curls while focusing on the movements of the curl bar (external focus) or on their arms (internal focus). In Experiment 1, movements were performed faster under external than under internal focus conditions. Also, integrated EMG (iEMG) activity was reduced when performers adopted an external focus. In Experiment 2, movement time was controlled through the use of a metronome, and iEMG activity was again reduced under external focus conditions. Those findings are in line with the *constrained action hypothesis* (G. Wulf, N. McNevin, & C. H. Shea, 2001), according to which an external focus promotes the use of more automatic control processes.

Key words: attentional focus, biceps curls, electromyography (EMG), motor control

The performer's focus of attention has been shown to play an important role in the performance and learning of motor skills (e.g., Singer, 1985, 1988; Singer, Lidor, & Cauraugh, 1993; Wulf & Prinz, 2001). Specifically, focusing on one's body movements (i.e., adopting an internal focus) during the execution of a motor skill has been found to be relatively ineffective. In contrast, giving instructions or feedback that directs the performers' attention to the effects that their movements have on the environment, for example, the apparatus or implement (i.e., adopting an external focus), has been found to result in more effective learning than does inducing an internal focus or giving no specific focus instructions (e.g., Shea & Wulf, 1999; Wulf, Höß, & Prinz, 1998; Wulf, McConnel, Gärtner, & Schwarz, 2002; Wulf, Shea & Park, 2001; Wulf, Weigelt, Poulter, & McNevin, 2003; for a review, see Wulf & Prinz). In the first study that demonstrated the comparative advantages of external over internal focus, Wulf et al. (1998, Experiment 1) used a ski-simulator task and found that instructing performers when to exert force on the wheels of the platform on which they were standing (which were located directly under the performers' feet) was more beneficial for learning (i.e., retention) than was instructing the performers to focus on when to exert force with their feet or providing no instructions. Furthermore, in learning to balance on a stabilometer, directing participants' attention to markers attached to the stabilometer platform in front of their feet facilitated learning as compared with directing their attention to the feet themselves (e.g., Wulf et al., 1998, Experiment 2; Wulf, McNevin, & Shea, 2001). In recent studies, performance and learning advantages of directing attention to the movement effect have also been demonstrated for sport skills such as golf (Wulf, Lauterbach, & Toole, 1999), tennis (Wulf, McNevin, Fuchs, Ritter, & Toole, 2000), volleyball, and soccer (Wulf, et al., 2000; Wulf, Wächter, & Wortmann, 2003). Most interesting, in studies that included control conditions without attentional focus instructions (Landers, Wulf, Wallmann, & Guadagnoli, 2003; Wulf et al., 1998; Wulf & McNevin, 2003; Wulf, Weigelt, et al., 2003), external focus instructions resulted in more effective learning than did both internal focus instructions and no instructions. That is, an external focus seems to enhance learning.

Wulf and colleagues have invoked the *constrained action hypothesis* to explain the comparative benefits of adopting an external rather than an internal focus of attention

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(McNevin, Shea, & Wulf, 2003; Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001). According to that view, when individuals are asked to adopt an internal focus (and perhaps also when they are not given any attentional focus instructions), they try to consciously control their movements—which constrains the motor system and inadvertently disrupts automatic control processes. In contrast, focusing on the movement effect, or adopting an external focus, allows unconscious or automatic processes to control the movement—resulting in more effective performance (and learning). Support for the notion that the adoption of an external focus promotes the use of more automatic motor control processes comes from a recent study by Wulf, McNevin, and Shea (2001). They measured probe reaction times (RTs) to assess the attentional demands of balancing on a stabilometer under internal (feet) or external (markers) focus conditions. External focus participants demonstrated shorter probe RTs, indicating reduced attentional demands under that condition than under internal focus conditions. In addition, the frequency characteristics (mean power frequency [MPF]) of the platform movements showed higher frequency adjustments for external than for internal focus participants (see also McNevin, Shea, & Wulf; Wulf, Shea, & Park). 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 (Thompson & Stewart, 1986). That is, a higher frequency of responding is seen as an indication of an effective increase in and integration of the active degrees of freedom associated with performing a motor task and greater confluence between reflexive and voluntary control mechanisms (for a discussion, see Newell & Slifkin, 1996). Consciously intervening in those control processes by adopting an internal focus seems to result in a "freezing" or constraining of the degrees of freedom (Vereijken, van Emmerik, Whiting, & Newell, 1992) and in a less automatic movement execution.

To assess performance and learning in previous studies of the effects of internal versus external foci of attention, investigators have exclusively used outcome measures (Magill, 2001; Schmidt & Lee, 1999) such as movement amplitudes on a ski-simulator (Wulf et al., 1998, Experiment 1), deviations of the stabilometer platform from the horizontal (e.g., McNevin, Shea, & Wulf, 2003; Shea & Wulf, 1999; Wulf et al., 1998, Experiment 1; Wulf et al., 2001), movement accuracy in hitting golf balls (Wulf et al., 1999), serving volleyballs, or passing soccer balls (Wulf et al., 2000), as well as the speed of riding a Pedalo (Totsika & Wulf, 2003). Also, inferences about differences in the motor control processes associated with different attentional foci have been based on outcome measures, such as probe RT and the MPF of balance movements (e.g., McNevin & Wulf, 2002; Wulf, Mercer, McNevin, & Guadagnoli, 2004; e.g., Wulf, McNevin, & Shea, 2001).

In the present study, we therefore wanted to examine whether performance differences between external and internal focus conditions would also be observed at a neuromuscular level, because that information may provide more direct evidence for the constrained action hypothesis. Specifically, we used electromyography (EMG) to measure the differences in electrical activity associated with muscle contractions under internal and external focus conditions. Performance production measures (Magill, 2001) such as EMG may provide more insight into how the nervous system operates to produce attentional focus effects. If, as proposed by the constrained action hypothesis, an external focus results in a more automatic type of control than an internal focus does, one may expect to see differences between EMG activity in external and internal focus conditions. Specifically, under the assumption that "automaticity" imparts greater economy in movement production, we might expect to see more discriminate motor unit recruitment under external than under internal focus conditions. That prediction is based on the rationale that an external focus promotes greater coherence between sensory input and motor output (McNevin & Wulf, 2002). The greater sensorimotor coherence allows the motor system to adjust adaptively to the sensory consequences of the intended outcome. Because the motor output would presumably be more specific to the task demands, only the minimally necessary number of motor units required to produce a desired outcome would be recruited. Thus, one might expect fewer motor units to be recruited under external than under internal focus conditions for the same task requirements.

Participants in the present study performed biceps curls under both internal and external focus conditions (within-participant design). That is, we examined the immediate effects of the type of attentional focus on performance rather than its effects on learning. We used biceps curls because the EMG activity of agonist and antagonist muscles groups could be measured relatively easily, and the degrees of freedom—and therefore the potential variability between (and within) participants—were relatively limited. Under internal focus conditions, participants were instructed to concentrate on their arms, whereas under external focus conditions they were instructed to focus on the curl bar. EMG activities of the biceps and triceps brachii muscles during the curls were measured. If movements are indeed controlled more automatically under external than under internal focus conditions, one might expect to see less EMG activity under external focus conditions. However, the type of attentional focus may also have an influence on movement time. One possible outcome was that participants would show greater average EMG activity under internal than under external focus conditions, with movement times per repetition being similar. However, with no time restrictions and with participants being allowed to perform the repetitions at their own pace, another possibility was that movements would generally be performed faster under external than under internal focus conditions but that average EMG activity would be similar. To examine those possibilities, we did not restrict movement time in Experiment

1, but we constrained movement time through the use of a metronome in Experiment 2.

EXPERIMENT 1

In this experiment, participants performed biceps curls while focusing either on their arms (internal focus) or the curl bar (external focus). If movement control is more automatic when the performer adopts an external focus—with movements being more fluid and less affected by conscious control attempts—then one might expect to see a more rapid movement execution under that condition. Therefore, we analyzed angular velocity, average EMG activity, as well as integrated EMG (iEMG) activity, which reflects the combined influence of the temporal (movement time) and spatial (EMG amplitude) characteristics of muscle activity.

Finally, we conducted fast Fourier transform (FFT) analyses on the raw EMG data. From that analysis, we computed MPF. The MPF measure enabled us to detect subtle differences in motor unit recruitment patterns under the various experimental conditions. In particular, we were interested in differences that may occur between attentional focus conditions but also across repetitions or sets. (Two sets of 10 repetitions were performed under each attentional focus condition.) In previous studies (e.g., McNevin, Shea, & Wulf, 2003; Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001) in which MPF was determined for the frequency adjustments of the balance platform, external focus participants showed more and faster adjustments (i.e., they had higher MPF values) compared with those of internal focus participants. That finding was interpreted as an indication of the use of a more automatic mode of control under external focus conditions. In the present study, we wanted to examine whether attentional focus differences, if any, would also manifest themselves in the MPF of EMG activity. Because motor units are recruited on an incremental basis, with successively larger motor units recruited in a graded fashion, one may be able to detect differences in the pattern of motor unit recruitment as a function of the frequency characteristics of a given EMG signal (e.g., Olson, Carpenter, & Henneman, 1968). That is, because the amount of tension produced by the recruited motor units is a function of the summated firing rates of the motor units recruited, a higher frequency content in the EMG signal would reflect the recruitment of more motor units. Assuming a greater economy in the motor unit recruitment pattern under external focus conditions—with fewer (and therefore smaller) motor units being recruited to produce the desired motor output—one might expect to see a lower frequency output (MPF) under external than under internal focus conditions across all or at least some of the repetitions.

Method

Participants

Participants were 11 male university students (age = 26 ± 6 years, mass = 86 ± 17 kg, and height = 177 ± 10 cm) who were currently participating in university elective weight-training courses, personal weight-training activities, or both. Informed consent was obtained before participation, in compliance with the university's Institutional Review Board.

Apparatus, Task, and Procedure

Participants performed biceps curls with a bar that was weighted with a mass equivalent to the estimated 50% bilateral maximal force. To enable us to determine that force, participants underwent a strength assessment. For that purpose, we asked them to complete three 5-s maximal-effort isometric contractions of the right elbow-flexor muscles, with the elbow positioned to 90° of flexion, using an isokinetic dynamometer (KinCom; Chattanooga, TN). We averaged the peak forces produced during the unilateral isometric contraction to estimate each participant's 50% bilateral maximal force production. Participants were instructed to perform the curl task while standing upright with their back against a wall. Our reasoning for requiring that position (and for instructions given to them) was that we wanted to relatively immobilize their brachia so that the activity was performed at the elbow and not the shoulder.

Participants performed the curl task under both internal and external focus of attention conditions. They were informed that they would have to perform two sets of 10 repetitions under each condition. We made no mention regarding the speed of execution. For the internal focus condition, participants were instructed to concentrate on their biceps muscles; for the external focus condition, they were instructed to concentrate on the curl bar. Reminders regarding the focus of attention (internal or external) were given before each set. It should be pointed out that participants did not look directly at their arms or the bar; rather, under both conditions, participants were asked to look straight ahead and to concentrate on their muscles or the bar, respectively.

We instrumented participants with an electrogoniometer (Penny & Giles, Christchurch, Dorset, UK) spanning the left elbow to record flexion and extension. Surface-mounted Ag/AgCl EMG electrodes (Noraxon, Scottsdale, AZ) were positioned on the skin above the belly of the right biceps brachii muscle and above the belly of the long head of the right triceps brachii muscle. A common electrode was positioned above the acromion process of the right scapula. Participants were instructed to perform an unweighted, maximal-effort isometric contraction (MIC) of the elbow flexors at 90° of elbow flexion, then the elbow extensors at full elbow extension, before the beginning of the curl task. We used peak EMG magnitude during the MIC to normalize EMG magnitudes as a percentage of MIC. We sampled electrogoniometer and EMG data at a frequency of 1000 Hz by using Noraxon Myoresearch Version 2.0 software (Norazon, U.S.A, Scottsdale, AZ).

All participants performed two sets of 10 repetitions of the curl task under each of the two attentional focus conditions, resulting in a total of 40 repetitions. The order of attentional focus conditions was counterbalanced between participants (6 participants performed the four sets in the order internal-external-internal-external, whereas 5 participants performed them in the order external-internal-external-internal). They were given rest periods of about 5 min between each of the MIC trials and each of the attentional focus conditions.

Data Analysis

Using a Butterworth low-pass filter (f_c = 100 Hz) with custom laboratory software (MATLAB; Natick, MA), we removed DC bias, full-waved rectified, and filtered raw biceps and triceps EMG data. We normalized processed EMG data recorded during the curl task for the biceps and triceps brachii muscles to the peak EMG value recorded during the unweighted MIC of the elbow flexors and extensors to yield trial EMG data in percentage of MIC. We filtered electrogoniometer data by using a Butterworth low-pass filter (f_c = 50 Hz) and reduced the data to calculate total repetition, elbow flexion and extension times, and angular velocity for each repetition of the weighted curl bar. Using a fast Fourier transformation, we calculated power spectral densities (PSD) for each trial from unfiltered, processed, and normalized EMG data. Mean power frequencies (MPF) for each trial were calculated as the average of the integral of the PSD from 1 to 250 Hz.

Dependent measures included average angular velocity of the movements, range of motion, biceps and triceps average EMG (EMG in percentage of MIC), biceps and triceps integrated EMG (iEMG in percentage of MIC × s), and biceps and triceps MPF. To examine whether attentional focus, set, or repetition had differential effects on the flexion and the extension phases of the movement, we also analyzed the dependent variables separately for the flexion phase (flexion) and extension phase (extension), in addition to the total repetition (total).

For all dependent measures, only Repetitions 2–9 were analyzed. The first and last repetitions in each condition were excluded because they were mechanically different from the other repetitions. Specifically, the first repetition started from the stopped position and the last repetition ended in a stopped position, whereas all other repetitions were preceded or followed by a repetition. Dependent measures were analyzed in 2 (focus of attention: internal vs. external) × 2 (set) × 8 (repetition: 2–9) analyses of variance (ANOVAs) with repeated measures on all variables.

Results

Angular Velocity

Total Angular Velocity

As can be seen in Figure 1, the average angular velocity of the movements generally decreased across repetitions. The main effect of repetition was significant, $F(7, 70) = 5.14$, $p < .001$. There was no main effect of set, $F(1, 10) < 1$. However, the Set × Repetition interaction was significant,

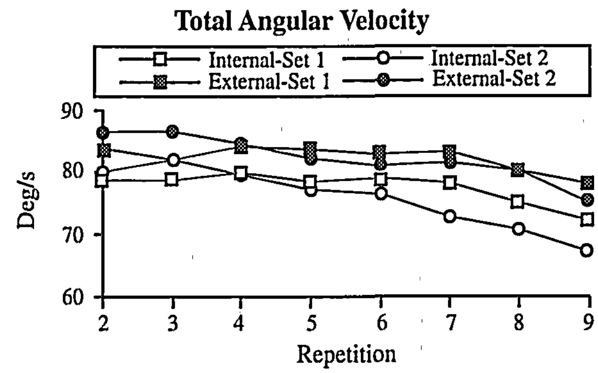

FIGURE 1. Total angular velocity across sets and repetitions for the internal and external focus conditions in Experiment 1.

$F(7, 70) = 4.24$, $p = .01$, as a result of a generally greater decrease in angular velocity across repetitions in Set 2 than in Set 1. Of particular importance, angular velocity differed between attentional focus conditions: Whereas the average angular velocity was 76.7°/s under internal focus conditions, it was 82.2°/s under external focus conditions. The difference was significant, $F(1, 10) = 5.59$, $p < .05$. Thus, movements were performed faster when an external focus was adopted.

Flexion Angular Velocity

For the flexion phase, angular velocity also generally decreased across repetitions, $F(7, 70) = 11.86$, $p < .001$. Again, the decrease was greater for the second than for the first set, as indicated by a significant Set × Repetition interaction, $F(7, 70) = 2.36$, $p < .05$. Flexion movements tended to be faster under external (80.4°/s) than under internal (75.8°/s) focus conditions, although the main effect of attentional focus just failed to reach significance, $F(1, 10) = 4.06$, $p = .07$. No other main or interaction effects were significant.

Extension Angular Velocity

During the extension phase, angular velocity also tended to be higher when participants focused externally (85.7°/s) rather than internally (79.8°/s). However, the main effect of attentional focus was again not quite significant, $F(1, 10) = 3.99$, $p = .07$. Also, none of the other main or interaction effects were significant.

Thus, although movement velocity generally decreased across repetitions, the important result was a difference between attentional focus conditions: Movements were faster when attention was directed at the bar than when attention was directed at the arms (muscles). Although that finding does not provide direct evidence for the automaticity notion (constrained action hypothesis), it is in line with the view that the regulatory processes involved in movement control under external focus conditions are mediated by more automatic control mechanisms.

Range of Motion

The average range of motion per repetition (flexion and extension) was 210.9° under internal and 205.1° under external conditions. Despite the relatively small numeric difference (2.75%), the main effect of attentional focus was significant, $F(1, 10) = 5.48, p < .05$.

EMG

Total EMG

Total biceps and triceps EMG activity generally increased across repetitions, with $Fs(7, 70) = 6.09$ and 3.68, and $ps < .001$ and $< .01$, for biceps and triceps, respectively. Although there was no main effect of set for biceps EMG, $F(1, 10) < 1$, EMG activity increased from Set 1 to Set 2 for triceps, $F(1, 10) = 10.72, p < .01$. There was no main effect of attentional focus for either biceps, $F(1, 10) < 1$, or triceps, $F(1, 10) = 1.81, p > .05$. None of the interaction effects were significant.

Flexion EMG

As was the case for total EMG, both biceps and triceps activity increased across repetitions for biceps, $F(7, 70) = 3.44, p < .01$, and for triceps $F(7, 70) = 2.46, p < .05$. Again, there was no main effect of set for biceps EMG, $F(1, 10) < 1$. For triceps, however, EMG activity increased from the first to the second set, $F(1, 10) = 6.24, p < .05$. The main effect of attentional focus was not significant for biceps, $F(1, 10) < 1$, or triceps, $F(1, 10) = 2.59, p > .05$. Yet, the Focus of Attention × Repetition interaction was significant for both biceps and triceps, $Fs(7, 70) = 2.77$ and 2.29, respectively, $ps < .05$. The interaction resulted from the fact that EMG activity tended to be lower for the external than for the internal focus condition during the first three or so repetitions in each set, whereas similar activity was demonstrated for the remaining repetitions. Post hoc tests failed to identify the exact source of the interaction, however.

Extension EMG

EMG activity during the extension phase also tended to increase as a function of repetition. The effect was significant only for biceps, however, $F(7, 70) = 5.68, p < .001$, but failed to reach significance for triceps, $F(7, 70) = 1.91, p = .08$. EMG activity tended to increase from Set 1 to Set 2. The set main effect was not significant for biceps, $F(1, 10) = 3.86, p = .08$, but was significant for triceps $F(1, 10) = 11.44, p < .01$. Last, EMG activity did not differ as a function of attentional focus for either biceps or triceps, $Fs(1, 10) < 1$. None of the interaction effects were significant.

Thus, EMG activity generally increased across repetitions and (for triceps) across sets. Also, at least for the flexion phase, EMG activity tended to be lower under the external than under the internal focus condition on the first few repetitions. The EMG results have to be seen in light of the fact that angular velocity and therefore the overall duration of movement repetitions varied as a function of attentional focus, $F(1, 10) = 7.81, p < .05$. Therefore, we determined iEMG activity, a measure that takes into account the overall movement time and can perhaps be regarded as a more meaningful index of neuromuscular activity in the present context.

iEMG

Total iEMG

Average biceps and triceps iEMG activity across Repetitions 2–9 in each set are shown in Figure 2 (top and bottom, respectively). As can be seen, total iEMG activity generally increased across repetitions. The main effect of repetition was significant for both biceps and triceps, $Fs(7, 70) = 17.09$ and 5.53, respectively, $ps < .001$. Furthermore, although biceps iEMG did not differ across sets $F(1, 10) = 1.13, p > .05$, triceps iEMG generally increased from Set 1 to Set 2, $F(1, 10) = 6.09, p < .05$. Also important, total iEMG activity of both biceps and triceps muscles was consistently higher under internal than under external focus conditions. The focus of attention main effect was significant for both biceps, $F(1, 10) = 9.80, p < .05$, and triceps,

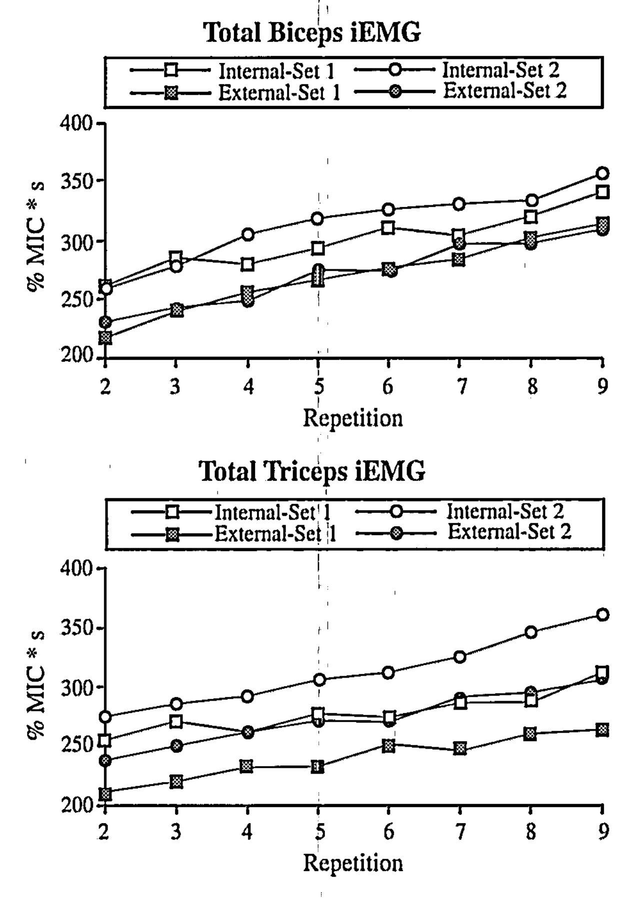

FIGURE 2. Total biceps (**top**) and triceps (**bottom**) integrated electromyographic (iEMG) activity across sets and repetitions for the internal and external focus conditions in Experiment 1. % MIC = percentage of maximal-effort isometric contraction.

$F(1, 10) = 11.64$, $p < .01$. None of the interaction effects were significant.

Flexion iEMG

Activities of the biceps and triceps muscles during the flexion phase generally reflected those seen for total iEMG. There was an overall increase in activity across repetitions for both biceps and triceps, *F*s(7, 70) = 19.58 and 6.17, respectively, *ps* < .001. Similar to total iEMG, there was no increase in activity across sets for the biceps, $F(1, 10) < 1$. For triceps, even though there was a trend for increased activity across sets, the main effect of set failed to reach significance, $F(1, 10) = 3.31$, $p = .10$. The main effect of attentional focus was again significant for biceps as well as for triceps, *F*s(1, 10) = 7.50 and 8.66, respectively, *ps* < .05, indicating reduced iEMG activity under external focus conditions. No interaction effects were significant.

Extension iEMG

During the extension phase, there were again increases in activity across repetitions (even though they tended to be smaller than those seen for the flexion phase). The main effect of repetition was significant for biceps, $F(7, 70) = 4.63$, $p < .001$, but not for triceps, $F(7, 70) = 1.63$, $p > .05$. Furthermore, whereas the increase in activity from Set 1 to Set 2 failed to reach significance for biceps activity, $F(1, 10) = 3.75$, $p = .08$, it was significant for triceps, $F(1, 10) = 10.59$, $p < .01$. Also important, there were again differences between attentional focus conditions: For both biceps and triceps, iEMG was significantly greater under internal than under external focus conditions, *F*s(1, 10) = 10.19 and 11.80, respectively, *ps* < .01.

Thus, whereas iEMG activity generally increased across repetitions (and sets for triceps during extension), the most important result was a clear difference between attentional focus conditions: Compared with an internal focus, an external focus was associated with reduced iEMG activity.

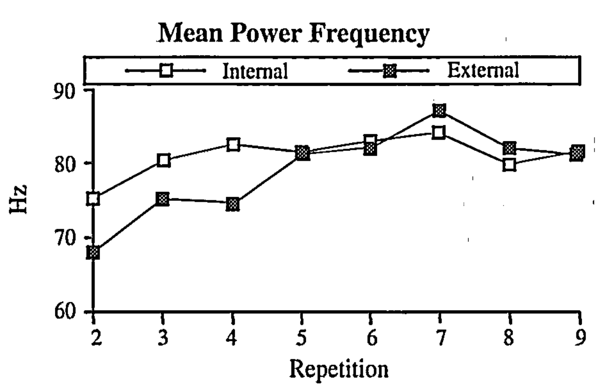

FIGURE 3. Mean power frequency for the internal and external focus conditions (average of Sets 1 and 2) across repetitions for biceps activity during flexion in Experiment 1.

MPF

Total MPF

For biceps activity, MPF increased across repetitions, $F(7, 70) = 4.01$, $p = .001$, but not across sets, $F(1, 10) < 1$. For triceps activity, there was an increase in MPF across sets, $F(1, 10) = 5.19$, $p < .05$, but not across repetitions, $F(1, 10) = 1.46$, $p > .05$. There were no main effects of attentional focus for either biceps, $F(1, 10) = 1.24$, $p > .05$, or triceps, $F(1, 10) < 1$, activity. Also, there were no significant interactions.

Flexion MPF

During flexion, MPF increased as a function of repetition for biceps activity, $F(7, 70) = 2.45$, $p < .05$. Also, biceps MPF was initially lower under the external than under the internal focus condition in both sets (see Figure 3). That finding was confirmed by a significant interaction of focus of attention and repetition, $F(7, 70) = 2.23$, $p < .05$. No other effects were significant.

Extension MPF

Biceps MPF generally increased across repetitions, $F(7, 70) = 3.93$, $p = .001$, as well as from Set 1 to Set 2, $F(1, 10) = 5.13$, $p < .05$. For the triceps, there was an increase in MPF across sets, $F(1, 10) = 7.94$, $p < .05$. Also, triceps MPFs tended to show a greater increase across repetitions under internal than under external conditions, although the Focus of Attention × Repetition interaction was not quite significant, $F(7, 70) = 2.00$, $p = .068$.

Overall, whereas MPFs generally increased across time (repetitions or sets), MPFs were also higher—at least temporarily—under internal than under external focus conditions. That finding suggests that at least during initial trials, external focus instructions promoted greater economy in motor unit recruitment. Subsequent increases in MPF under external focus conditions suggested a graded response to the relative force requirements. In contrast, MPFs under internal focus conditions seemed to reflect the recruitment of relatively larger motor units, with no attempt to sample what force was actually needed to achieve the desired outcome.

Discussion

Several results of Experiment 1 were in line with the notion that the adoption of an external rather than an internal focus promotes the use of more automatic control processes. First, movements were generally executed faster (i.e., angular velocity was higher) under external than under internal focus conditions. Even though movement speed was not an explicit goal in the curl task, the fact that movements were spontaneously performed more rapidly when participants focused on the curl bar rather than their arms is in accordance with the automaticity notion (constrained action hypothesis; e.g., Wulf, McNevin, & Shea, 2001). A more automatic mode of control typically results in more fluid and smoother movements, which in turn may lead to faster movement execution (e.g., see also Totsika & Wulf, 2003).

More important in the present context, however, are the findings related to the comparison between EMG activity under external and internal focus conditions. Even though average EMG activity did not differ between attentional focus conditions overall, there was an interaction between focus of attention and repetition during the flexion phase. That result suggests that, at least during the initial repetitions of each set, EMG activity was lower with an external focus. Given that EMG activity generally increased across repetitions (and sets), suggesting an increase in muscular effort required to produce the same result (i.e., lifting the weight), the initially reduced EMG activity under external focus conditions may be viewed as reflecting a greater economy in movement production.

The EMG results have to be seen in light of the fact that movement repetitions were produced faster under external than under internal focus conditions. Therefore, iEMG activity, which represents EMG activity as a function of movement time, can be regarded as a more meaningful measure in the present context. The iEMG results were clear in showing that, compared with focusing on the arms (internal focus), focusing on the curl bar (external focus) was associated with reduced neuromuscular activity. Because iEMG activity generally increased across repetitions—reflecting an increase in effort—the generally smaller iEMG activity under external focus conditions confirms the view that movements were produced with less energy in that condition than in internal focus conditions. That is, the reduced iEMG seen under the external focus condition was a result of similar absolute muscular activity exerted over a shorter period of time. Because the movement outcome (weight lifted) was identical under both conditions, that finding indicates a greater movement economy when an external focus was adopted.

The MPF results were also in line with the notion that movements are controlled more automatically if the performer focuses on the movement effect rather than on the movements themselves (e.g., McNevin, et al., 2003; Wulf, McNevin, & Shea, 2001). On the basis of that view, one would expect to see greater economy in the number of motor units recruited to achieve the desired movement outcome. The MPF results in the present experiment support the view that, at least initially, external focus instructions promoted a conservative use of available motor units, with additional motor units added on an as-needed basis. Conversely, internal focus instructions appeared to promote a superfluous response strategy, in that participants recruited more motor units than were required right from the outset. The latter strategy is similar to that adopted by older adults whose motor unit deficit results in a failure to modulate the amount of force produced in response to the amount of force required (e.g., Graves, Kornatz, & Enoka, 2000).

Even though the results of the first experiment seemed to corroborate the constrained action hypothesis, we felt that the support would be even stronger if differences in EMG activity could be found that were not mediated by differences in movement time. Therefore, we asked whether such differences would manifest themselves if movement time was kept constant under external and internal focus conditions. We addressed that question in a second experiment. In addition, it was somewhat disconcerting that the range of motion was smaller under the external than under the internal focus condition in Experiment 1, even though the difference was numerically minor. Nevertheless, we tried to replicate the findings of Experiment 1 in a second experiment, in which movement time was constrained by a metronome and in which, hopefully, no differences in the range of motion would occur.

EXPERIMENT 2

Our purpose in Experiment 2 was to compare EMG activity under internal and external focus conditions when the timing of the biceps curls was prescribed. For that purpose, we used a metronome and required participants to perform their movements in synchrony with the clicks produced by the metronome. If differences in EMG or iEMG were found despite those constraints, then that would increase our confidence that the type of attentional focus indeed affects neuromuscular activity and that the effects on iEMG found in Experiment 1 were not simply a function of the shorter movement time seen under external than under internal conditions.

Method

Participants

Participants were 12 university students (10 men, 2 women) who were taking part in personal weight-training activities. Informed consent was obtained before the collection of data. None of the participants had participated in Experiment 1, and all were naive as to our exact purpose in the experiment.

Apparatus, Task, and Procedure

The apparatus, task, and procedure were basically identical with those used in Experiment 1, except that we used a metronome to prescribe the movement time. For both internal and external focus conditions, the metronome was set to produce a click every 1.5 s. Participants were instructed to try to time their curls in synchrony with the metronome so that the end of each upward and downward movement coincided with one click.

Data Analysis

The data analysis was the same as in Experiment 1.

Results

Angular Velocity

The average angular velocity of the movements was basically identical for the internal (64.5°/s) and external

(64.4°/s) focus conditions, $F(1, 11) < 1$. Also, velocity did not change across sets, $F(1, 11) = 1.34$, $p > .05$, and repetitions, $F(7, 77) < 1$. That finding was presumably the result of the metronome, which paced participants' movements. However, participants could apparently maintain the average angular velocity (which was slower than the velocities seen in Experiment 1) only through a tradeoff between velocities during flexion and extension. During flexion, velocity generally decreased across trials from about 67°/s to about 62°/s, $F(7, 77) = 2.59$, $p < .05$, whereas it increased across trials from about 64°/s to 68°/s, $F(7, 77) = 2.42$, $p < .05$, during the extension phase. Angular velocity during extension also increased across sets (65°/s in Set 1 vs. 67°/s in Set 2), $F(1, 11) = 5.84$, $p < .05$. Thus, with increasing fatigue and more time needed for the actual lifting of the weight, participants maintained the overall angular velocity by using a compensatory increase in speed during extension. There was no interaction with the type of attentional focus.

Range of Motion

The total range of motion per repetition was very similar for the internal (194.8°) and external (192.7°) focus conditions. The main effect of attentional focus was not significant, $F(1, 11) < 1$.

EMG

There was a general increase in EMG activity across trials for both total biceps and total triceps EMG activity, $Fs(7, 77) = 13.52$, and 10.47, respectively, $ps < .001$. The trial main effects were also significant for both the flexion phase, $Fs(7, 77) = 11.65$ (biceps) and 6.10 (triceps), and the extension phase, $Fs(7, 77) = 16.46$ (biceps) and 8.77 (triceps), all $ps < .05$. Total biceps EMG activity tended to be lower under external (.724) than under internal focus (.767) conditions, but that effect failed to reach significance, $F(1, 11) = 3.13$, $p = .10$. Those trends were also seen for both the flexion, $F(1, 11) = 2.25$, $p = .16$, and extension, $F(1, 11) = 3.19$, $p = .10$, phases. For triceps activity, there were no differences between attentional focus conditions. Also, no other main or interaction effects were significant.

iEMG

The iEMG activity of both biceps and triceps muscles generally increased across repetitions, except for triceps activity during extension. For biceps, the increase was significant for total iEMG, $F(7, 77) = 14.86$, $p < .001$, as well as for flexion, $F(7, 77) = 12.54$, $p < .001$, and extension, $F(7, 77) = 11.33$, $p < .001$. For triceps, the increase in total iEMG, $F(7, 77) = 7.83$, $p < .001$, was mainly mediated by increasing activity during flexion, $F(7, 77) = 11.49$, $p < .001$, whereas there was no increase during extension, $F(7, 77) = 1.07$, $p > .05$. There was a trend for higher activity under internal conditions for total biceps iEMG, $F(1, 11) = 4.20$, $p = .065$. When we considered only the flexion phase, that difference was significant, $F(1, 11) = 5.11$, $p < .05$ (see Figure 4). That is, during flexion, iEMG activity was reduced under external focus relative to its level under internal focus conditions. For the extension phase, there was a similar but nonsignificant trend, $F(1, 11) = 1.27$, $p > .05$. No attentional focus differences were found for triceps activity, all $Fs(1, 11) < 1$.

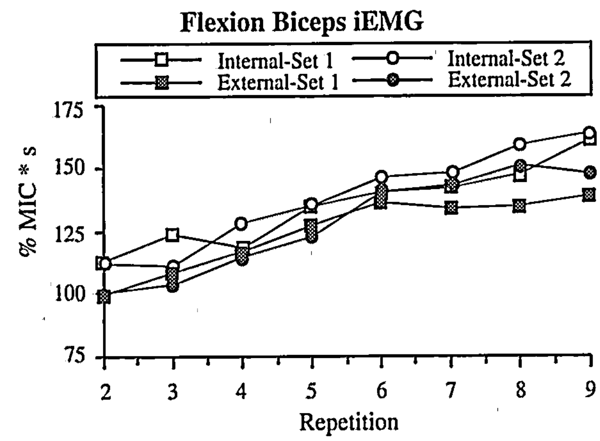

FIGURE 4. Biceps integrated electromyographic (iEMG) activity across sets and repetitions for the internal and external focus conditions during the flexion phase in Experiment 2. % MIC = percentage of maximal-effort isometric contraction.

MPF

MPF values generally increased across repetitions, with the exception of triceps during flexion: Biceps total, $F(7, 77) = 7.51$, biceps flexion, $F(7, 77) = 6.12$, biceps extension, $F(7, 77) = 5.76$; triceps total, $F(7, 77) = 3.53$, and triceps extension, $F(7, 77) = 3.28$; all $ps < .01$; triceps flexion, $F(7, 77) = 1.56$, $p > .05$. MPFs tended to be higher under internal than under external conditions for total biceps activity, $F(1, 11) = 2.01$, $p > .05$, and in particular for biceps activity during the flexion phase (internal = 115.5; external = 105.5), $F(1, 11) = 2.59$, $p = .14$. The other attentional focus main effects were not significant either, all $Fs < 1$. Also, there were no interaction effects.

Discussion

The most important finding of Experiment 2 was the reduced iEMG activity under external compared with that in internal focus conditions. That effect was significant for biceps activity during flexion, which is arguably the most important component of the biceps curl task. Of particular importance, that effect occurred even though the average range of motion was similar and movement time was kept constant between attentional focus conditions. Similar trends were seen for biceps EMG activity during both flexion and extension, although those effects did not reach significance. Thus, it appears that the adoption of an external focus indeed results in the production of more economical movements than does the adoption of an internal focus.

There was also a trend for MPFs to be lower under external than under internal focus conditions, indicating a greater economy in the recruitment of motor units (as in Experiment 1). However, that effect did not reach statistical significance. One reason why some of the attentional focus effects (MPF, EMG) failed to reach significance may be that participants' attentional capacity was taxed more in this experiment than in Experiment 1 (and in other attentional focus studies). Not only did they have to direct their attention to what they were instructed to focus on (arms, curl bar), they also had to direct attentional resources to the timing of their movements in synchrony with the metronome. Even though the metronome was turned on a minute or so before the beginning of the first set and remained on in between sets so that participants were able to get used to the timing, it appeared to be relatively difficult for them to time their movements accordingly. Thus, especially at the beginning of the experiment, they presumably had to devote considerable attentional capacity to that aspect of the task. Consequently, less capacity could be directed at the critical attentional manipulation (internal versus external). Nevertheless, the fact that differences between attentional focus conditions were observed suggests that the type of focus is a relatively powerful variable and that its effects manifest themselves even at the level of neuromuscular control.

GENERAL DISCUSSION

Although in numerous previous studies, focusing on the movement effect (external focus) has been found to result in more effective movement outcomes than focusing on the movement itself (internal focus; see Wulf & Prinz, 2001, for a review), the present study was the first investigation of whether the influence of an individual's attentional focus would also be seen at the neuromuscular level. Several findings of the present study provide support for the assumption that the adoption of an external focus results in a greater degree of automaticity than does the adoption of an internal focus. First, in Experiment 1, movements were generally executed with greater speed when participants were instructed to adopt an external focus. Assuming that greater automaticity in movement control results in faster movement execution, that result is in line with previous findings and with theoretical predictions. Second, both experiments showed that iEMG activity was reduced under external focus conditions. More important, as demonstrated in Experiment 2, differences in movement time or velocity (which is reflected in iEMG) cannot account for the difference between attentional focus conditions. Rather, when movement time was controlled in Experiment 2, the external focus condition still resulted in less iEMG activity. Third, there was some indication that an external focus was associated with more effective recruitment of motor units. In the first experiment, smaller MPF values were seen, at least at the beginning of each set, under external than under internal focus conditions. In the second experiment, there was a similar, although nonsignificant, trend for smaller MPFs under external conditions (however, that finding has to be viewed in light of the fact that participants could not direct their full attention to their arms [internal] or the curl bar [external], respectively, because they had to pay partial attention to the metronome).

Also interesting, in Experiment 1, not only did the external focus result in reduced iEMG activity of the biceps muscles (i.e., the agonists), it also caused reduced iEMG for the triceps muscles (i.e., the antagonists). Because the triceps counteracts the biceps throughout the movement, triceps activity should be as low as possible to facilitate the effectiveness and efficiency of biceps activity. The fact that that level of triceps activity was achieved to a greater extent with an external than with an internal focus seems to suggest that movement economy was enhanced, at least in part, through a more effective coordination between agonist and antagonist muscle groups. In general, movement economy can be increased through a more effective recruitment of muscles fibers within a muscle (intramuscular coordination; Hollmann & Hettinger, 2000) or through enhanced coordination between muscles (intermuscular coordination; Hollmann & Hettinger). Whether, or to what extent, an external focus promotes one or the other type of coordination should be examined more closely in future research.

The present study did not include a control condition without attentional focus instructions. It is therefore unclear whether the external focus instructions resulted in a reduction of muscular activity or whether the internal focus instructions led to an increase in activity, as compared with muscle activity in so-called normal conditions. That issue needs to be examined in a future study. Previous studies that did include control (or baseline) conditions (Landers et al., 2003; Wulf et al., 1998; Wulf & McNevin, 2003; Wulf, Weigelt, et al., 2003) have all demonstrated enhanced performance under external conditions as compared with performance in both internal focus and control conditions, with no difference between the latter two. If those results are generalizable to muscular activity, one would expect to see reduced iEMG activity for an external focus compared with that of a control condition as well.

In addition to the theoretical importance of our findings, the present results may also have implications for practical settings. For example, in sports in which (maximum) forces have to be generated in a short period of time (e.g., shot put, discus, power-lifting), focusing on the object that the force is being exerted upon may result in more effective performance than would focusing on the body movements that produce the action. Whereas a focus on the object or implement being manipulated has already been shown to be beneficial for various other tasks (e.g., golf [Wulf et al., 1999]; soccer and volleyball [Wulf et al., 2002]; ski-simulator and stabilometer [Wulf et al., 1998]), the present results suggest that that effect may generalize to tasks requiring (maximum) force production. Aside from the mass of the muscle groups involved, the coordination within and between muscles is critical for the effectiveness and efficiency of performance on those tasks (Hollmann & Hettinger, 2000). Thus, if an external focus indeed enhances those aspects of performance—as the present results suggest—one might expect to see beneficial effects of an external focus for skills requiring force production as well.

Overall, the present results provide converging evidence for the view that focusing on the movement effect (i.e., adopting an external focus) rather than on the movements themselves (i.e., adopting an internal focus) is more effective and efficient. Whereas the increased effectiveness of an external focus in terms of movement outcome has been demonstrated in numerous previous studies (for a review, see Wulf & Prinz, 2001), the greater movement velocity seen under external focus conditions in the present study suggests that that effectiveness might even be achieved incidentally, that is, without explicit instructions regarding the outcome. More important, the present results provide the first direct evidence for differential control mechanisms induced by external foci than are induced by internal foci of attention. Those appear to be more efficient under external focus conditions. The iEMG data revealed generally reduced neuromuscular activity when the individual adopted an external focus. In addition, the MPF results (as well as the EMG results) indicated a greater economy in motor unit recruitment and a graded response to the actual force requirements under external than under internal focus conditions. Thus, the present results provide further insights into how the type of attentional focus affects motor performance. Moreover, they demonstrate the effectiveness of the automatic control capabilities of the motor system—if it is unhampered by conscious control attempts.

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