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Gabriele Wulf^a & Janet S. Dufek^a

^a University of Nevada, Las Vegas

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Increased Jump Height with an External Focus Due to Enhanced Lower Extremity Joint Kinetics

Gabriele Wulf, Janet S. Dufek

University of Nevada, Las Vegas.

ABSTRACT. Individuals jump higher when they adopt an external focus of attention, relative to an internal focus or no focus of attention (G. Wulf, T. Zachry, C. Granados, & J. S. Dufek, 2007). In the present study, the authors determined the underlying cause of this effect. Participants performed a vertical jump-and-reach task for (a) an external focus condition (i.e., participants focused on the rungs of a Vertec [Perform Better, Cranston, RI] measurement device that they touched) and (b) an internal focus condition (i.e., participants focused on the finger with which they touched the rungs). Participants' jump height, center-of-mass displacement, jump impulse, and lower extremity joint moments were greater with an external focus compared with an internal focus. These results suggest that participants jump higher by producing greater forces when they adopt an external focus. This finding adds to evidence that an external focus facilitates the production of effective and efficient movement patterns.

Keywords: focus of attention, joint moments, jumping, motor performance, skill

In the past 10 years, in many studies researchers have shown that an individual's focus of attention has an important influence on the performance and learning of motor skills (see Wulf, 2007a, 2007b). In particular, if a performer's attention is directed to the movement effect (external focus), compared with the actual movement (internal focus), the result is typically greater movement accuracy and efficiency for the performer. For example, instructing a golfer to focus on the swing of the club, compared with the swing of his or her arms, has been demonstrated to enhance the accuracy of the shots (e.g., Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007). Researchers have also found attentional focus benefits for various balance tasks (e.g., Totsika & Wulf, 2003; Wulf, Höb, & Prinz, 1998) and sport skills, including shooting basketballs (Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002; Zachry, Wulf, Mercer, & Bezodis, 2005), kicking soccer balls (see Wulf, McConnel, Gärtner, & Schwarz, 2002, Experiment 2), and serving volleyballs (see Wulf et al., 2002, Experiment 1). Moreover, the advantages of an external focus seem to be independent of the type of skill, the performer's skill level, or the performer's age (see Wulf, 2007b). The advantages of an external focus are not only seen when compared with internal focus conditions, but also when compared with control conditions (e.g., Landers, Wulf, Wallmann, & Guadagnoli, 2005; McNevin & Wulf, 2002; Wulf, et al., 1998; Wulf & McNevin, 2003; Wulf, Weigelt, Poulter, & McNevin, 2003). This pattern of results suggests that an external focus has the capacity to enhance performance and learning.

The predominant explanation for the attentional focus effects is based on the assumption that an external focus promotes greater automaticity in movement control (constrained action hypothesis; Wulf, McNevin, & Shea, 2001). Whereas directing attention to one's movements constrains the motor system by inducing a conscious type of control, directing attention to the movement effect is thought to result in a more automatic mode of control. The idea that conscious attempts to control one's movements are detrimental to performance is in line with other theoretical views (e.g., Masters, 1992; Maxwell, Masters, & Eves, 2000; Singer, 1985, 1988). Masters, for example, suggested that instructions given to learners be reduced to a minimum: Otherwise learners would be more likely to adopt a controlled mode of information processing, assumed to impede the learning process. Instead, Masters advocated an implicit type of learning, which should make it less likely for a learner to engage in conscious thought processes that could interfere with the automatic execution of the movement. In contrast to this approach of withholding explicit movement-related information from the learner, though, the supposition put forward in the constrained action hypothesis is that attention should be directed to the movement effect on the environment to facilitate automaticity in movement control.

Although the constrained action hypothesis for the attentional focus effects has been challenged and researchers have offered alternative explanations (e.g., Hommel, 2007; Künzell, 2007; Poolton, Maxwell, Masters, & Van der Kamp, 2007; Wrisberg, 2007; Ziessler, 2007; but see the rebuttal by Wulf, 2007c), several lines of evidence support this constrained-action notion. For example, faster probe reaction times, indicating greater movement automaticity (e.g., Abernethy, 1988), have been associated with an external focus relative to an internal focus (Wulf, McNevin, et al., 2001). Postural adjustments in balance tasks also generally show higher frequency characteristics when performers adopt an external focus; researchers view this as an indication for the greater use of fast, reflexive, and automatic control processes (e.g., McNevin, Shea, & Wulf, 2003; Wulf, McNevin et al. Wulf, Shea, & Park, 2001). In general, directing attention to the movement effect seems to speed the learning process (Wulf, 2007b) so that automaticity is achieved sooner than it would be with a more traditional approach to learning.

Correspondence address: Gabriele Wulf, Department of Kinesiology and Nutrition Sciences, University of Nevada, Las Vegas, 4505 Maryland Parkway, Las Vegas, NV 89154-3034. e-mail: gabriele.wulf@unlv.edu

which assumes that novices need to direct their attention to the step-by-step coordination of their movements (e.g., Beilock & Carr, 2001; Gray, 2004).

The adoption of an external focus also resulted in lower electromyographic (EMG) activity than did adoption of an internal-focus or control conditions (Marchant, Greig, & Scott, in press; Marchant, Greig, Scott, & Clough, 2006; Vance, Wulf, Töllner, McNevin, & Mercer, 2004; Zachry et al., 2005), suggesting that movement efficiency is also enhanced. Vance et al., for example, had participants perform biceps curls while focusing on the curl bar (external focus) or their arms (internal focus). EMG activity was significantly reduced in the external focus condition relative to the internal focus condition (see also Marchant et al., 2006). Because the movement outcome (weight lifted) was identical under both conditions, movement efficiency was enhanced by the external focus. Zachry et al. also found reduced EMG activity during basketball free-throw shooting when participants adopted an external focus compared with an internal focus. Because participants' free-throw accuracy was greater for the external focus condition as well, Zachry et al. argued that an external focus of attention might not only enhance movement efficiency but might also reduce noise in the motor system that hampers fine movement control and makes the outcome of the movement less reliable. This contention was supported by increased EMG activity in the internal focus condition, which was found not only in the main agonist muscles (i.e., the muscles to which attention was directed) but also in other muscle groups, including antagonists (Vance et al.; Zachry et al.).

On the basis of findings that indicated increased movement efficiency with an external focus, Wulf et al. (2007) speculated that external focus advantages might also be found for tasks that require the production of maximal forces. Tasks that require such production of maximal forces include those in which an object or one's body has to be propelled. The optimal timing and direction of the generated forces necessary to accelerate the object or body determine success for such tasks. Cocontractions, for example, are expected to result in less-than-optimal performance. Wulf et al. used a task requiring maximum force production to examine effects of attentional focus. In their study, participants performed a vertical jump-and-reach task using a Vertec (Perform Better, Cranston, RI) measurement device for each of two instructional conditions in which participants (a) focused on the rungs that they would eventually touch (external focus) or (b) focused on the finger that they would eventually use to touch the rung (internal focus). The results show that jump height and vertical center-of-mass (COM) displacement were greater in the external focus condition than in the internal focus condition. Thus, those findings provided initial support for the idea that a focus on the movement effect can facilitate performance on maximum force-production tasks.

Still, Wulf et al.'s (2007) results did not explain why jump height differed among focus conditions. In other words, what are the underlying mechanisms that allow performers to jump

higher when they adopt an external focus? Vanezis and Lees (2005), who looked at possible factors that distinguish good and poor jumpers, may provide a lead in answering that question. From a sample of 50 male soccer players, Vanezis and Lees selected 9 participants who produced the highest vertical jump (high group) and 9 individuals who produced the lowest vertical jump (low group). Although the researchers observed no major differences with regard to the technique the two groups used, Vanezis and Lees found significant differences in the amount of force the participants produced. Specifically, peak power and work that the ankle joint produced (and, when arm swing was prohibited, peak power and work that the knee joint produced) were significantly different between the high and low groups. Thus, despite similarities in age, height, weight, and technique, expert performers were somehow able to produce more force that enabled them to jump higher. Although differences in fast-twitch muscle fibers, for example, between high- and low-group participants could not be excluded as a possible explanation for Vanezis and Lees's results, a more likely explanation seemed to be a more effective coordination pattern (e.g., a lower level of cocontractions) that the individuals in the high group exhibited. On the basis of the assumption that an external focus compared with an internal focus speeds the learning process (Wulf, 2007b) by facilitating the production of effective and efficient movement patterns, researchers might expect to find similar differences in force production during jumping, when individuals adopt an external focus rather than an internal focus.

Therefore, the purpose of the present study was to follow up Wulf et al.'s (2007) findings, which showed increased jump height with an external focus, by examining possible differences in kinetics or force production (e.g., impulse, joint moments) as a function of attentional focus. In contrast with the between-participant design that Vanezis and Lees (2005) used, which makes it difficult—if not impossible—to rule out interindividual differences as possible explanations for performance differences between groups, our design was a within-participant design. Participants performed a jump-and-reach task for internal and external focus conditions in a counterbalanced order. As did Wulf et al., we instructed participants to focus on the rungs of the Vertec instrument (external focus) or on the finger with which they would eventually touch the rungs (internal focus). In addition to jump-and-reach height and change in vertical COM displacement, we computed the impulse and lower-extremity sagittal-plane joint moments produced under those conditions.

Method

Participants

Participants were 10 healthy physically active university students (range = 20–30 years; 6 female students, 4 male students). They were not aware of the specific purpose of the

study. We obtained informed consent from all participants before beginning the experiment.

Apparatus and Task

A graduate student ran the experiment, and from here on is referred to as the *experimenter*. The task required participants to produce maximum countermovement jumps. The experimenter used a Vertec measurement device to record vertical jump-and-reach height. It comprised horizontal plastic rungs (0.5 in. or 1.3 cm in width) at different heights, which participants reached for during the jumps. The Vertec was positioned to the participant's right side, and the lowest rung was adjusted to each participant's height so that the participant could reach it with his or her fingertips when standing upright with the arm extended. To measure vertical ground reaction forces (vGRFs) and determine COM displacement, the experimenter obtained kinetic data (1080 Hz) using a force platform (40 × 60 cm; Kistler, Model 8600B, Winterthur, Switzerland). The experimenter obtained kinematic data using the Vicon motion-capture automated-tracking system (120 Hz; Vicon, Oxford, UK). The experimenter calibrated the Vicon motion-capture automated-tracking system per manufacturer's instructions (i.e., by first using a static calibration frame, and then dynamically calibrating the capture volume by moving a 50-cm rod about the movement volume).

Procedure

The experimenter instructed participants to jump straight up and touch the highest rung they could reach with the tips of the fingers of their right hand. Participants were allowed to warm-up and practice submaximally until they felt comfortable with the equipment, protocol, and technique. Following practice and instruction, participants were instrumented with reflective markers placed on the lower extremity in accordance with Vicon's Plug-in Gait model (modified Helen Hayes marker set; Vicon, Oxford, UK). The experimenter attached sixteen 25-mm reflective markers to the lower extremity of each participant, including bilateral placement on the anterior superior iliac spine, posterior superior iliac spine, lateral epicondyle of the knee, thigh (aligned with the greater trochanter and lateral epicondyle), lateral malleoli, lateral tibia (aligned with the lateral epicondyle and lateral malleolus markers), head of second metatarsal, and heel.

Each participant performed 10 jumping trials under each of the internal and external focus conditions. Condition order was counterbalanced among participants. In internal focus conditions, the experimenter instructed participants to concentrate on the tips of their fingers, reaching as high as possible during the jumps, whereas under external focus conditions, the experimenter instructed them to concentrate on the rungs of the Vertec, reaching as high as possible. The experimenter gave attentional focus reminders several times between trials. At the start of a trial, the experimenter instructed the participant to step onto the force platform with

his or her right foot while the left foot was symmetrically placed on the flooring adjacent to the platform and to stand still. After approximately 1 s, the participant was given the *go* signal and jumped on that prompt. Participant landing was not explicitly controlled, although the experimenter did require all participants to land with only the right foot on the force platform, suggesting right-left symmetry in jump-land performance. Any obvious asymmetric landings that the experimenter observed by visual or auditory means led the experimenter to deem the performance as unsatisfactory, and such trials were repeated.

Dependent Variables and Data Analysis

For each jump, the experimenter recorded the highest rung that the participant touched and displaced. To determine change in COM displacement, we first computed vertical acceleration of the COM following Newton's second law of motion (force-weight = mass × acceleration) and embraced the common assumption that the resulting vGRF vector that the force platform measured is a reflection of the inertial characteristics of the system (i.e., movement of the participant's COM). Only one limb was in contact with the force platform during the jump phase. The algorithm to measure vertical acceleration of the COM (force measured^{-1/2} body weight = ^{1/2} mass × acceleration) assumed bilateral symmetry and accounted for single-limb force measurement. The resulting vertical acceleration values were doubly integrated, resulting in a measure of the vertical position of the system COM. The maximum change in position for each trial and the vertical position of the COM in the prejump (standing) orientation were identified. The difference between these two measures resulted in the change in vertical position (displacement) of the COM during the jump.

We obtained single-leg impulse values for the jumping phase by first identifying the start of the jump phase as the point at which the vGRF decreased to less than 50% of body weight. Termination of the jump phase was determined as when the vGRF was equal to zero (takeoff of the jump). We then integrated the force divided by this defined time to produce the impulse during the jump phase, noting that this jump impulse was representative of the impulse produced by only the right extremity.

We computed three-dimensional joint moments of force for the ankle, knee, and hip joints (i.e., joint torque) using standard inverse dynamics procedures and commercially available Vicon software. We smoothed kinematic data using the Woltring (1985) routine with a smoothing factor of 15. Leg and thigh segments were modelled as truncated cones, whereas the foot was modelled as a pyramid. Using Vicon's validated Plug-in Gait lower-extremity modeling software, we also computed segment lengths and girths of the reflective markers from the known locations in space denoting anatomical locations. We calculated center of pressure and mapped it to the plantar surface of the foot to position the resultant ground reaction-force vector to the participant. We combined

joint reaction forces along with their respective moment arms (moment = force \times moment arm) to determine the resulting rotation (torque) at the ankle joint. This procedure was repeated up the link segment including the knee and hip joints (for a more detailed description, including model limitations, see Winter, 1990). Although we computed moments in three dimensions, our interest was in the sagittal plane torques only.

We analyzed jump-and-reach height (converted into centimeters), COM displacement, and impulse in 2 (attentional focus: internal, external) \times 10 (trials) analyses of variance (ANOVAs) with repeated measures on both factors. On rare occasions, markers were obscured, and joint moments could not be calculated for those trials. Therefore, we averaged joint moments across trials and analyzed them by a 2 (attentional focus: internal, external) \times 3 (joints: ankle, knee, hip) repeated-measures ANOVA.

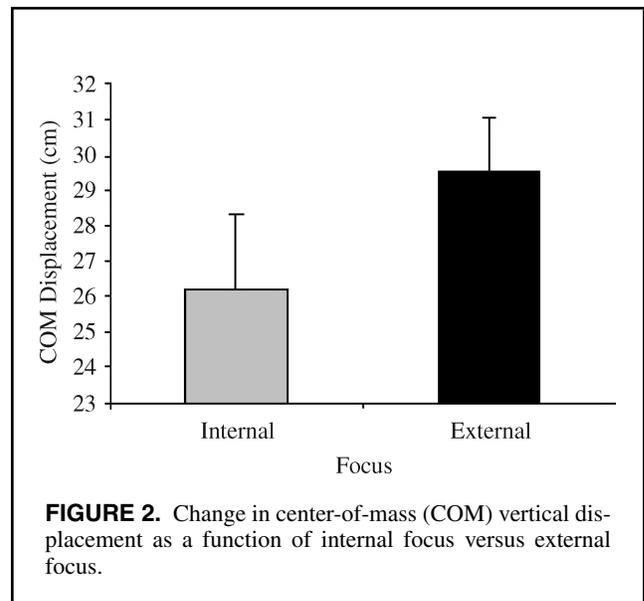
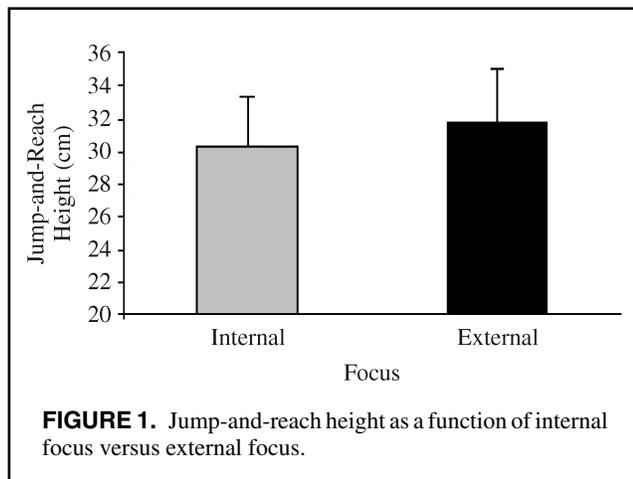
RESULTS

Jump-and-Reach Height

Jump-and-reach height was greater when participants adopted an external focus ($M = 31.9$ cm, $SE = 3.23$ cm) rather than an internal focus ($M = 30.4$ cm, $SE = 3.04$ cm; see Figure 1). The main effect of attentional focus was significant, $F(1, 9) = 5.71$, $p < .05$, whereas the main effect of trial, $F(9, 81) = 1.66$, $p > .05$, and the interaction of attentional focus and trial, $F(9, 81) = 1.33$, $p > .05$, were not significant.

COM Displacement

The vertical displacement of the COM was also greater for the external-focus condition ($M = 29.5$ cm, $SE = 1.5$ cm) compared with the internal-focus condition ($M = 26.2$ cm, $SE = 2.1$ cm; see Figure 2). The main effect of focus was significant, $F(1, 9) = 6.56$, $p < .05$. The main effect of trial and the Focus \times Trial interaction, $F_s(9, 81) < 1$, were not significant.

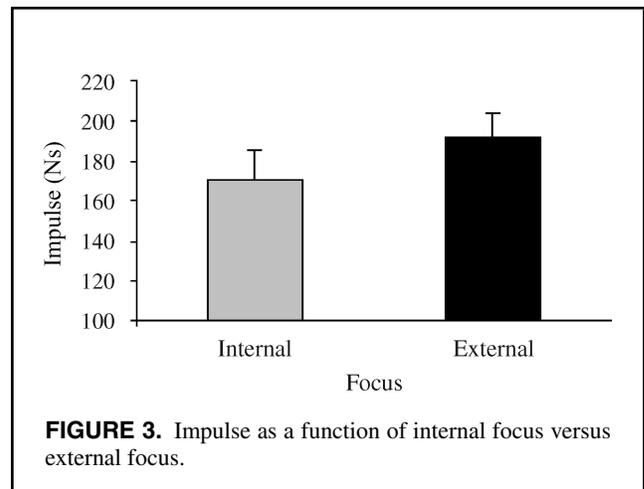


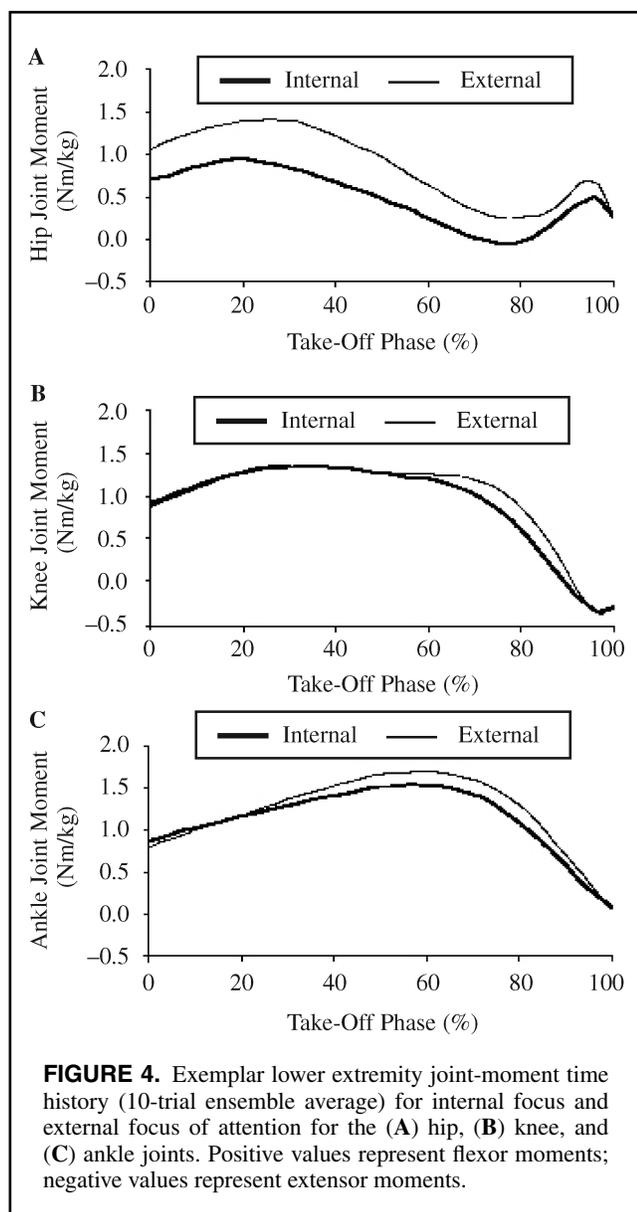
Impulse

Participants produced greater impulse values with an external focus ($M = 191.4$ Ns, $SE = 12.62$ Ns) compared with an internal focus ($M = 169.9$ Ns, $SE = 14.56$ Ns; see Figure 3). The main effect of focus was significant, $F(1, 9) = 6.02$, $p < .05$. The effects of trial and of Focus \times Trial were again not significant, $F_s(9, 81) < 1$.

Joint Moments

It is not surprising that the moments produced at the ankle ($M = 1.73$ body mass, $SE = 0.084$ body mass), knee ($M = 1.67$ body mass, $SE = 0.087$ body mass), and hip joints ($M = 1.07$ body mass, $SE = 0.085$ body mass) varied in size (Figures 4 and 5). It is most important that joint moments were overall higher when an external focus was adopted ($M = 1.57$ body mass, $SE = 0.055$ body mass) relative to when an internal focus was adopted ($M = 1.41$ body mass,

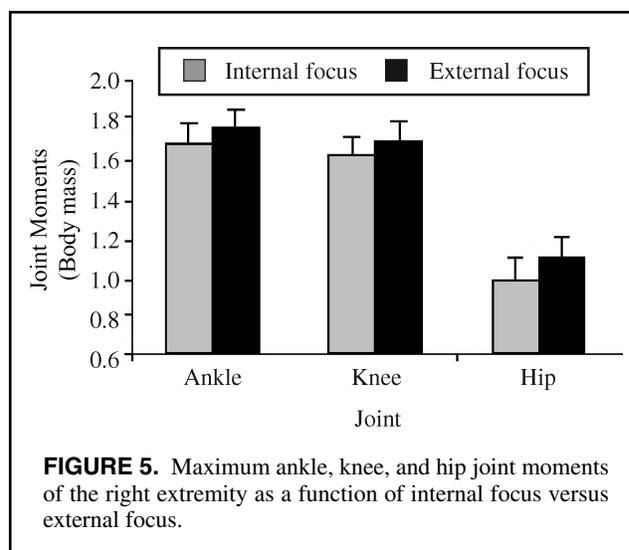




$SE = 0.097$ body mass). The main effects of joint, $F(2, 18) = 37.64$, $p < .001$, and focus, $F(1, 9) = 5.18$, $p < .05$, were significant. The interaction of joint and focus was not, $F_s(2, 18) < 1$.

Discussion

The purpose of the present study was to examine the causes underlying increases in jump height when performers are instructed to adopt an external focus (Wulf et al., 2007). In line with previous findings, maximum jump-and-reach height and vertical COM displacement were affected by the type of attentional focus that individuals adopted. Although participants tried to jump as high as possible in both conditions, their success at doing so clearly depended on the instructed attentional focus. External-focus instructions (i.e., to focus



on the rungs) resulted in significantly greater heights than did internal-focus instructions (i.e., to focus on the finger). The present findings also showed that increased jump height was the result of greater force production: Impulses and joint moments about the ankle, knee, and hip joints were significantly greater under the external-focus condition. In the following sections, we discuss various aspects of the results, including the use of multiple dependent measures (biomechanical parameters), the function of attentional focus in force production, and how attentional focus affects the learning process.

Are the Various Biomechanical Parameters Redundant?

Researchers could argue that the dependent measures used in the present study are interrelated (e.g., jump-and-reach height should be directly related to impulse or joint moments), and therefore, redundant. Yet, correlations between those measures suggest that that was not the case (see Table 1). With the exception of significant correlations between COM displacement and impulse and among the moments produced around the various joints, none of the correlations were significant. In particular, jump-and-reach height did not correlate with any of the other variables. Similarly, COM displacement and impulse did not correlate with other variables (other than each other). The lack of relation among measures is presumably a reflection of the complexity of the motor system, with its numerous degrees of freedom, which does not necessarily lead to a direct translation among measured biomechanical parameters and any given movement outcome. The lack of correlation, therefore, justifies the use of multiple measures. More important, that external focus advantages were seen in all measures makes an even stronger case for the influence of attentional focus. Thus, the present results validate the supposition that mechanical parameters change because of focus instructions (Wulf, 2007b). The present results provide converging evidence that the increased jump height with an external focus was achieved

TABLE 1. Correlations Among Dependent Measures Overall and for Internal-Focus and External-Focus Conditions Separately

Variable	Jump-and-reach height	COM displacement	Impulse	JM ankle	JM knee	JM hip
Jump-and-reach height	—	.140 ^a , .041 ^b	.182 ^a , .061 ^b	.108 ^a , .208 ^b	-.021 ^a , -.112 ^b	.126 ^a , .223 ^b
COM displacement	.114	—	.876 ^{a**} , .797 ^{b**}	.402 ^a , .197 ^b	.212 ^a , -.468 ^b	.051 ^a , .087 ^b
Impulse	.139	.853 ^{**}	—	.302 ^a , .145 ^b	.170 ^a , -.439 ^b	.188 ^a , .492 ^b
JM ankle	.157	.387	.294	—	.793 ^{a*} , .536 ^b	.740 ^{a*} , .330 ^b
JM knee	-.031	.083	.033	.744 ^{**}	—	.664 ^{a*} , -.019 ^b
JM hip	.192	.152	.384	.603 ^{**}	.446 [*]	—

Note. COM = center of mass; JM = joint moment.

^aInternal-focus condition. ^bExternal-focus condition.

* $p < .05$, two-tailed. ** $p < .01$, two-tailed.

through greater force production expressed through kinematic performance modifications during the jump.

How Does the Focus of Attention Influence Force Production?

It is evident that the maximum force that an individual is able to produce is not fixed. Although it is well known that life-threatening situations, for example, enable individuals to produce greater forces than they are able to produce voluntarily under normal circumstances, it is interesting that even a simple change in a person's attentional focus can result in an increase in force production. Because the performance benefit of an external focus has been found not only with respect to an internal focus but also when compared with control conditions without explicit focus instructions (Wulf et al., 2007), the present results suggest that instructions to focus on the movement effect enhance performance beyond what participants would typically achieve.

Marchant et al.'s (in press) study also showed beneficial effects of an external focus on maximum force production. Using an isokinetic dynamometer, Marchant et al. had participants produce maximum voluntary contractions of the elbow flexors under internal-focus (i.e., focus on arm and muscles) or external-focus (i.e., focus on the crank hand-bar) conditions. The results showed that participants produced significantly greater peak joint torque when they focused externally compared with internally. It is more interesting that this was achieved with significantly less muscular (EMG) activity. These findings fit into the overall picture that seems to be emerging from different studies examining the effects of attentional focus. An external focus relative to an internal focus enables an individual to (a) lift the same weight repeatedly with less muscular activity (Marchant et al., 2006; Vance et al., 2004; see also Zachry et al., 2005); (b) produce greater impulses, joint moments (present study), and greater peak forces with less muscular activity (Marchant

et al., in press); and (c) achieve greater movement accuracy with less muscular activity (Zachry et al.). Thus, when an individual adopts an external focus, movements not only are more effective (e.g., resulting in greater movement accuracy, enhanced balance, larger movement amplitudes; for a review, see Wulf, 2007b) but are also produced more efficiently (i.e., with less metabolic or mental energy; for a review, see Wulf & Lewthwaite, in press), with the consequences being that the resultant maximum forces are greater and that the same forces are produced with less muscular energy.

How does an external focus act to increase maximum force production? To generate maximum forces, as required by tasks that involve propelling an object or one's body, the direction and timing of the contributing forces need to be optimal. Aside from an effective recruitment of muscle fibers within a muscle, this entails an effective coordination pattern between agonist and antagonist muscle groups (e.g., Hollmann & Hettinger, 2000). Unnecessary cocontractions would result in less-than-maximal force output (and subsequently, jump height). Various sets of findings suggest that an internal focus leads to inefficient cocontractions (Marchant et al., 2006; Vance et al., 2004; Zachry et al., 2005). In contrast, an external focus seems to provide a release from the constraints that an internal focus imposes on the motor system, which interfere with automatic control processes (e.g., Wulf, McNevin, et al., 2001). In addition, a focus on the movement effect evidently results in greater movement efficiency by reducing muscular activity that not only is unnecessary but also apparently impedes the production of maximum forces.

Focusing on One Body Part May Constrain the Whole Motor System

Our findings that directing attention to the movements of a certain body part (e.g., finger) affects unrelated parts of

the body (e.g., legs) indicate that an internal focus on one part of the body may have general constraining effects on the whole motor system (see also EMG activity in Vance et al., 2004; Zachry et al., 2005). Other studies have also shown that focusing on the finger or hands (internal focus) compared with an object to be touched or held (external focus), for example, could have an effect on whole-body coordination (e.g., McNevin & Wulf, 2002; Wulf et al., 2003). In those studies, balance was influenced by the type of focus participants were instructed to use on the touching or holding task. In the present study, additional evidence for the constraining effects of an internal focus appears to come from our correlational analyses. Table 1 (bottom left half) shows the correlations obtained for both attentional focus conditions combined. As can be seen, there were significant correlations between the joint moments produced around the ankle, knee, and hip (ankle-knee: $r = .744$, $p < .01$; ankle-hip: $r = .603$, $p < .01$; knee-hip: $r = .446$, $p < .05$). However, the analyses that we conducted separately for the internal and external focus conditions yielded a somewhat different picture (see Table 1, upper right half). Although the correlations between joint moments were all significant in the internal focus condition (ankle-knee: $r = .793$, $p < .05$; ankle-hip: $r = .704$, $p < .05$; knee-hip: $r = .664$, $p < .05$), none of those correlations were significant in the external focus condition (ankle-knee: $r = .536$; ankle-hip: $r = .330$; knee-hip: $r = -.019$). These between-participant analyses suggest that participants responded similarly when instructed to focus on their finger, presumably by freezing their degrees of freedom (e.g., Vereijken, van Emmerik, Whiting, & Newell, 1992). In contrast, the instructions to focus on the rungs seem to have

encouraged the use of individual solutions that enabled the motor system to automatically produce a movement pattern that was conducive to producing a more effective outcome (i.e., great jump height; see also Slobounov, Yukelson, & O'Brien, 1997).

We followed up these results by computing correlations among the different variables for each individual participant for each focus condition. We were particularly interested in how often the joint moments would correlate with any of the other variables. Under the assumption that an internal focus constrains the motor system (i.e., links the semi-independent moving segments so that they move together), relative to an external focus (e.g., Wulf, McNevin, et al., 2001), researchers might expect to see a greater number of such correlations when participants are instructed to focus on the finger. As can be seen in Table 2, this was the case. In the internal-focus condition, there were overall more significant correlations between joint moments and other variables (27) than in the external-focus condition (21). It is most important, though, that this relation varied considerably among participants who showed an external-focus advantage in jump height and those who did not (see Table 2). Those who benefited in jump height from the instructions to focus on the rungs exhibited 22 (internal focus) versus 11 (external focus) significant correlations, whereas those who performed similarly under both conditions also showed a similar number of correlations in the internal-focus conditions versus external-focus conditions (5 vs. 6). Thus, individuals who were successful at following the instructions and changing their focus of attention accordingly seemed to display more of a release from the bodily constraints when focusing on the

TABLE 2. Number of Significant Correlations With Body (Ankle, Knee, or Hip-Joint Moments) and Number of Significant Negative Correlations Between Body and Outcome (Jump-and-Reach Height, Impulse, or Center-of-Mass Displacement)

Participant no.	Jump-and-reach height (cm)		External focus advantage (yes or no)	Correlations with body		Negative correlations between body and outcome	
	Internal focus	External focus		Internal focus (yes = 22, no = 5)	External focus (yes = 11, no = 6)	Internal focus (yes = 6, no = 1)	External focus (yes = 2, no = 4)
1	43.5	44.6	Yes	8	0	2	0
2	21.3	21.3	No	1	2	1	0
3	16.9	16.7	No	2	3	0	2
4	21.7	24.1	Yes	3	2	2	0
5	35.8	40.1	Yes	3	1	0	0
6	33.9	31.3	No	2	5	0	2
7	43.4	46.4	Yes	0	1	0	0
8	36.7	38.4	Yes	1	3	0	1
9	28.0	31.1	Yes	3	1	2	1
10	22.4	24.8	Yes	4	3	0	0

Note. Correlations are for all participants, including those who showed (and did not show) greater jump-and-reach heights with an external focus.

movement effect (i.e., rungs to be touched). In contrast, participants (2, 3, and 6) who were perhaps less able or willing to follow the focus instructions presumably adopted similar coordination patterns in both conditions, and thus, did not show the external-focus benefit in jump height.

In a final analysis, we counted the number of times a body-related variable (i.e., joint moment) correlated negatively with an outcome variable (i.e., jump-and-reach height, impulse, COM displacement). This would be the case, for example, if an increase in joint moment was associated with a decrease in jump-and-reach height. Although this association did not occur frequently, we saw this more often in the internal-focus condition (6) than in the external-focus condition (2). This association was the case at least for those participants who benefited from an external focus in terms of jump height (see Table 2); those who did not benefit tended to show more negative correlations in the external-focus condition (4) rather than the internal-focus condition (1), adding evidence for the idea that it is an inefficient coordination pattern that hampers the movement outcome.

Overall, these results seem to suggest that the motor system is capable of optimizing the movement outcome if the performer focuses on that outcome. Attempts to force an effective outcome by focusing on and trying to control one's body movements are generally less successful, presumably because they interfere with the body's natural organizational capabilities.

Attentional Focus and the Learning Process

It has been suggested that giving learners instructions that induce an external—rather than internal—focus of attention speeds the learning process so that an advanced level of performance is achieved sooner (Wulf, 2007b). The present results seem to be in line with this view. The greater joint moments observed in the external focus condition versus internal focus condition correspond to the increased joint moments that Vanezis and Lees (2005) found for good jumpers versus poor jumpers. When we instructed participants in the present study to focus on the movement effect (i.e., rungs), instead of their body movements (i.e., fingers), their performance resembled to a greater extent that of skilled jumpers, not only in terms of the outcome (i.e., greater jump height), but also in terms of how this outcome was achieved (i.e., greater joint moments). Although the between-participant design that Vanezis and Lees used did not allow them to exclude other explanations for the differences between good and poor jumpers (e.g., the percentage of fast- and slow-twitch fibers), they seemed to favor the explanation that neuromuscular activity was coordinated more effectively, that is, that the coactivation of antagonists reduced in the group of good jumpers. The within-participant design used in the present study is advantageous because it precludes interindividual differences as a confounding factor. The present study may, therefore, also lend more credence to Vanezis and Lees' interpretation of their results, because our findings suggest

that coordination within or between muscles is indeed a decisive factor in jumping performance and maximum force generation (see also Marchant et al., in press).

The present study identified a mechanical underpinning for the effects of attentional focus on motor performance. Our findings show that motor coordination is affected by an individual's focus of attention. An interesting direction for future studies would be to examine how muscular coordination patterns are influenced as a function of attentional focus. Studies using EMG, for example, may shed light on how the timing and degree of muscle activation in agonists and antagonists are affected when people adopt an external focus versus an internal focus. It is now clear that one's focus of attention has a pervasive effect on performance and learning, and as the present study demonstrates, this even generalizes to aspects of performance that are typically thought to be relatively fixed, such as a person's capability to produce maximum force.

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