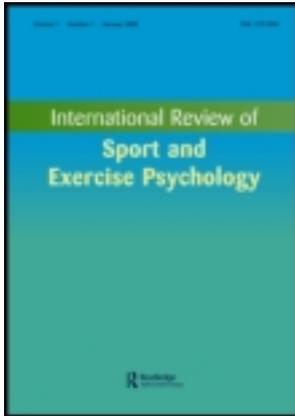


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Attentional focus and motor learning: a review of 15 years

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Attentional focus and motor learning: a review of 15 years

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Over the past 15 years, research on focus of attention has consistently demonstrated that an external focus (i.e., on the movement effect) enhances motor performance and learning relative to an internal focus (i.e., on body movements). This article provides a comprehensive review of the extant literature. Findings show that the performance and learning advantages through instructions or feedback inducing an external focus extend across different types of tasks, skill levels, and age groups. Benefits are seen in movement effectiveness (e.g., accuracy, consistency, balance) as well as efficiency (e.g., muscular activity, force production, cardiovascular responses). Methodological issues that have arisen in the literature are discussed. Finally, our current understanding of the underlying mechanisms of the attentional focus effect is outlined, and directions for future research are suggested.

Keywords: external focus; instructions; feedback; motor performance; movement effectiveness; movement efficiency

Introduction

A central question for any athlete or coach is: How can skill learning be facilitated, and how can performance be optimized? Those who are concerned with motor skill learning from a more theoretical perspective are interested in the same question, in addition to understanding the mechanisms that underlie the variables that influence performance and learning. The performer's focus of attention has intrigued both practitioners and researchers as a potentially influential factor for a long time. Attentional focus has been viewed from different perspectives and has been characterized, for example, as either associative (i.e., focusing on bodily sensation) or dissociative (i.e., blocking out sensations resulting from physical effort) (Morgan, 1978; Weinberg, Smith, Jackson, & Gould, 1984), or in terms of its width (broad versus narrow) and direction (internal versus external) (Moran, 1996; Nideffer & Sagal, 1998). Over the past 15 years, another distinction has been found to have an important impact on the effectiveness and efficiency of motor performance, and on the speed of the learning process. Empirical evidence has amassed for the benefits of adopting an *external focus* on the intended movement effect (e.g., on an implement) relative to an *internal focus* on body movements. Since the publication of the first study demonstrating the differential effects of external versus internal foci on learning (Wulf, Höß, & Prinz, 1998), many studies have followed. Much of this

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research has been reviewed elsewhere (e.g., Lohse, Wulf, & Lewthwaite, 2012; Marchant, 2011; Wulf, 2007a, 2007b; Wulf & Lewthwaite, 2010).

In the present article, I provide an updated review of the findings, particularly with regard to the influence of attentional focus on *movement effectiveness*, such as balance or accuracy, and *movement efficiency*, as measured by muscular activity, maximum force production, speed, or endurance. A few studies have examined changes in movement kinematics as a function of focus instructions, and they demonstrate that sometimes even a single instructional cue can impact whole-body coordination. Subsequently, I outline our current understanding of the underlying mechanisms of the attentional focus effect. One of the main purposes of this article is to discuss conceptual and methodological issues related to this line of research. For example, potentially confounding influences of other variables can presumably explain some of the apparently contradictory findings, or lack of focus effects. Finally, I summarize the main findings and provide some suggestions for future research.

External versus internal focus of attention

Skilled performance is characterized by high levels of movement effectiveness and efficiency (e.g., Guthrie, 1952). That is, a high skill level is associated with accuracy, consistency, and reliability in achieving the movement goal (i.e., effectiveness), as well as fluent and economical movement executions and automaticity, as evidenced by the investment of relatively little physical and mental effort (i.e., efficiency). Numerous studies have provided converging evidence that an external focus of attention speeds up the learning process so that a higher skill level – characterized by both increased effectiveness and efficiency – is achieved sooner (Wulf, 2007b). Of course, both aspects of performance usually develop in concert and are not independent of each other. However, because most studies on attentional focus have used measures of either effectiveness or efficiency (although some have examined both aspects), the following review is organized accordingly. A few studies have also looked at how different attentional foci affect movement kinematics. These are reviewed in a subsequent section.

Interestingly, and in contrast to other variables studied in the motor learning literature, a person's attentional focus often has a similar influence on both immediate *performance* (i.e., during the practice phase when focus instructions are given) and *learning*, which reflects a more permanent change in the capability to perform a skill, and is measured by retention or transfer tests (i.e., after a certain interval and without instructions or reminders). Therefore, in addition to traditional motor learning paradigms, using between-participant designs and retention or transfer tests, within-participant designs have been used in studies on attentional focus to examine effects on performance.

Movement effectiveness

The line of research examining the influence of an internal versus external focus of attention began with my personal experience in windsurfing (see Wulf, 2007b). While practicing a power jibe, I found that directing attention to the position of my feet, the pressure they were exerting on the board to change its direction, or the location of

my hands on the boom, resulted in many failed attempts and frequent falls into the water over several hours of practice. With the spontaneous decision to simply focus on the tilt of the board while turning came instantaneous success. Even though not all subsequent jibes were flawless, the difference in the quality and fluidity of the jibes resulting from my change in attentional focus was striking. Perhaps not coincidentally, the first experiments we conducted to examine the effectiveness of instructions inducing an internal or external focus of attention involved balance tasks. Table 1 gives an overview of attentional focus studies in which movement effectiveness was assessed, the tasks and groups/conditions used in those studies, and the results.

Balance

In the first experiment (Wulf, Höß, & Prinz, 1998, Experiment 1), we used a ski-simulator and directed participants' attention to either the pressure they exerted on the wheels of the platform on which they were standing (external focus), or to their feet that were exerting the force (internal focus). On a retention test, the external focus group demonstrated superior learning (i.e., larger movement amplitudes) compared with both the internal focus and a control group without focus instructions. Faced with reviewer skepticism, we went on to replicate findings in a subsequent experiment that involved balancing on a stabilometer (Wulf, Höß, & Prinz, 1998, Experiment 2). Again, directing participants' attention externally, that is, on keeping markers on the balance platform horizontal, led to more effective balance learning than inducing an internal focus by asking them to try to keep their feet horizontal. (It is important to point out that attentional focus refers to the performer's concentration, not visual focus, and that visual information is typically kept constant, especially on balance tasks, by asking participants to look straight ahead.) Since the initial studies, numerous researchers have replicated the benefits of an external focus for other balance tasks.

Aside from the ski-simulator and stabilometer (see also Chiviakowsky, Wulf, & Wally, 2010; Jackson & Holmes, 2011; McNevin, Shea, & Wulf, 2003; Shea & Wulf, 1999; Wulf & McNevin, 2003; Wulf, McNevin, & Shea, 2001; Wulf, Weigelt, Poulter, & McNevin, 2003), the balance tasks used in various studies on attentional focus included standing still on an inflated rubber disk (Wulf, Landers, Lewthwaite, & Töllner, 2009; Wulf, Mercer, McNevin, & Guadagnoli, 2004; Wulf, Töllner, & Shea, 2007) or other movable platforms, such as the Balance Master and Biodex Stability systems (Landers, Wulf, Wallmann, & Guadagnoli, 2005; Laufer, Rotem-Lehrer, Ronen, Khayutin, & Rozenberg, 2007; Rotem-Lehrer & Laufer, 2007; Thorn, 2006), or standing still on a stable surface while performing a supra-postural task (McNevin & Wulf, 2002). Balance performance or learning, as measured by deviations from a balanced position or various measures of postural sway, has been shown to be enhanced when the performer's attention is directed to minimizing movements of the platform (or markers attached to it) or disk as compared to those of their feet. Another balance task, riding a Pedalo, was used by Totsika and Wulf (2003). With instructions to focus on pushing the boards under their feet forward, participants showed more effective learning compared with instructions to focus on pushing their feet forward. When control conditions without focus instructions were included (e.g., Landers et al., 2005; Wulf et al., 1998, Experiment 1; Wulf et al., 2003,

Table 1. Studies related to movement effectiveness (e.g., balance, accuracy).

Study	Movement Effectiveness		
	Task	Groups/ Conditions	Results
Wulf, Höß, & Prinz (1998, Exp. 1)	Ski-simulator	EF, IF, C	EF > IF, C
Wulf, Höß, & Prinz (1998, Exp. 2)	Stabilometer	EF, IF	EF > IF
Shea & Wulf (1999)	Stabilometer	EF, IF	EF > IF
Wulf, McNevin, & Shea (2001)	Stabilometer	EF, IF	EF > IF
Wulf, Shea, & Park (2001, Exp. 1)	Stabilometer	EF, IF	EF > IF
Wulf, Shea & Park (2001, Exp. 2)	Stabilometer	EF, IF	EF > IF
Wulf & McNevin (2003)	Stabilometer	EF, IF, C	EF > IF, C
McNevin, Shea, & Wulf (2003)	Stabilometer	EF, IF	EF > IF Note: Different EF conditions
Wulf, Weigelt, Poulter, & McNevin (2003, Exp. 1)	Stabilometer	EF, IF	EF > IF Note: Focus on supra-postural task
Wulf, Weigelt, Poulter, & McNevin (2003, Exp. 2)	Stabilometer	EF, IF, C	EF > IF, C Note: Focus on supra-postural task
Chiviawsky, Wulf, & Wally (2010)	Stabilometer	EF, IF	EF > IF
Jackson & Holmes (2011)	Stabilometer	EF, IF	EF > IF
McNevin & Wulf (2002)	Standing still	EF, IF, C	EF > IF, C Note: Focus on supra-postural task
Wulf, Mercer, McNevin, & Guadagnoli (2004)	Balance (inflated disk) and supra-postural task	EF, IF	EF > IF
Landers, Wulf, Wallmann, & Guadagnoli (2005)	Balance Master	EF, IF, C	EF > IF, C
Wulf (2008)	Balance (inflated disk)	EF, IF, C	C > EF, IF Note: Balance acrobats
Wulf, Landers, Lewthwaite, & Töllner (2009)	Balance (inflated disk)	EF, IF, C	EF > IF, C
de Bruin, Swanenburg, Betschon, & Murer (2009)	Balance (Biodex)	EF, IF	EF = IF
Rotem-Lehrer & Laufer (2007)	Balance (Biodex)	EF, IF	EF > IF
Laufer, Rotem-Lehrer, Ronen, Khayutin, & Rozenberg (2007)	Balance (Biodex)	EF, IF	EF > IF
Cluff, Gharib, & Balasubramaniam (2010)	Stick balancing	EF, IF	EF = IF
Totsika & Wulf (2003)	Pedalo	EF, IF	EF > IF
Wulf, Lauterbach, & Toole (1999)	Golf pitch shot	EF, IF	EF > IF

Table 1 (Continued)

Study	Movement Effectiveness		
	Task	Groups/ Conditions	Results
Wulf & Su (2007, Exp. 1)	Golf pitch shot	EF, IF, C	EF > IF, C
Wulf & Su (2007, Exp. 2)	Golf pitch shot	EF, IF, C	EF > IF, C
An, Wulf, & Kim (forthcoming)	Golf (full swing)	EF, IF, C	EF > IF, C
Bell & Hardy (2009)	Golf chip shot	EF, IF	EF > IF Note: Different EF conditions
Perkins-Ceccato, Passmore, & Lee (2003)	Golf pitch shot	EF, IF	EF = IF Note: See text for limitations
Granados (2010)	Golf putting	EF, IF	EF > IF
Poolton, Maxwell, Masters, & Raab (2006, Exp. 1)	Golf putting	EF, IF	EF > IF
Poolton, Maxwell, Masters, & Raab (2006, Exp. 1)	Golf putting	EF, IF	EF = IF Note: Multiple EF and IF instructions
Wulf, McConnel, Gärtner, & Schwarz (2002, Exp. 1)	Volleyball serve	EF, IF	EF > IF
Wulf, McConnel, Gärtner, & Schwarz (2002, Exp. 2)	Soccer kick	EF, IF	EF > IF
Zachry (2005)	Football kick	EF, IF, C	EF > IF, C
Al-Abood, Bennett, Hernandez, Ashford, & Davids (2002)	Basketball free throw	EF, IF	EF > IF
Zachry, Wulf, Mercer, & Bezodis (2005)	Basketball free throw	EF, IF	EF > IF
Wulf, Chiviawowsky, Schiller, & Ávila (2010)	Soccer throw-in	EF, IF	EF > IF
Freedman, Maas, Caligiuri, Wulf, & Robin (2007)	Force production	EF, IF	EF > IF
Fasoli, Trombly, Tickle- Degnen, & Verfaellie (2002)	Object manipulations	EF, IF	EF > IF
Chiviawowsky, Wulf, & Ávila (2012)	Beanbag toss	EF, IF	EF > IF
Saemi, Porter, Wulf, Ghotbi-Varzaneh, & Bakhtiari (2012)	Tennis ball toss	EF, IF	EF > IF
Southard (2011, Exp. 1)	Throwing (form)	EF, IF	EF > IF Note: Multiple EF and IF conditions
Southard (2011, Exp. 2)	Throwing (accuracy)	EF, IF	EF > IF Note: Multiple EF and IF conditions
Emanuel, Jarus, & Bart (2008)	Dart throwing	EF, IF	EF = IF Note: See text for limitations

Table 1 (*Continued*)

Study	Movement Effectiveness		
	Task	Groups/ Conditions	Results
Lohse, Sherwood, & Healy (2010)	Dart throwing	EF, IF	EF > IF
Marchant, Clough, & Crawshaw (2007)	Dart throwing	EF, IF, C	EF > IF, C
Marchant, Clough, Crawshaw, & Levy (2009)	Dart throwing	EF, IF	EF > IF
Schorer, Jaitner, Wollny, Fath, & Baker (2012)	Dart throwing	EF, IF	EF = IF Note: Different EF and IF conditions
Ong, Bowcock, & Hodges (2010)	Frisbee throwing	EF, IF	EF > IF
Porter & Anton (2011)	Pursuit rotor	EF, IF, C	EF > IF, C
Zentgraf & Munzert (2009)	Juggling	EF, IF, C	EF, C > IF IF > EF, C Note: See text for limitations
Duke, Cash, & Allen (2011)	Piano	EF, IF	EF > IF Note: Different EF conditions
Lawrence, Gottwald, Hardy, & Khan (2011)	Gymnastics routine	EF, IF, C	EF = IF = C Note: See text for limitations

Notes: 'Groups/Conditions' and 'Results' are simplified as some studies included more than one external or internal focus condition, more than one dependent variable, or more than one measure of learning (i.e., retention and/or transfer test in learning studies). EF = external focus; IF = internal focus; C = control condition or group; > stands for 'outperformed'.

Experiment 2; Wulf et al., 2009), they yielded similar performances as internal focus instructions, and therefore inferior outcomes to external focus instructions.

Accuracy

Several studies have assessed movement effectiveness by using outcome measures such as accuracy in hitting a target. Accuracy in hitting golf balls has been demonstrated to be enhanced when performers were asked to focus on either the swing of the club (Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007), the clubface, or the intended ball trajectory (Bell & Hardy, 2009) rather than on their arms (Wulf et al., 1999; Wulf & Su, 2007) or wrists (Bell & Hardy, 2009). Similarly, putting accuracy was increased with focus instructions directed at the movements of the putter compared to movements of the hands (Granados, 2010). Interestingly, external focus instructions enhanced performance even in experienced athletes relative to internal focus (Bell & Hardy, 2009; Wulf & Su, 2007) and control conditions (Wulf & Su, 2007).

Accuracy in throwing balls, darts, and Frisbees, or kicking balls has also been found to be improved with an external focus. For instance, basketball free-throw shooting accuracy benefited from a focus on the basket or ball trajectory compared to a focus on wrist flexion or movement form (Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002; Zachry, Wulf, Mercer, & Bezodis, 2005). Similarly, accuracy in dart throwing has been demonstrated to increase with an external focus (Lohse, Sherwood, & Healy, 2010; Marchant, Clough, & Crawshaw, 2007), particularly when the focus is more distal (i.e., on the bullseye) rather than proximal (i.e., the trajectory of the dart) (McKay & Wulf, 2012). Chiviawsky, Wulf, and Ávila (2012) found that mentally challenged children learned to toss beanbags more accurately when asked to focus on the movement of the beanbag rather than the movement of their hand. Similar findings were obtained for 10-year old children with attention deficit hyperactivity disorder (Saemi, Porter, Wulf, Ghotbi-Varzaneh, & Bakhtiari, 2012). In addition to enhancing throwing accuracy, the automaticity resulting from an external focus also seems to make performance more resistant to skill failure under pressure (Ong, Bowcock, & Hodges, 2010).

Volleyball serves, soccer kicks (Wulf, McConnel, Gärtner, & Schwarz, 2002), and soccer throw-ins (Wulf, Chiviawsky, Schiller, & Ávila, 2010) have been demonstrated to result in more accurate outcomes when participants were given feedback inducing an external rather than internal focus. Also, in football kicking, directing participants' attention to the part of the ball that they would strike (external) rather than the part of the foot that would contact the ball resulted in greater accuracy in hitting the target (Zachry, 2005).

Duke, Cash, and Allen (2011) examined attentional focus effects on music performance. Music majors were asked to perform a keyboard passage, which consisted of 13 alternating sixteenth notes (A and F) that were to be played as quickly and evenly as possible. All participants played the sequence under four conditions: with a focus on their finger movements, on the movements of the piano keys, on the hammers, or on the sound of the keyboard. On a transfer test that involved the reverse tone sequence, a focus on the more distal movement effects (sound or hammers) resulted in greater consistency than either focusing on the more proximal effect (keys) or the internal focus (fingers).

On a pursuit-rotor task, Porter and Anton (2011) asked older adults who suffered from symptoms consistent with "chemo-brain" to focus either on the handle of the stylus (external) or their hand (internal) while tracking the rotating light. The external focus condition resulted in increased time on target relative to both the internal focus and a control condition in which participants were simply instructed to do their best.

In several other studies, participants were asked to produce a certain amount of force while concentrating on the effector, such as the hand, tongue (Freedman, Maas, Caligiuri, Wulf, & Robin, 2007), or foot (Lohse, 2012; Lohse, Sherwood, & Healy, 2011), or on the device against which the force was exerted, such as a bulb or platform. For example, Lohse trained participants to produce either 25% or 50% of their maximum voluntary contraction (MVC) in a plantar flexion task. Participants trained under the external focus condition were significantly more accurate by the end of practice phase (60 trials) than the internal focus group. More importantly, even one week later, the external focus participants remained significantly more

accurate on the retention test and also outperformed the internal focus group on a transfer test requiring a new percentage of their MVC.

Movement efficiency

A movement pattern is considered more efficient or economical if the same movement outcome is achieved with less energy expended. Direct measures of efficiency that have been used in examinations of attentional focus effects include muscular (electromyographic or EMG) activity, oxygen consumption, and heart rate. In other studies, more indirect measures such as maximum force production, movement speed, or endurance were used. Typically, in these types of studies, within-participant designs are used to assess differences in performance (rather than learning) to control not only for electrode placement but also for individual differences in skill or physical shape. Table 2 provides a summary of studies related to movement efficiency, the tasks and groups/conditions used in those studies, and the results.

Muscular activity

Some studies have used bicep curl tasks to examine muscular activity under various focus conditions. In a study by Vance, Wulf, Töllner, McNevin, and Mercer (2004), instructing participants to focus on the weight bar (external) as opposed to their arms (internal) resulted in lower integrated EMG activity (iEMG) in both agonist (biceps brachii) and antagonist (triceps brachii) muscles. In a follow-up study, Marchant, Greig, and Scott (2008) added a control condition and found that control and internal focus conditions yielded similar levels of EMG activity, but muscular activity was lower with an external focus.

EMG activity has also been measured in studies using target-oriented tasks such as free-throw shooting in basketball (Zachry et al., 2005) and dart throwing (Lohse et al., 2010). These studies are particularly interesting as they demonstrate a possible association between muscular activity and movement accuracy. In the Lohse et al. study, an external focus on the flight of the dart not only improved throwing accuracy but also resulted in reduced EMG activity in the triceps muscle. Similarly, in Zachry et al.'s study, participants who were instructed to focus on the basketball hoop (external) rather than the wrist flexion of their throwing arm (internal) while performing free-throws, demonstrated greater accuracy as well as reduced EMG activity in both the biceps and triceps brachii. Thus, EMG activity was affected in muscle groups that participants were not specifically instructed to focus on, demonstrating that a performer's attentional focus on one part of the body can 'spread' to other muscle groups, thus increasing movement inefficiency at a more general level. Similar 'spreading' effects were seen in other studies as well (e.g., Vance et al., 2004; Wulf, Dufek, Lozano, & Pettigrew, 2010).

A higher degree of co-contractions of agonist and antagonist muscles with an internal focus was found by Lohse et al. (2011) using an isometric force production task. Participants' task was to press against a force platform with their dominant foot with 30% of their maximum force. Focusing on the calf muscles (internal) led to less accurate force production than concentrating on the force platform (external) and to increased co-contractions between the soleus (agonist) and tibialis anterior

Table 2. Studies related to movement efficiency (e.g., muscle activity, maximum force production, speed and endurance).

Study	Movement Efficiency		
	Task	Groups/ Conditions	Results
Vance, Wulf, Töllner, McNevin, & Mercer (2004, Exp. 1)	Bicep curls	EF, IF	EF > IF
Vance, Wulf, Töllner, McNevin, & Mercer (2004, Exp. 2)	Bicep curls	EF, IF	EF > IF
Marchant, Greig, & Scott (2008)	Bicep curls	EF, IF, C	EF > IF, C
Lohse, Sherwood, & Healy (2011)	Isometric force production	EF, IF	EF > IF
Lohse (2012)	Isometric force production	EF, IF	EF > IF
Marchant, Greig, & Scott (2009)	Isokinetic force production	EF, IF	EF > IF
Marchant, Greig, Bullough, & Hitchen (2011)	Weightlifting (number of repetitions)	EF, IF	EF > IF
Lohse & Sherwood (2011, Exp. 1)	Wall-sit	EF, IF	EF > IF
Lohse & Sherwood (2011, Exp. 2)	Wall-sit	EF, IF	EF > IF
Maurer (2011)	Jump-and-reach	EF, IF, C	EF > C > IF
Wulf, Zachry, Granados, & Dufek (2007, Exp. 2)	Jump-and-reach	EF, IF, C	EF > IF, C
Wulf & Dufek (2009)	Jump-and-reach	EF, IF	EF > IF
Wulf, Dufek, Lozano, & Pettigrew (2010)	Jump-and-reach	EF, IF	EF > IF
Porter, Anton, & Wu (forthcoming)	Standing long-jump	EF, IF	EF > IF Note: Different EF conditions
Porter, Ostrowski, Nolan, & Wu (2010)	Standing long-jump	EF, IF	EF > IF
Wu, Porter, & Brown (2012)	Standing long-jump	EF, IF, C	EF > IF, C
Zarghami, Saemi, & Fathi (2012)	Discus throwing	EF, IF	EF > IF
Porter, Nolan, Ostrowski, & Wulf (2010)	Agility	EF, IF, C	EF > IF, C
Porter, Wu, Crossley, & Knopp (2012)	Sprinting	EF, IF, C	EF > IF, C
Schücker, Hagemann, Strauss, & Völker (2009)	Running	EF, IF	EF > IF Note: Different EF conditions
Stoate & Wulf (2011)	Swimming	EF, IF, C	EF, C > IF Note: Experts

Table 2 (Continued)

Study	Movement Efficiency		
	Task	Groups/ Conditions	Results
Parr & Button (2009)	Rowing	EF, IF	EF > IF
Banks (2012)	Kayaking	Distal EF, proximal EF, C	Distal EF > proximal EF > C
Neumann & Brown (forthcoming)	Sit-ups	EF, IF	EF > IF

Notes: 'Conditions' and 'Results' are simplified as some studies included more than one external or internal focus condition, more than one dependent variable, or more than one measure of learning (i.e., retention and/or transfer test in learning studies). EF = external focus; IF = internal focus; C = control condition or group; > stands for 'outperformed'.

(antagonist) muscles, indicating a less efficient coordination between muscle groups. Lohse and colleagues also analyzed the power spectral density of the EMG signal and found increases in the median power frequency – indicating superfluous motor unit recruitment of larger motor units within the muscles – when participants focused internally (see also Vance et al., 2004).

Reduced muscular activity with an external focus relative to an internal focus is associated not only with more accurate force production (see above) but also with the production of greater maximal forces (e.g., Marchant, Greig, & Scott, 2009; Wulf & Dufek, 2009; Wulf, Dufek, Lozano, & Pettigrew, 2010). In the study by Marchant et al., a focus on the crank bar while performing bicep curls resulted in increased peak joint torque, and less EMG activity, compared with an internal focus on the arm muscles. In line with these findings, Wulf and colleagues found that greater jump height was achieved with an external focus, accompanied by lower EMG activity in various leg muscles, when an external focus was adopted. I elaborate on findings related to maximum force production in the next section.

Maximum force production

The production of maximum forces requires an optimal activation of agonist and antagonist muscles, as well as optimal muscle fiber recruitment. Unnecessary co-contractions, imperfect timing, and/or direction of forces would result in less-than-maximal force output. Studies examining maximum force production also demonstrate differences in muscular coordination, or movement efficiency, as a function of attentional focus (for a review, see Marchant, 2011). For example, Marchant, Greig, and Scott (2009) had experienced exercisers produce maximum voluntary isokinetic contractions of the elbow flexors, while focusing on either their arm muscles (internal) or the crank bar of the dynamometer (external). They found that participants produced significantly greater peak joint torque when they focused externally.

In other studies, maximum vertical jump height was found to be increased with an external relative to an internal focus (and control conditions) for both adults (Wulf & Dufek, 2009; Wulf, Dufek, Lozano, & Pettigrew, 2010; Wulf, Zachry,

Granados, & Dufek, 2007) and children (Maurer, 2011). Using within-participant designs, participants in these studies were instructed to concentrate on the tips of their fingers (internal) or on the rungs (external) of the measurement device (Vertec) they attempted to displace during the jumps. The findings of these studies demonstrated that participants jumped significantly higher in the external focus than in the internal focus conditions (or in a control condition; Maurer, 2011; Wulf, Zachry, Granados, & Dufek, 2007). Furthermore, the vertical displacements of the center of mass, impulses, and joint moments about the ankle, knee, and hip joints were significantly greater, indicating that increased jump height with an external focus was achieved through greater force production (Wulf & Dufek, 2009).

Standing long-jump performance has also been shown to be enhanced with an external focus (Porter, Anton, & Wu, forthcoming; Porter, Ostrowski, Nolan, & Wu, 2010; Wu, Porter, & Brown, 2012). For example, in the study by Porter and colleagues (2010), different groups were instructed to either focus on extending their knees as rapidly as possible (internal) or jumping as far past the start line as possible (external). Average jumping distance was 10 cm greater with an external relative to an internal focus. In a follow-up study by Wu et al., the external focus instruction to jump as close to a target as possible also resulted in considerable benefits compared to internal focus (14 cm) and control conditions (20 cm).

Finally, Zarghami, Saemi, and Fathi (2012) had male participants, who had some discus-throwing experience, execute five maximum-effort discus throws under different attentional focus conditions, which were completed on consecutive days. External focus instructions directed at the discus resulted in significantly greater throwing distances than internal focus instructions directed at the hand and wrist.

Speed and endurance

Due to the enhanced movement automaticity and efficiency associated with an external focus, movement speed has been found to be increased as well. The shorter movement times and greater peak velocities found by Fasoli, Trombly, Tickle-Degnen, and Verfaellie (2002) for various functional reach tasks in persons after stroke and age-matched controls, when given external relative to internal focus instructions, suggest greater fluidity in their motions. Another task in which fluidity plays a crucial role (Chen, Liu, Mayer-Kress, & Newell, 2005) is the Pedalo task used by Totsika and Wulf (2003). The Pedalo, which consists of two small platforms (one for each foot) between sets of wheels, moves by alternately pushing the upper platform forward and downwards. Instructing participants to focus on pushing the platforms forward (external focus) resulted in increased movement speed relative to instructing them to focus on pushing their feet forward (internal focus).

In longer-duration tasks for which fatigue is a limiting factor, such as tasks requiring sub-maximal or maximal force production over an extended period of time, an external focus enables performers to maintain a certain sub-maximal force level longer, or to increase the force level for a given period of time (e.g., 10 s). For example, Porter and colleagues demonstrated the benefits of adopting an external focus for tasks involving running (Porter, Nolan, Ostrowski, & Wulf, 2010; Porter, Wu, Crossley, & Knopp, 2012). In one of these studies, Porter et al. (2010) found that an external focus reduced the time taken to complete a whole-body agility task (so-called 'L' run). Relative to internal focus instructions and control conditions, the

same participants ran faster when given external focus instructions. In another study (Porter et al., forthcoming), 20-m sprint times were significantly reduced with an external focus (i.e., clawing the floor with the shoes), compared with an internal focus (i.e., moving the legs and feet down and back as quickly as possible) or a control condition (i.e., running as quickly as possible).

An external focus of attention has also been found to increase swim speed. Asking intermediate crawl swimmers to focus on pushing the water back (external focus) resulted in significantly shorter times (over 16 m) than asking them to focus on pulling their hands back or giving no focus instructions (Freudenheim et al., 2010). Similarly, expert swimmers with several years of competitive experience swam faster with external relative to internal focus instructions (Stoate & Wulf, 2011). However, compared with a control condition, the external focus instruction provided no additional advantage in this case, presumably because in these experts movements were already highly automatized. Interestingly, self-reports indicated that the experts' 'normal' focus (i.e., in the control condition) differed among participants, and those swimmers who reported more of an internal focus (e.g., hip rotation, spinning arms, high elbow) had slower swim times than others who reported focusing on the overall outcome (e.g., speed, tempo, going fast, swimming hard). This finding is similar to the results of a study by Jackson, Ashford, and Norsworthy (2006, Experiment 2), in which soccer players performed a dribbling task. When asked to set themselves a process goal, those who chose a goal related to the technique (internal focus) performed more slowly, whereas those who set a goal related to the strategy, such as the position of the ball in relation to the cones (external focus), maintained performance speed.

Banks (2012) asked experienced kayakers to paddle a distance of 75 m under different focus conditions. Instead of including an internal focus condition, he compared the effects of a distal external focus (i.e., on the finish line) and a proximal external focus (i.e., on boat stability) with a control condition. The distal focus led to greater racing speed than the control condition, while the proximal focus produced the slowest time. (The influence of the 'distance' of the external focus is discussed in a later section.)

Marchant, Greig, Bullough, and Hitchen (2011) demonstrated the influence of attentional focus on muscular endurance in trained individuals performing exercise routines. The authors measured the number of repetitions to failure during various exercises (i.e., bench press tests on a Smith Machine, free bench press, free squat lift) with weights corresponding to 75% of each participant's repetition maximum. An external focus on the movement of the bar being lifted allowed for a significantly greater number of repetitions than an internal focus on the movements of the limbs involved (i.e., arms, legs) in all three exercises. The number of repetitions with an external focus also exceeded that in the control conditions in most cases. In another study using an isometric force production task (wall-sit), Lohse and Sherwood (2011) measured time to failure with external versus internal focus instructions. They also found an increase in participants' capability to hold the posture with an external focus on keeping imaginary lines between their hips and knees horizontal, as opposed to an internal focus on the horizontal position of their thighs.

Another interesting example of how changing the focus of attention can improve movement efficiency comes from a study by Schücker, Hagemann, Strauss, and Völker (2009). These authors had skilled runners focus their attention either

internally on a movement-relevant aspect of the task (running form), internally on a movement-irrelevant aspect of the task (breathing), or externally on a video display that simulated running outdoors, while running on a treadmill. For three 10-min periods each, runners concentrated on the running movement (internal focus), on their breathing (internal focus), or on the virtual surroundings (external focus). Schücker et al. found reduced oxygen consumption with an external focus of attention compared with either of the internal foci.

Finally, Neumann and Brown (forthcoming) gave different attentional focus instructions while participants performed several sets of sit-ups. External focus instructions to ‘make your movements smooth’ or ‘make your movements flow’, compared to internal focus instructions to ‘focus on your stomach muscles’ or ‘feel your stomach muscles working’, resulted in reduced heart rate and EMG activity, despite a larger range of motion.

Movement kinematics

Aside from a more efficient and effective coordination within muscles (i.e., motor unit recruitment) and between muscles (i.e., co-contractions) (see above), there is accumulating evidence that the attentional focus induced by instructions can also affect movement coordination on a larger scale, providing another piece in the puzzle that some scientists have been looking for (e.g., Peh, Chow, & Davids, 2011). In addition to expert ratings of movement form (Wulf, Chiviacowsky, Schiller, & Ávila, 2010), analyses of movement kinematics and kinetics used in some recent studies have shown that whole-body coordination patterns seem to be optimized with external focus as well (An, Wulf, & Kim, forthcoming; Lohse et al., 2010; Parr & Button, 2009; Southard, 2011; Wulf & Dufek, 2009).

Wulf and Dufek (2009) argued that a ‘freeing’ of the body’s degrees of freedom may contribute to the increased force output seen with an external focus. This suggestion was based on the findings of their study, using the jump-and-reach task, which showed that joint moments around various joints (i.e., ankle, knee, hip) were correlated with each other when an internal focus (on the finger) was adopted – presumably representing a ‘freezing’ of degrees of freedom (Vereijken, van Emmerik, Whiting, & Newell, 1992) – but not with an external focus (on the rungs). In addition, there was a greater number of negative correlations between joint moments and outcome-related variables, such as jump height, with an internal focus than with an external focus. Along the same lines, Ford, Hodges, Huys, and Williams (2009) found higher correlations across the displacements of various joints for soccer kicks when the players’ focus was on their body movements (internal) compared to a focus on the ball trajectory (external). Thus, an internal focus seems to have the effect of linking semi-independent body segments, thereby constraining the motor system, whereas an external focus releases those constraints (see also Hossner & Ehrlenspiel, 2010).

These findings seem to provide support for the idea that an external focus on the intended movement effect allows for ‘functional variability’ (e.g., Müller & Loosch, 1999), such that the motor systems automatically adjust the various degrees of freedom to achieve that effect (Wulf & Prinz, 2001). Wulf and Prinz cited evidence from studies demonstrating that variability in the movement outcome was smaller than the combined variability in the movement parameters contributing to that

outcome. For example, in a study by Loosch (1995) using a dart-throwing task, the variability of hits on the dartboard was smaller than the theoretical variability calculated from the variability in the velocity of the dart at release and its vertical release angle, particularly in skilled darts players. Also, negative correlations between these parameters indicated that a smaller release angle was compensated by a higher velocity of the dart, and vice versa. Using an attentional focus manipulation, Lohse et al. (2010) found some evidence for increased functional variability with an external relative to an internal focus. When instructed to focus on the flight of the dart, participants' variability in the shoulder angle at the moment of release was significantly greater (2.3 degrees) than when the focus was on their arm (1.9 degrees), and throwing accuracy was greater as well. Although more research is needed to confirm these findings, these results provide initial support for the notion that an external focus results in greater accuracy due to increased functional variability (similar to that typically seen in more skilled performers).

Differential effects of external versus internal focus instructions are also seen in the kinematics of other skills requiring whole body coordination. In novice rowers, for instance, a set of instructions directed at the blade (e.g., 'Keep the blade level during the recovery') rather than the hands (e.g., 'Keep your hands level during the recovery') led to greater improvements in the technique, as evidenced by various kinematic measures after a seven-week retention interval (Parr & Button, 2009). Parr and Button found that participants who were given external focus instructions demonstrated a shorter time and distance to lock (i.e., from maximum reach to the blade being fully immersed) on retention and transfer tests (involving crews of four learners), indicating the learning of a more efficient movement pattern.

A recent study by An et al. (forthcoming) examined the effects of attentional focus instructions on the learning of movement form and carry distance in novice golfers. An important contributor to the carry distance is the so-called X-factor (i.e., the rotation of the shoulders relative to the pelvis). Its increase during the downswing (so-called X-factor stretch) is associated with the carry distance of the ball, and both have been shown to be associated with an early weight shift toward the front leg during the downswing (e.g., Hume, Keogh, & Reid, 2005). Therefore, An et al. instructed one group of participants to focus on shifting their weight to their left foot while hitting the ball (internal) and another group to focus on pushing against the left side of the ground (external). After a three-day retention interval, the external focus group demonstrated a greater X-factor stretch, higher maximum angular velocities of the pelvis, shoulder, and wrist, and a greater carry distance of the ball than the internal focus and a control group, which showed very similar performances. These findings demonstrate that both movement outcome and form can be enhanced in complex skill learning by providing learners with relatively simple external focus instructions.

How does the attentional focus affect performance and learning?

In our first attempts to provide an explanation for the differential effects of different foci, we referred to Prinz's (1990, 1997) common-coding theory of perception and action (see Wulf et al., 1998; Wulf & Prinz, 2001). According to that theory, there is a common brain representation for perception and action. Both refer to 'distal events', as this is the only format that allows for commensurate coding. Thus, the finding that

movements were more effective when they were planned in terms of their intended outcome or effect (i.e., with an external focus), rather than in terms of the specific movement patterns (i.e., with an internal focus), is in line with common-coding theory assumptions. Yet, because the theory is rather abstract, it does not specifically predict the differential learning effects of external versus internal attentional foci. It also does not explain any underlying mechanisms of this effect.

Subsequently, we proposed the constrained action hypothesis (Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001) as a testable explanation. According to this view, an internal focus induces a conscious type of control, causing individuals to constrain their motor system by interfering with automatic control processes. In contrast, an external focus promotes a more automatic mode of control by utilizing unconscious, fast, and reflexive control processes. Several converging lines of research support this notion. Studies have shown an association of external focus instructions and various measures of automaticity, including demonstrations of reduced attentional-capacity demands (Wulf, McNevin, & Shea, 2001), high-frequency movement adjustments (e.g., McNevin et al., 2003; Wulf, Shea, & Park, 2001), and reduced pre-movement times, representing more efficient motor planning (Lohse, 2012). The question remains, however: How exactly is it that instructions that induce different attentional foci produce automaticity versus conscious control?

We recently expanded the constrained action view (Wulf & Lewthwaite, 2010). We were particularly struck by the fact that often a one- or two-word difference in the instructions (e.g., ‘focus on the markers’ versus ‘focus on your feet’; Wulf et al., 1998, Experiment 2) had such a strong impact on performance. We therefore suggested that an internal focus may act as a ‘self-invoking trigger’. That is, references to one’s body parts or bodily movement are assumed to facilitate access to the neural representation of the *self* and result in self-evaluative and self-regulatory processing. Given that the self appears to be highly accessible, even unconsciously, in many circumstances, including all movement contexts – influencing thoughts, actions, and behavior (e.g., Bargh & Morsella, 2008; Chartrand & Bargh, 2002) – we argued that conditions that trigger neural activation in the self system (e.g., internal focus instructions) result in what we called ‘micro-choking’ episodes. As a consequence, performance is degraded (for a more elaborate discussion, see Wulf & Lewthwaite, 2010).

Are there contradictory findings? (Or: Methodological considerations for attentional focus research)

Despite the pervasive evidence for the benefits of adopting an external focus, some researchers seem to have remained skeptical (e.g., Peh et al., 2011; Schorer, Jaitner, Wollny, Fath, & Baker, 2012; Zentgraf & Munzert, 2009). The idea that novices do *not* learn more effectively when their attention is directed to the coordination of their body movements seems to be a particularly difficult one to abandon. The perpetuation of the notion that novices (should) show enhanced learning with internal focus instructions, or that ‘form’ skills (should) benefit from an internal focus, is perhaps ‘intuitive’, or based on individuals’ own learning experiences or the beliefs most researchers have held for decades. Perhaps not coincidentally, it often coincides with mis- or over-interpretations of findings and/or confounds in the instructions used in some studies. I elaborate on the latter points below. I will also

highlight some methodological issues researchers need to consider when designing studies to examine attentional focus effects.

The argument that an internal focus is necessary and beneficial in early learning is frequently backed up with findings showing that novices perform more effectively when their attention is directed to the skill ('skill focus') rather than an irrelevant secondary task (i.e., dual-task conditions) (e.g., Beilock, Bertenthal, McCoy, & Carr, 2004; Beilock, Carr, MacMahon, & Starkes, 2002; Gray, 2004). However, a 'skill focus' has not been clearly defined and has been operationalized differently in different studies. That is, the instructions given in skill-focused conditions have varied in terms of whether they induced an internal focus (e.g., foot in soccer dribbling, Beilock et al., 2002) or external focus (e.g., straight club motion in golf putting, Beilock et al., 2004; motion of baseball bat, Gray, 2004). The fact that inexperienced individuals demonstrate more effective performance when they focus on the skill (with either an external or internal focus), compared to when they are distracted by a secondary task, will be hardly surprising to most people. Importantly, these studies did not explicitly compare performances under external versus internal focus conditions. That is, this line of research has pursued a different question. Both external and internal foci are typically related to the skill and thus constitute, perhaps in a broad sense, a 'skill focus'. Presumably, not too many people would disagree with the idea that learners need instructions and feedback related to their performance of the skill they are trying to learn. Research on external versus internal foci of attention is merely concerned with the question of how and why different foci (on the skill) affect performance and learning differently. To address those issues, it is important that the instructions used in experiments differ only with regard to the attentional focus they induce.

Some claims of superiority of an internal relative to an external focus can be attributed to experimental manipulations that confounded the type of attentional focus with other variables. To be able to compare the effectiveness of external versus internal foci, the respective instructions should be as similar as possible in terms of the content of the information they provide and the amount of information the performer is confronted with. Also, it is important that the processing of other types of information (e.g., visual) not be encouraged through one set of instructions (e.g., external) but not the other (e.g., internal). In our studies, we have always attempted to make external and internal focus instructions so similar that they differed in only one or two words to avoid confounds with other variables (e.g., 'focus on the swing of the club' versus 'focus on the swing of your arms', Wulf & Su, 2007; 'focus on the wheels' [under the feet] versus 'focus on your feet', Wulf et al., 1998; 'focus on the rungs' versus 'focus on your fingers' [touching the rungs], Wulf & Dufek, 2009). While most other researchers have applied the same stringent criteria to the formulation of their instructions, in some cases such confounds presumably contributed to what have been interpreted as contradictory results (Canning, 2005; Emanuel, Jarus, & Bart, 2008; Perkins-Ceccato, Passmore, & Lee, 2003; Zentgraf & Munzert, 2009).

For instance, in a study with persons who had Parkinson's disease, Canning (2005) examined how different instructions affected their gait when they were carrying a tray with glasses on it. Instructions to focus on 'maintaining big steps while walking' (which Canning interpreted as internal focus) produced greater stride length and faster walking speed than a focus on 'balancing the tray and glasses'

(which Canning considered an external focus). Aside from the fact that it is questionable to what extent the respective instructions actually induced an internal or external focus, they clearly referred to different aspects of the task. Similarly, in a study that used a juggling task (Zentgraf & Munzert, 2009), external focus instructions ('focus on the balls... Both balls should reach approximately the same height') and internal focus instructions ('focus on your arms and hands... Juggling should mainly be performed from the forearm, not the whole arm...') were directed at different aspects of the skill. Not surprisingly, the former instructions resulted in more similar ball heights, whereas the latter ones led to more similar elbow displacements. What the findings of these studies (e.g., Canning, 2005; Zentgraf & Munzert, 2009) show is that participants followed the instructions. They performed more effectively on whatever aspect of the task was emphasized in the instructions. Yet, because of the confounded instructions, the findings do not tell us anything about the relative effectiveness of the two foci per se.

In addition to avoiding confounding instructions, it is also necessary to make instructions specific enough for performers to understand what exactly they are asked to concentrate on. In the study by Perkins-Ceccato et al. (2003) – frequently cited as evidence for the benefits of an internal focus in novices – participants hitting golf balls at a target were given external focus instructions ('concentrate on hitting the ball as close to the target pylon as possible') or internal focus instructions ('concentrate on the form of the golf swing and to adjust the force of their swing depending on the distance of the shot') (p. 596). Aside from the fact that the instructions again referred to different aspects of the task, there were no references to the performer's *body* in the 'internal' focus instructions. Therefore, these instructions do not conform to the definition of an internal focus. Second, because of the vagueness of the instructions, it is not clear what exactly participants focused on. With an emphasis placed on the force of the swing (and participants being asked to judge the appropriateness of the force they had used after a trial), performers may, in fact, have focused on the impact the club had on the ball, which would constitute an external focus. The performance advantage seen under this condition would actually be in line with other findings showing that a focus on the club is more effective than a focus on the target in novices (Wulf, McNevin, Fuchs, Ritter, & Toole, 2000). It should also be noted that differences between focus conditions in the Perkins-Ceccato et al. study were found only in the shot variability, not in accuracy. Furthermore, performance differences between groups were observed only in certain subgroups (i.e., those that performed under the respective attentional focus conditions first). Considering the issues raised above, it is unfortunate that the Perkins-Ceccato et al. study is so frequently cited as showing a benefit of an internal focus.

Other researchers have observed null effects in their studies (e.g., Castaneda & Gray, 2007; Cluff, Gharib, & Balasubramaniam, 2010; de Bruin, Swanenburg, Betschon, & Murer, 2009; Emanuel et al., 2008; Lawrence, Gottwald, Hardy, & Khan, 2011; Poolton, Maxwell, Masters, & Raab, 2006; Schorer et al., 2012). Some therefore questioned the reliability and generalizability to certain tasks (i.e., those being evaluated on movement form) or populations (children, older adults). However, there appear to be relatively simple explanations for almost all of these failures to replicate the advantages of an external focus. In some cases, powerful visual feedback (e.g., a moving point representing the center of gravity relative to a

target on a balance task; de Bruin et al., 2009) presumably obfuscated effects of focus instructions. In other cases, body-related instructions in external focus conditions may have attenuated potential benefits (e.g., Southard, 2011). Also, when attentional focus instructions create a dual-task situation – as in a study by Castenada and Gray (2007), in which participants hitting baseballs had to make a judgment regarding the direction in which their hands (internal) or the bat (external) were moving when a tone was presented – the additional demands imposed on novices may cancel out any focus effects. In other studies, the sheer number of instructional statements may explain the lack of effect (Emanuel et al., 2008; Poolton et al., 2006, Experiment 2). That is, any potential effect of different focus instructions was presumably thwarted by the overwhelming informational load imposed upon learners. In addition, the lack of comparability of the internal and external focus instructions, as well as the different number of instructions in each condition (4 versus 6), constituted confounding variables in Emanuel et al.'s study. Their study, using a dart-throwing task, is often cited as demonstrating learning benefits of internal focus instructions for children. Furthermore, those researchers found only an interaction effect of age (children versus adults) and focus (internal versus external) for one of the two tests of learning (transfer, but not retention) for one of the two dependent variables (radial error, but not variable error). Post-hoc tests to determine whether the two groups of children actually differed significantly were not conducted, or at least not reported. This study is another example of how the over-interpretation of findings can lead to repeated, and perhaps unchecked, claims that an external focus might not 'work' for children. (There is, in fact, evidence to the contrary: Chiviawosky et al., 2012; Maurer, 2011; Saemi et al., 2012; Wulf, Chiviawosky, Schiller, & Ávila, 2010).

Lawrence et al. (2011) have recently argued that external focus instructions might not be appropriate for tasks in which the main objective is to produce the correct movement form, such as gymnastics routines (see also Peh et al., 2011). The null effect obtained in that study is not surprising, though, when considering the instructions relative to the complexity of the task and scoring system. Instructions given to participants (novices) for the complex, five-part floor routine were to focus on the movement pathway and on exerting an even pressure on the support surface (external focus) versus exerting an equal force on their feet, keeping their arms out straight and level with their shoulders (internal focus) (Lawrence et al., 2011, p. 434). Thus, not only were the focus instructions confounded with the information they provided, but they were also completely irrelevant to most aspects of the routine – consisting of a lunge, arabesque, full turn, etc. – and to the 30 or so different criteria used to evaluate movement form (e.g., height of elements, extension in preparation for landing, dynamics, amplitude of elements). The lack of a clear improvement during practice, as well as the lack of group differences in retention and transfer, is not surprising. More appropriate, and comparable, instructions may well have produced the typical attentional focus effect. It is difficult to see why motor skills requiring 'movement form' would be coordinated completely differently from motor skills that involve implements.

Thus, in most cases there appear to be clear methodological reasons for the inconsistencies in the results, or lack of findings. Specifically, researchers should take care to avoid visual feedback that may overpower any attentional focus, use instructions that are relevant to task performance, and use motor tasks that are challenging enough. In addition, researchers must ensure there are no potential

confounding factors and that instructions are comparable in wording and information content. By so doing, much of the confusion in the literature will likely be reduced.

Summary and practical implications

A rough count of the number of studies that have used comparable instructions under different focus conditions reveals that in about 80 experiments significant advantages of external relative to internal foci (or, in some cases, distal relative to proximal foci) were found, sometimes in more than one measure of performance. Only a handful of those studies obtained null effects (e.g., Cluff et al., 2010; de Bruin et al., 2009; Poolton et al., 2006), some presumably for reasons mentioned above. In no case was an internal focus advantageous. In this section, I summarize the findings reviewed in the previous sections, which will demonstrate the broad generalizability of the attentional focus effect across tasks, populations, and performance measures. I also highlight some important aspects of the findings that indicate the potency of the external focus advantages. Finally, I comment on some practical implications of this research.

Generalizability across tasks and populations

As reviewed above, the benefits of an external compared to an internal focus have been shown for a variety of skills, ranging from pressing keys (Duke et al., 2011; Nedelko, Stoppel, Hassa, Dettmers, & Schoenfeld, 2009) to driving golf balls (e.g., An et al., forthcoming). In addition, they have been found for different levels of expertise, ranging from the novices in most studies to intermediate (e.g., Wulf et al., 2002) and experienced performers (e.g., Bell & Hardy, 2009; Wulf & Su, 2007). Furthermore, the external focus advantages have been found for people of various age groups, including children (Chiviawsky et al., 2012; Thorn, 2006; Wulf, Chiviawsky, Schiller, & Ávila et al., 2010), the young adults used in the majority of studies, as well as older adults (e.g., Chiviawsky et al., 2010). Benefits of external focus instructions have not only been found for healthy adults but also for adults with injuries (Laufer et al., 2007; Rotem-Lehrer & Laufer, 2007) and with motor impairments caused by stroke or Parkinson's disease (Fasoli et al., 2002; Landers et al., 2005; Wulf et al., 2009), as well as for children with intellectual disabilities (Chiviawsky et al., 2012).

Generalizability across measures of performance

Performance and learning advantages with the adoption of an external relative to an internal focus have also been demonstrated using a variety of measures reflecting movement effectiveness (e.g., accuracy, consistency, balance) and movement efficiency (e.g., EMG, heart rate, force production, speed, endurance). In addition, some studies have shown kinematic changes in movement patterns with an external focus that resemble those typically seen in experienced performers (An et al., forthcoming; Lohse et al., 2012; Parr & Button, 2009). Together, these results provide evidence that an external focus speeds up the learning process, thereby enabling performers to achieve a higher level of expertise sooner (Wulf, 2007b).

Learning effects

That those effects are indeed learning effects (i.e., reflect relatively permanent changes) is underscored by the fact that they are seen not only on retention tests without focus instructions or reminders, but that they transfer to novel situations (e.g., Duke et al., 2011; Lohse, 2012; Ong et al., 2010; Wulf, Chiviawsky, Schiller, & Ávila, 2010). Some of the transfer tests involved pressure to perform well (Bell & Hardy, 2009), time pressure, or a distractor task to prevent the use of the instructed focus (Totsika & Wulf, 2003). Perhaps the most direct evidence that the changes in performance are learning effects (i.e. are seen even when the [external or internal] attentional focus is no longer directed at the task at hand) comes from the study by Wulf et al. (2003). In that study, attention was directed to a supra-postural task (i.e., holding an object still), either internally or externally, during practice of the stabilometer task. Not only was balance performance improved by the external focus on the supra-postural task as well, but even when the supra-postural task was removed on the transfer test – thereby eliminating the opportunity to focus externally – balance was still enhanced.

Learning enhancements

It is also important to point out that an external focus of attention enhances learning, as opposed to an internal focus degrading learning. When control conditions without focus instructions were included, internal focus and control conditions almost invariably resulted in similar performances, while an external focus led to more effective performance than both (An et al., forthcoming; Freudenheim et al., 2010; Landers et al., 2005; Marchant et al., 2008; Porter, Nolan, Ostrowski, & Wulf, 2010; Wulf, Zachry et al., 2007; Wulf et al., 1998, 2003, 2009; Wulf & Su, 2007). The only exceptions to this pattern of results were seen in a study using a dart-throwing task in which the target may have facilitated an external focus in the control condition (Marchant et al., 2007), and in studies in which highly skilled performers did not benefit from the external focus instructions and showed similar performances in external focus and control conditions (Banks, 2012, Experiment 2; Stoate & Wulf, 2011). Interestingly, in the latter two studies involving kayaking and swimming, respectively, participants had presumably executed millions of strokes over their lifetime, suggesting a very high level of automaticity that could not be further enhanced by external focus instructions (at least the ones given in these studies). The only case so far in which performance in a control condition was superior to one with an instructed external (and internal) focus appears to be a study with world-class balance acrobats (Wulf, 2008). While standing on an inflated rubber disk, the acrobats showed no difference in postural sway among the three conditions, but automaticity (as measured by the mean power frequency of their center-of-pressure movements) was disrupted by the additional focus instructions.

Potency of the effect

When attentional focus was crossed with other variables, such as performers' preferences (Marchant, Clough, Crawshaw, & Levy, 2009; Weiss, Reber, & Owen, 2008; Wulf, Shea, & Park, 2001) or expectancies (e.g., Lohse & Sherwood, 2011), the

instructed focus had a stronger effect than other variables. That is, independent of whether participants indicated a preference for an external or internal focus when given a choice, those who were asked to adopt an external focus typically outperformed those who were asked to adopt an internal focus. In other words, the attentional focus had a stronger effect on performance than performers' focus preference (although the majority of participants indicated preferences for an external focus) (Marchant, Clough, Crawshaw, & Levy, 2009; Weiss, Reber, & Owen, 2008; Wulf, Shea, & Park, 2001). Similarly, when participants were led to believe that an internal or external focus, respectively, was more effective (for an isometric force production task), an instructed external focus resulted in more effective performance (i.e., time to failure) (Lohse & Sherwood, 2011). Thus, despite the relatively powerful influence of performers' expectancies on motor performance and learning (e.g., Stoate, Wulf, & Lewthwaite, 2012; Wulf, Chiviawosky, & Lewthwaite, 2012), the instructed attentional focus had a greater influence. These findings underscore the potency of the external focus benefit.

Distance effect

In a few studies, the effectiveness of different external foci was compared (e.g., Banks, 2012; Bell & Hardy, 2009; McKay & Wulf, 2012; McNevin et al., 2003; Porter, Anton, & Wu, forthcoming). As was first demonstrated by McNevin et al., increasing the distance of the external focus from the body – in this case, the distance of markers on the stabilometer platform from the feet – increased the advantage of the external focus. McNevin and colleagues argued that a more distal focus makes the movement effect more easily distinguishable from the body movements that create the effect than a more proximal focus. Results of various follow-up studies have been in line with these initial findings. Banks found greater benefits of a focus on the finish line (distal) in kayaking as opposed to boat stability (proximal). Bell and Hardy's study demonstrated greater accuracy in hitting golf balls when the focus was on the ball trajectory and landing point (distal) compared to the club (proximal). McKay and Wulf found that accuracy in dart throwing was improved with a focus on the bullseye (distal) as opposed to the flight of the dart (proximal). Finally, in Porter et al.'s study, participants jumped farther when they focused on jumping as close as possible to a target (distal) than when they focused on jumping as far past the start lines as possible (proximal). Thus, there is converging evidence in support of the 'distance' effect. By analyzing the mean power frequency of the balance platform movements, McNevin et al. showed that a greater distance of the external focus increased automaticity in movement control.

Practical implications

Even though the attentional focus effect is now well established in the motor behavior literature, the translation of this research into practice is lagging behind. In interviews conducted by Porter, Wu, and Partridge (2010), 84.6% of track and field athletes who competed at national championships reported that their coaches gave instructions related to body and limb movements. As a consequence, the majority of athletes (69.2%) indicated that they focused internally when competing. Porter et al. noted that the coaching literature for track and field coaches as well as the curriculum for USA Track and Field coaches lacked content on motor learning

and control. Awareness of the research literature appears to be somewhat more advanced in physical therapy. However, the vast majority of practitioners adhere to established or intuitive instructional methods. In an analysis of feedback statements used by physical therapists in their treatment of people after stroke, 95.5% of feedback statements were related to the patient's body movements (Durham, van Vliet, Badger, & Sackley, 2009). Thus, there is certainly potential to improve performance through the education of practitioners. The only cost involved may be a little bit of creativity in the wording instructions or feedback. As Mark Verstegen (President and Founder, Athletes' Performance and Core Performance) eloquently put it, 'If everyone... could make this 2.0 communication upgrade, they would experience immediate improvement in everything they do. No magic pill, device needed!' (personal communication, 24 October 2011).

Future directions

While the behavioral and neurophysiological effects of external versus internal foci of attention appear to be quite clear and consistent, some questions remain. An intriguing issue is the 'distance' effect. While the physical distance of the external focus from the body appears to play a role in enhancing the external focus benefits (e.g., markers on a balance platform at different distances from feet), a more distant movement effect sometimes also represents a higher 'hierarchical' movement goal (e.g., golf club motion versus ball trajectory). As Vallacher and colleagues (Vallacher, 1993; Vallacher & Wegner, 1987) pointed out, with an increase in skill level, actions tend to be monitored at higher hierarchical levels. A challenge for future research will be to disentangle these potential influences, and how the distance, or hierarchy, of the external focus might interact with performers' level of expertise.

More experimental work related to movement form as a function of attentional focus would also be desirable. While there is some evidence that movement form can be enhanced by appropriately worded (i.e., external focus) feedback or instructions (Wulf, Chiviakowsky et al., 2010) – and that sometimes single attentional cues can impact movement form (e.g., An et al., forthcoming) – further studies are needed to examine to what extent these findings generalize to other skills. Also, motor skills that do not involve an implement (e.g., diving) and/or those judged by form (e.g., figure skating) have rarely been used in studies, perhaps because it is more challenging to find appropriate focus instructions for those types of situations. A related question is how a performer's focus should be directed in longer-duration serial skills, such as a pole vault or even a gymnastics routine, that involve different sub-routines. Could a sequence of external focus cues be used effectively in such skills – in pole vaulting, for example, clawing the ground during the run-up, bending the pole, and clearing the bar?

The exact underlying mechanisms of the attentional focus effect need to be explored further. Are attempts at controlling body movements the precondition for less-than-optimal performance? Or are simple references to the body able to invoke the self system (Wulf & Lewthwaite, 2010) and trigger self-related thoughts which, in turn, cause micro-choking episodes? The finding that believing that a body-related performance aspect will be evaluated (Jackson & Holmes, 2011) resulted in performance decrements, appears to lend preliminary support to the self-invoking

trigger idea. Studies are necessary to determine the exact preconditions for internal and/or self-related foci, and how they impact performance.

Future research will hopefully elucidate how brain activity changes when a certain task is performed under different focus conditions. In a first fMRI study, using a sequential key-press task, Zentgraf, Lorey, Bischoff, Stark, and Munzert (2009) found higher activation in the primary somatosensory and motor cortex for an external focus (on keys) relative to an internal focus (on fingers). Whether or not this activation pattern was specific to the (tactile) nature of the task, and how it might be different for different tasks and foci, are open questions. It will also be interesting to find out what effect practice with different attentional foci has on brain activity in the longer term, as evidenced, for example, by the amount of brain activation (Wu, Kansaku, & Hallett, 2004), effective connectivity of the brain motor networks (Wu, Chan, & Hallett, 2008), or changes in gray matter volume (Taubert et al., 2010).

Conclusions

The enhancements in motor performance and learning through the adoption of an external relative to an internal focus of attention are now well established. The breadth of this effect is reflected in its generalizability to different skills, levels of expertise, and populations, as well as its impact on both the effectiveness and efficiency of performance. Future studies that are carefully designed (e.g., with clear instructions, absence of confounding influences) will presumably shed more light on the exact mechanisms underlying the effect. The current findings have implications for all practical settings that involve motor performance and learning (e.g., sports, athletic training, physical and occupational therapy, music). They may also have broader implications for motor learning research, for example for studies that involve feedback, observational learning, etc., or in which general task instructions are provided. Evidently, subtle differences in the wording of instructions or feedback can have significantly different effects on performance and learning.

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