Skill Acquisition in Sport
Research, theory and practice
Second edition

Edited by Nicola J. Hodges
and A. Mark Williams
3 Attentional focus affects movement efficiency

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Introduction

Without doubt, motor behavior is subject to a variety of social–cognitive–affective influences (Lewthwaite & Wulf, 2010a). For instance, the instructions or feedback given to learners not only provide them with “cold” information about the task, what to do, or how to correct errors, but also influence the learner’s emotional state directly impacting on the performance, learning, and control of movements (e.g., Lewthwaite & Wulf, 2010b). This effect is exemplified by how small differences in the wording of instructions or feedback influence performance and learning (e.g., Hutchinson, Sherman, Martinovic, & Tenenbaum, 2008; Jourden, Bandura, & Banfield, 1991; Wulf & Lewthwaite, 2009). One line of research in which differential effects on motor skill learning as a function of instructions have been found consistently is research on attentional focus (see Wulf, 2007a, 2007b). Specifically, if attention is directed to the performer’s body movements (i.e., inducing an internal focus of attention), motor learning is generally hampered compared with attention directed at the movement effect (i.e., inducing an external focus).

Most researchers examining attentional focus effects have assessed movement effectiveness, using outcome measures such as accuracy in hitting a target (e.g., Bell & Hardy, 2009; Marchant, Clough, & Crawshaw, 2007) or producing a certain amount of force (e.g., Freedman, Maas, Caligiuri, Wulf, & Robin, 2007; Lohse, 2011; Lohse, Sherwood, & Healy, 2011), the minimization of deviations from a balanced position (Chiviacowsky, Wulf, & Wally, 2010; Wulf, McNevin, & Shea, 2001), postural sway (Lauber, Rotem-Lehrer, Renen, Khayutin, & Rosenberg, 2007; Wulf, Mercer, McNevin, & Guadagnoli, 2004), or movement speed (Fasoli, Trombly, Ticke-Degnen, & Verfaellie, 2002; Porter, Nolan, Ostrowski, & Wulf, 2010; Torsika & Wulf, 2003). In the first study that demonstrated the effectiveness of instructions inducing an external relative to an internal focus of attention (Wulf, Hôf, & Prinz, 1998), the learning of dynamic balance tasks was enhanced when participants’ attention was directed to the movements of the platform on which they were standing (specifically, wheels on a ski simulator platform or markers on a stabilometer platform; Wulf et al., 1998, Experiments 1 and 2 respectively) as compared with the movements of their feet. Group differences were seen on delayed retention tests without focus instructions or reminders, suggesting that they reflected differential effects on learning. Since then, numerous researchers have replicated the benefits of instructions or feedback inducing an external focus.

Several studies have demonstrated learning advantages of an external focus for sport skills, such as hitting a golf ball (e.g., Bell & Hardy, 2009; Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007), basketball free-throw shooting (Al-Abood, Bennett, Hernandez, Ashford, & Davide, 2002; Zachry, Wulf, Mercer, & Berodis, 2005), dart throwing (Marchant et al., 2007), and volleyball serves and soccer kicks (Wulf, McConnell, Gärtner, & Schwarz, 2002). Overall, the benefits of an external compared with an internal focus have been shown not only for a variety of skills, but also for levels of expertise and age groups, as well as healthy individuals and those with motor impairments. Many of these findings related to movement effectiveness have been reviewed elsewhere (see Wulf, 2007a, 2007b).

In this chapter, we review mostly newer studies that have been concerned with movement efficiency as a function of attentional focus. The efficiency of movement production is a central characteristic of skill (Guthrie, 1952). As individuals become more skilled, their movements not only become more accurate and consistent, but are also performed more efficiently (Sparrow & Newell, 1998). A movement pattern is considered more efficient or economical if the same movement outcome is achieved with less energy expended. Although distinctions between the terms efficient and economic have been made (e.g., Sparrow & Newell, 1998), here we will use them interchangeably.

An important prediction is that movements should be more efficient when the performer uses an external as opposed to an internal focus. In the following sections, we first briefly discuss explanation(s) for the effects of attentional focus, and then review attentional focus studies in which researchers have examined what can be interpreted as measures of movement efficiency, such as electromyographic (EMG) activity and oxygen consumption. We conclude by reviewing how the focus of attention might enhance learning and performance by improving movement efficiency, and make recommendations for athletes, coaches and therapists who can manipulate the focus of attention in applied settings to optimize performance.

How does attentional focus affect performance and learning?

The differential effects of internal versus external foci have been explained within the constrained action hypothesis (Wulf, McNevin, & Shea, 2001), according to which an internal focus on the body induces a conscious type of control. As a consequence, individuals tend to constrain their motor system by interfering with automatic control mechanisms that have the capacity to control movements effectively and efficiently. In contrast, focusing on the movement effect promotes a more automatic mode of control. That is, it allows for the utilization of unconscious, fast and reflexive control processes, with the result that the desired outcome is achieved almost as a byproduct. Several converging lines of research support this notion. These include demonstrations of reduced attentional capacity demands with an external focus of attention (Wulf, McNevin, & Shea, 2001), high-frequency movement adjustments (e.g., McNevin, Shea, & Wulf, 2003; Wulf, Shea, & Park,
A number of alternative explanations for the attentional focus effects have been suggested, ranging from visual advantages (e.g., Maurer & Zentgraf, 2007; Russell, 2007) to a greater functional relevance (e.g., Hommel, 2007; Künzell, 2007; Wrisberg, 2007; Zietske, 2007) or reduced information-processing demands of an external relative to an internal focus (Poolton, Maxwell, Masters, & van der Kamp, 2007). However, none of these explanations can account for the entirety of the findings documented in the literature (see Wulf, 2007a, 2007b). For example, visual information is often controlled or prevented between attention focus conditions. In this way, identical visual information is available in both internal and external focus conditions, and any performance or learning differences between conditions are attributable to attention and not visual information (e.g., McNevin & Wulf, 2002; Wulf et al., 1998; Wulf, McNevin, & Shea, 2001).

Also, the idea that an external focus is more functionally relevant or goal directed cannot explain some key findings, such as differential balance performance when the focus is on the feet as opposed to boards (Totsika & Wulf, 2003), rectangles (Landers, Wulf, Wallmann, & Guadagnoli, 2005), or wheels (Wulf et al., 1998) under one’s feet. From a functional relevance perspective, it is also not clear for example, why increasing the distance of the external focus from the body, such as the distance of markers from the feet on balance tasks (e.g., McNevin et al., 2003), would enhance the effectiveness of the external focus (for further arguments against alternative views, see Wulf, 2007c).

More recently, Wulf and Lewthwaite (2010) have expanded the constrained action notion by suggesting how a one- or two-word difference in instructions might create a chain of events resulting in differential control of movement. The internal focus of attention may act as a self-invoking trigger in that references to one’s body parts or bodily movement, such as those involved in the internal focus conditions, may facilitate access to the self-construct and related self-evaluative and self-regulatory processing. Conditions that invoke the self (e.g., internal focus instructions) may result in “micro-choke” episodes. The self-construct appears to be highly accessible, implicitly or explicitly, in many circumstances, including all movement contexts and laboratory experimental settings, influencing thoughts, actions, and behavior (see Bargh & Morsella, 2008; Chartrand & Bargh, 2002; Leary, 2004; Stapel & Blanton, 2004). Self-focused attention (Carver & Scheier, 1978) or self-related processing may produce something akin to a series of ongoing “micro-choke” episodes with attempts to right thoughts and bring emotions under control. The resulting attempts to harness thoughts and emotions may explain the effects of attentional focus on the efficiency of movement production, which we review next.

**Attentional focus and movement efficiency**

A series of recent studies have yielded findings strongly suggesting that changes in motor control as a function of attentional focus underlie differences in outcome. These studies also provide indirect evidence (maximum force production, movement speed, endurance) or direct evidence (EMG activity, oxygen consumption) that the focus of attention affects movement efficiency—generally demonstrating that training with an external focus enhances not only effectiveness, but also efficiency, allowing for better or equal production of outcomes with less physiological and mental effort.

**Maximum force production**

Many tasks require the production of maximum forces. These tasks include those in which one’s own body (e.g., high jump, long jump, pole vault, basketball dunk) or an object has to be propelled (e.g., discus, hammer, football), as well as static force production tasks sometimes used for diagnostic purposes (e.g., dynamometry). Maximum force production requires and may be tantamount to an optimal activation of agonist and antagonist muscles, as well as optimal muscle fiber recruitment within a muscle or motor unit. Unnecessary co-contractions, imperfect timing, and/or direction of forces would result in less-than-maximal force output. Studies demonstrating that maximum force production varies under external versus internal focus conditions strongly suggest differences in muscular coordination, or movement efficiency (for a review, see Marchant, 2011).

In a series of experiments, maximum vertical jump height has been found to be increased with an external relative to an internal or uninstructed attentional focus (Wulf & Dufek, 2009; Wulf, Dufek, Lozano, & Pettigrew, 2010; Wulf, Zachry, Granados, & Dufek, 2007). A within-participant design was used in those studies, in which all participants performed the task under different focus conditions in a counterbalanced order. Thus, any differences in jump height could be attributed to differences in the coordination of the forces between and/or within muscles. The measurement device (Vertec) used to record jump height consisted of plastic rungs at different heights that the participant reached for during the jumps. Participants were instructed to concentrate on the tips of their fingers in the internal focus condition and on the rungs in the external focus condition, and no focus instructions were given in the control condition. The results of Wulf, Zachry, et al. (2007, Experiment 1) showed that participants jumped significantly higher in the external focus condition than in either the internal focus or the control conditions, with the last two resulting in similar jump heights. Furthermore, the vertical displacement of the center of mass (COM) was greatest when participants were instructed to adopt an external focus. A subsequent study demonstrated that, in addition to increased jump height and COM displacement, impulses as well as joint moments about the ankle, knee, and hip joints were significantly greater in the external focus condition (Wulf & Dufek, 2009) (see Figures 3.1 and 3.2). Thus, increased jump height with an external focus was achieved through greater force production.
jumping as far past the start line as possible. The average jumping distance was 10 cm greater with an external (187 cm) than with an internal focus (177 cm). These findings nicely illustrate the generalizability of the external focus advantages for tasks requiring the production of maximum forces.

Beneficial effects of an external focus on maximum force production have also been shown by Marchant, Greig, and Scott (2009). Using an isokinetic dynamometer, these researchers asked experienced exercisers to produce maximum voluntary contractions of the elbow flexors, with the goal of producing maximal force over the full movement range, under internal (i.e., focus on arm muscles) or external focus conditions (i.e., focus on the crank hand-bar). They found that participants produced significantly greater peak joint torque when they focused externally than when they are focused internally.

Clearly, the "maximum" force an individual can produce is not fixed. It is well known that certain situations, such as those in which someone's life is in danger, enable individuals to produce greater forces than under normal circumstances. Also, "psyching-up" has been found to increase force production (Tod, Iredale, McGuigan, Strange, & Gill, 2005). However, it is interesting that even a simple change in a person's attentional focus can result in an increase in force production.

Given that 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, these findings suggest that external focus instructions enhance maximum force production above and beyond what a person would "normally" achieve.

Aside from a more efficient and effective recruitment of motor units (see below), a "freeing" of the body's degrees of freedom as a result of an external focus may contribute to the increased force output. There is converging evidence to suggest that an internal focus has a constraining effect on the motor system – by linking semi-independent body segments – with a detrimental effect on efficient movement production. In Wulf and Dufek's (2009) study using the jump-and-reach task, for example, 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 resulting in a "freezing" of degrees of freedom (Vereijken, van Emmerik, Whiting, & Newell, 1992), but not with an external focus on the rungs. Also, there were more negative correlations between joint moments and outcome-related variables, such as jump height, with an internal focus but not with an external focus. For soccer kicks, Ford, Hodges, Huys, and Williams (2009) also found higher correlations across the displacements of various joints when the players' focus was on their body movements (internal) than with a focus on the ball trajectory (external). These results suggest that attempts to "force" an effective outcome by trying to control one's body movements are generally not very successful, because they tend to have a
constraining effect on the motor system. In contrast, if the performer simply focuses on the desired movement outcome, the motor system is quite capable of optimizing that outcome.

Muscular activity

Several researchers have used surface EMG as a measure of muscle recruitment, thus providing a more direct measure of movement efficiency. Along with demonstrations of greater automaticity (e.g., Wulf, McNevin, & Shea, 2001), findings of reduced muscular activity with an external focus support the notion that external focus instructions speed the learning process (see Wulf, 2007b). This effect parallels what is typically seen in more advanced performers. There is evidence from studies using a variety of paradigms and methods that, when skill execution becomes automatized through practice, movement outcome (e.g., weight lifted) is enhanced, and at the same time movements are produced more efficiently (e.g., with less neuromuscular activity). For example, using magnetic resonance imaging (MRI) researchers have demonstrated increased efficiency in muscle recruitment as a function of practice (e.g., Conley, Stone, Nimmons, & Dudley, 1997; Green & Wilson, 2000; Flourez, Tesch, Biro, & Dudley, 1994). Thus, reduced EMG activity with external focus relative to internal focus (or no) instructions provides further evidence that the learning process is facilitated by an external focus.

In a first study, Vance, Wulf, Tellmader, McNevin, and Mercer (2004) recorded EMG activity of the agonist (biceps brachii) and antagonist (triceps brachii) muscles in the biceps curl under different attentional focus conditions. Reduced integrated EMG (iEMG) activity was found when participants adopted an external focus of attention than when they adopted an internal focus. Interestingly, this was the case for both the biceps and triceps muscles. In a follow-up study, Marchant, Greig, and Scott (2008) used an isokinetic dynamometer, allowing them more effective control of both movement time and range. These authors also added a control condition to assess EMG activity in external and internal focus conditions relative to one without focus instructions. Marchant et al. (2008) replicated the finding of Vance et al. (2004) in that externally focused instructions were again associated with lower EMG activity than internal focus instructions. In the control condition, similar levels of EMG activity were seen as in the internal focus condition. This latter finding suggests that, even in experienced performers, adopting an external focus can further promote movement efficiency (resembling findings of increased movement accuracy in skilled performers with external focus instructions; Wulf & Su, 2007).

Measures of EMG have also been applied to study how attentional focus affects the neuromuscular system while shooting free-throws with a basketball (Zachry, Wulf, Mercer, & Bezodis, 2005). In this experiment, participants were instructed to focus on either the motion of their wrist (internal focus) or the basketball hoop (external focus). Free-throw accuracy was greater in the external focus condition, and there was reduced EMG activity in the biceps and triceps brachii during the shooting motion when participants adopted an external focus of attention. Thus, congruent with the results of Vance et al. (2004), in the Zachry et al. (2005) study EMG activity was affected in muscle groups that participants were not specifically instructed to focus on. This finding suggests that the effects of the performer's attentional focus "spread" to other muscle groups - increasing inefficiency with an internal focus.

Lohse, Sherwood, and Healy (2010) used a dart-throwing task to examine accuracy and EMG activity as a function of attentional focus. In their study, participants were instructed to focus on either the flight of the dart (external) or the movement of their arm (internal), and participants were reminded at the beginning of each block of trials that, when they made errors (i.e., failed to hit the bulls-eye), they should correct their errors by changing the motion of their arm or the flight of the dart, respectively. An external focus of attention not only improved throwing accuracy but also resulted in reduced EMG activity in the triceps muscle of the throwing arm, thus confirming previous findings (e.g., Zachry et al., 2005).

In addition to measuring EMG activity, a few researchers have used an integrated fast Fourier transform of the raw EMG data to analyze the power spectral density of the recorded EMG. The spectral density represents how power is distributed across different frequencies in the EMG waveform, and represents physiological changes in motor unit recruitment that underlie changes in surface EMG. For instance, Vance et al. (2004) calculated the mean power frequency (MPF) of voluntary contractions in the biceps curl. In early repetitions, an external focus of attention led to smaller MPF than an internal focus of attention, suggesting that externally focusing attention improves movement economy at the level of muscle fiber recruitment. A smaller MPF suggests that fewer muscle fibers are being recruited, because muscle fibers are recruited incrementally (Olsen, Carpenter, & Henneman, 1968).

Increases in power spectral density (both MPF and median power frequency, MDF) are indicative of increased motor unit recruitment because recruitment of larger motor units with faster conduction velocities shifts the MDF/MPF upward (Arendt-Nielsen, Mills, & Forster, 1989; Farina, Foschi, & Merletti, 2002; Lindstrom, Magnusson, & Peterson, 1970; Solomonow et al., 1990). The power spectrum, however, seems to be insensitive to increased discharge rates and therefore is diagnostic only of increased motor unit recruitment (Lago & Jones, 1977; Van Boxtel & Schomaker, 1984) and only during isometric contractions (Farina, 2006; Farina, Merletti, & Enoka, 2004) when previous research on the focus of attention used dynamic contractions (e.g., a biceps curl, shooting a basketball, or throwing a dart).

Because previous research on attentional effects in muscle recruitment has studied dynamic contractions, instead of isometric contractions, there are some inconsistencies in findings about the effects of attention on MDF/MPF (compare Lohse et al., 2010, and Vance et al., 2004). Lohse et al. (2011) addressed this discrepancy by using an isometric force production task in which the length of the muscle does not change. Participants pressed against a force platform with their dominant foot, trying to produce a target force that was 30% of their maximum force while surface EMG measurements were taken from the soleus (agonist) and tibialis anterior (antagonist). Participants were given verbal feedback about their accuracy after each 4 s trial. There was no difference in the accuracy of forces produced in early trials but, over the course of training, mentally focusing on the force platform (external focus) led to more accurate force production than focusing on one's own
muscles that were actually producing the force (i.e., focusing on the agonist muscle, or internal focus).

An external focus also led to reduced surface EMG amplitude (as a percentage of EMG activity during a maximum voluntary contraction, %MVC) and reduced MDF in the antagonist muscle. Thus, when participants adopted an external focus of attention, they reduced the amount of co-contraction between the agonist and antagonist muscles, resulting in a more efficient pattern of motor unit recruitment both within and between muscles (reduced MDF and reduced co-contraction, respectively). Figure 3.3 shows hypothetical efficient and inefficient patterns of muscle activation for completing this plantar flexion task. Figure 3.4 shows representative raw data from three participants showing significantly less efficient neuromuscular coordination while focusing internally (i.e., intermuscular coordination is impaired through greater co-contraction of the soleus and anterior tibialis; intramuscular coordination is also impaired, shown by increased MDF indicating unnecessary motor unit recruitment within the muscles).

In the experiment by Lohse, Sherwood, and Healy (2011), there was evidence for more effective performance within a single experimental session (i.e., greater improvement in accuracy as function of external focus), but what about long-term learning? In a follow-up experiment, Lohse (2012) trained participants to produce either 25% or 50% of their MVC in an identical plantar flexion task. Participants trained under either external (focusing on the force platform) or internal focus conditions (focusing on the agonist muscle). Although both groups had equal accuracy in early trials, by the end of training (60 trials), the external focus group was significantly more accurate than the internal focus group. One week later, both groups returned to the laboratory for retention and transfer testing. Not only did the external focus participants remain significantly more accurate on the retention test, they significantly outperformed the internal focus group on the transfer test, suggesting that an external focus of attention improved participants’ ability to reparameterize the movement to remain accurate at new percentages of their MVC.

Finally, the production of greater maximal forces with an external focus (e.g., Marchant et al., 2009; Wulf & Dufek, 2009; Wulf, Dufek, Lorano, & Pettigrew, 2010) has been shown to be accompanied by reduced muscular activity. In the study by Marchant et al. (2009), a focus on the crank bar while performing biceps curls resulted not only in increased peak joint torque, but in less EMG activity than with an internal focus on the arm muscles. In line with those findings, Wulf and colleagues (2010) found that jump height was greater and, at the same time, EMG activity was lower in various leg muscles with an external focus than with an internal focus. Overall, the findings demonstrating greater force production with reduced muscular activity with an external focus clearly point to a greater efficiency in movement production in comparison with an internal focus.

Based on findings indicating that maximal (e.g., Marchant et al., 2008) and
submaximal forces (e.g., Lohse et al., 2011) are produced with less muscular energy when an external focus is adopted, one would predict that individuals should be able to maintain a certain submaximal force level (e.g., 80% of maximum) longer, or increase the force level for a given period of time (e.g., 10 s). Thus, one might expect to see shorter movement times for a given distance (i.e., increased speed) in running, swimming, bicycling, and the like, or more repetitions in lifting the same weight. In the next section, we review studies in which movement speed and endurance under different attentional focus conditions have been examined.

**Speed and Endurance**

A few researchers who have examined attentional focus effects have used movement speed as a dependent variable. In the first study (Tonsika & Wulf, 2003), two groups of participants practiced riding a pedalo: an apparatus that consists of two small platforms (one for each foot) between sets of wheels and moves by alternately pushing the upper platform forward and downward, similar to the pedals on a bicycle. 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). This finding was observed not only during the practice phase but also on transfer tests, which included requirements to perform the task under time pressure, to ride backward, or to count backward (i.e., with attention being directed elsewhere). Thus, participants who had received external focus instructions during practice not only learned a more efficient method of controlling the pedalo, but were able to transfer this newly learned skill to novel situations (i.e., riding backward) and situations with increased pressure to perform (i.e., time pressure).

A similar finding was observed by Porter, Nolan, Ostrowski, and Wulf (2010), who found that external focus instructions reduced the time taken to complete a whole-body agility task. In this task, participants completed an agility "L" run (which consists of a weaving run around three cones set 5 m apart) under external focus, internal focus, or control conditions. Participants had to run through the course as quickly as possible and with maximum effort. External focus instructions, which directed their attention toward accelerating between the cones and pushing off the ground in the turns, significantly decreased running time relative to both internal focus instructions, in which participants were asked to focus on moving their legs as fast as possible and planting their foot firmly in the turns, and a control condition.

An external focus of attention has also been found to increase movement speed in swimming. Recent reports suggest that giving swimmers external focus instructions related to the arm stroke in crawl swimming (e.g., “pushing the water back”) was more effective than internal focus instructions that directed attention towards the swimmer’s arms (e.g., “pulling your hands back”). This effect was demonstrated in both intermediate swimmers (Freudenheim, Wulf, Machureira, Pasetto, & Corrêa, 2010) and experts (Stoate & Wulf, 2011). These findings have obvious practical implications. For instance, in elite junior swimmers, an external focus of attention increased swim speed (i.e., reduced swim time) by an average of 0.18 s in a 25-yard (~23 m) crawl. In the 2008 Olympics, the difference between first place and second place in the men's 50 m crawl was only 0.15 s, and in the women's 50 m crawl 0.11 s. Thus, a swimmer's focus of attention could potentially determine his or her place on the medal stand.

It is also interesting to note that both of these studies used control conditions in which swimmers were not given specific instructions on how to focus their attention and were simply encouraged to swim as fast as possible. Intermediate swimmers performed similarly in the internal focus and control conditions (Freudenheim et al., 2010), whereas in experts the control and external focus conditions resulted in similar swim times (Stoate & Wulf, 2011). These results suggest that, whereas an instructed external focus enhanced movement automaticity and efficiency in less skilled participants, movements were already so highly automatized in experts that an external focus provided no additional advantage, or that experts had already discovered the value of an external focus and adopted one on demand or habitually (e.g., Gray, 2004). Self-report data from the Stoate and Wulf study indicated that experts’ “normal” focus (i.e., in the control condition) differed among participants, however. Whereas some swimmers reported more of an internal focus in the control condition (e.g., hip rotation, spinning arms, high elbow), others reported focusing on the overall outcome (e.g., speed, tempo, going fast, swimming hard) or “nothing.” Interestingly, those who adopted an internal focus in the control condition had slower swim times (13.55 s) than those who did not (13.02 s). These group differences in the control condition are consistent with the notion that an internal focus disrupts automaticity and results in poorer performance. Thus, when movements are controlled automatically at a high level of skill, external focus instructions may only help to reinforce a learned focus of attention, but feedback inducing an internal focus should clearly be avoided.

Finally, 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 with weights corresponding to 75% of each participant’s repetition maximum. The exercises included bench press tests on a Smith machine (allowing for vertical movement only), free bench press, and a free squat lift. External focus instructions directed participants’ attention to the movement of the bar being lifted and the force exerted against it, whereas internal focus instructions referred to movements of the limbs involved in the exercise (i.e., arms, legs). With an external focus, participants produced a significantly greater number of repetitions than with an internal focus in all three exercises. In addition, the number of repetitions exceeded those performed under control conditions (except for the restricted bench press on the Smith machine). Intriguingly, the effect size of the attentional focus manipulation increased as the movements became more complex; the effect size was smallest for the Smith machine bench press, in which the dimensions of movements are constrained, and greatest for the free squat, which is the most complex movement pattern, with the free bench press in between the two. The increasing magnitude of effect sizes suggests that the benefit of an external focus might increase as movement complexity increases (see also Wulf, Tollner, & Shea,
Overall, these findings demonstrate that the attentional focus adopted or induced through instruction has a significant influence on muscular endurance.

Oxygen consumption

An interesting example of how changing the focus of attention can improve movement efficiency comes from a study by Schücker, Hageman, Straus, and Volker (2009). These authors had skilled runners focus their attention 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) in a counterbalanced order. Consistent with previous research showing improved movement efficiency, Schücker and colleagues found improved metabolic efficiency with an external focus of attention, in that an external focus resulted in reduced oxygen consumption during the running task compared with either of the internal foci.

Implications for practice

As research on the focus of attention continues to demonstrate, even subtle differences in the wording of instructions or feedback that a participant is given can have profound effects on behavior and the underlying physiology. Thus, instructors, coaches, therapists, and performers themselves need to be aware of how these differences affect performance and should develop effective strategies to keep the performer’s attention focused externally on the intended effects of their movements. Internally focusing on one’s own movements constrains the motor system and leads to movements that are not only less accurate but also less efficient at the neuromuscular level. Numerous studies have shown that not only will an external focus of attention create a more efficient movement with the same outcome (e.g., same weight being lifted, same distance being run), but also that it can lead to more efficient movement with a significantly enhanced outcome (e.g., improved accuracy in dart throwing, increased jump height in the vertical jump, increased force production).

Although the attentional focus effect is well established in the motor behavior literature, the translation of this research into practice has been relatively slow. For example, in a recent analysis of feedback statements used by physiotherapists in their treatment of patients with stroke, Durham, Van Vliet, Badger, and Sackley (2009) found that 95.5% of feedback statements were related to the patient’s body movements. Similarly, in interviews of track and field athletes competing at the outdoor national championships, 84.6% reported that their coaches gave instructions related to body and limb movements (Porter, Wu, & Partridge, 2010). As a consequence, the majority of athletes (69.2%) indicated that they focused internally when competing. Interestingly, as Porter et al. (2010) noted, the coaching literature for track and field coaches as well as the curriculum for USA Track and Field coaches lacks content on motor learning and control. Thus, there is clearly potential to improve performance in various fields through the education of practitioners.

It is also important to remember that there is no “one-size-fits-all” approach to directing attention. Although an external focus of attention is generally beneficial to learning and performance across a wide variety of tasks and populations (see Wulf, 2007b, for a review), there may be differences, for instance, in the optimal external focus of attention between experts and novices. An external focus of attention is generally beneficial for both experts and novices (e.g., Wulf & Su, 2007); however, there is some evidence that novices benefit from a more proximal external focus (Wulf, McNevin, Fuchs, Ritter, & Toole, 2000) and the experts benefit from a more distal focus (Bell & Hardy, 2009). That is, experts can focus on controlling events farther down the kinetic chain than novices, who lack the necessary ability to control physically or temporally distant events. Consider, for example, a novice pool player who might focus only as far out as the cue meeting the cue-ball. In contrast, an expert might be focused past the cue, the cue-ball, the target ball, and the target pocket, to something as distal as the placement of the cue-ball for the next shot. Similarly, a novice tennis player may not have a procedural concept of how to hit an ace, so focusing on hitting one would be meaningless from a motor control standpoint, and the novice would benefit from a more proximal external focus (e.g., focusing on the angle of the racket at ball contact). A world-class player, on the other hand, can focus not only on hitting an ace on his or her serve, but probably on a very specific flight path for the ball to set up the shot he or she wants if the serve is returned (Ford, Hodges, Huys, & Williams, 2006). The optimal focus of attention is presumably more distal for the expert because experts have much more detailed action concepts than novices (Schack, 2004; Schack & Mechsner, 2006), which makes it meaningful for experts to direct their focus farther down the chain of kinetic events in the action. Future studies may help identify optimal attentional foci for different tasks and skill levels.

Moreover, it would be interesting to further elucidate how attentional focus affects movement efficiency at a more central level. How does brain activity change when a certain task is performed under different focus conditions? Moreover, what effect does practice with different attentional foci have on brain activity in the long term, as evidenced, for example, by the amount of brain activation (Wu, Kansak, & Hallett, 2004), effective connectivity of the brain motor networks (Wu, Chan, & Hallett, 2008), or changes in gray matter volume (Taubert et al., 2010)?

References


Advances in implicit motor learning

Richard S. W. Masters and Jamie M. Poolton

Advances in implicit motor learning

Much of the way in which humans respond and adapt to the environment occurs implicitly, without conscious awareness and often without intention (e.g., Frensch, 1998; Reber, 1967). Conscious processes are constrained by limits to the information-processing capacity of the brain (e.g., Baars, 1998; Kahneman, 1973), so it is not surprising that implicit (unconscious) processes underlie our interaction with the environment. Nor is it surprising that evolution has selected advantages of implicit (unconscious) learning, given that learning is a biological imperative, which provided our ancestors with a significant survival advantage (Claxton, 1997).

What is implicit learning?

To operationalize implicit learning is challenging and much debated (see Frensch & Rünger, 2003). It is generally agreed that implicit learning is the antithesis of explicit learning, during which purposeful hypothesis testing exposes rules and knowledge thought to govern effective behavior. In the 1960s, Arthur Reber used artificial grammar learning to examine how people learned compound rules governing complex tasks. Participants were not informed of the rules, but when later asked to determine whether unfamiliar exemplars followed the same rules they were surprisingly accurate, despite negligible conscious knowledge of the rules (see Pothos, 2007). Reber (1989) considered implicit learning to be the accrual of knowledge that “in some raw fashion, is always ahead of the capability of its processor to explicate” (p. 229).

Implicit learning has also been investigated using the serial reaction time task (SRTT), in which people are asked to react as quickly as possible by pressing a key to match positions indicated on a monitor. The order of positions on the monitor is repeated over numerous trials in a sequence that can involve many key presses. Although most participants are unaware of a repeating sequence, their responses become so fast that they anticipate the next position, suggesting that they have learned the sequence implicitly (e.g., Jiménez & Mendez, 1999; Nissen & Bullemer, 1987). One of the strengths of the SRTT is that informing participants of the repeating sequence establishes a test of explicit, rather than implicit, learning (Curran & Keele, 1993; Willingham, Nissen, & Bullemer, 1989), with learners