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TARGET ARTICLE

GABRIELE WULF ON ATTENTIONAL FOCUS AND MOTOR LEARNING

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EDITORIAL

ATTENTIONAL FOCUS AND MOTOR LEARNING: GABRIELE WULF ON TARGET

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In diesem kommentierten Beitrag berichtet Gabriele Wulf über ihre langjährige Forschungsarbeiten zum Aufmerksamkeitsfokus und motorischen Lernprozessen. Der zentrale Befund der referierten Studien besteht darin, dass ein externaler (= bewegungseffektbezogener) im Vergleich zu einem internalen (= körperbewegungsbezogenem) Aufmerksamkeitsfokus motorische Lernprozesse fördert. Der gegebene Überblick wird anschließend von 21 Expert/innen aus einer theoretischen und methodologischen wie grundlagen- und anwendungsorientierten Perspektive kommentiert. Zu den vorgebrachten Argumenten nimmt Gabriele Wulf in einer abschließenden Erwiderung Stellung. In diesem „Editorial" werden einige Hintergrundinformationen zu dem Forschungsthema sowie zu der Autorin des Hauptbeitrags gegeben.

Schlüsselwörter: Aufmerksamkeitsfokus, Forschungsmethodologie, antizipative Verhaltenskontrolle, motorisches Lernen, Anweisungen, Automatismus

In this target article, Gabriele Wulf reviews her long-lasting research on attentional focus and motor learning. The essential finding of the reviewed studies is the enhancing effect of an external (= movement-effect related) compared to an internal (= body-movement related) focus of attention for motor learning. Her review is then discussed by 21 experts from a theoretical and methodological as well as from a basic and an applied perspective. Finally, the arguments brought forward are disputed in a response given by Gabriele Wulf. This editorial serves as a basis for providing some background information on the research topic as well as on the main article's author.

Keywords: attentional focus, research methodology, anticipatory behavior control, motor learning, instructions, automaticity

2007 sees the first volume of the E-Journal "Bewegung and Training". This journal has been launched as an official organ by the "Deutsche Vereinigung für Sportwissenschaft" (German Society for Sport Science) for the special interest groups for motor control and learning, biomechanics, and training science. A special rubric of the E-journal is the target article in which theoretical approaches or reviews of empirical research are put forward for discussion. Target articles consist of a main article, a number of commentaries, and the author's response, each of them after having successfully passed a double-blind peer-review process (as it is mandatory for receiving the status of an "official organ" of the dvs). Instead of a free submission procedure, target article authors are nominated by the E-Journal's Editorial Board – in the future probably in annual recurrence and on the basis of suggestions given by the scientific community. Criteria for the nomination are the national or international standing of the candidate, the actual or potential impact of his/her line of research and the interdisciplinary character of his/her approach in order to stimulate commentaries from different fields within sport science and beyond. Keeping these criteria in mind, Gabriele Wulf, the author of the present target article, is an ideal candidate for nomination. Fortunately, she accepted the invitation to review her long-standing research on attentional focus and motor learning.

Gaby is – as not everybody might know – a "child" of German sport science as she graduated in 1982 from the German Sport University Cologne where she also earned her doctorate as a "Doctor of Sport Science" four years later. Her career took

Figure 1. Gabriele Wulf, the author of the target article 2007.

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a decisive turn when meeting Richard A. Schmidt (amongst others, the father of the famous schema theory) for the first time on a 1985 ZIF-conference in Bielefeld; she then spent the late 1980s at the University of California, Los Angeles, as a member of Schmidt's research team. From 1990 to 1999, Gaby worked as a Senior Research Scientist at the Max Planck Institute for Psychological Research in Munich in the research group of Wolfgang Prinz and completed her postdoctoral lecture qualification – the German "Habilitation" – in 1993 at the University of Munich (Wulf, 1994). After a short stay in Reading/UK, she was attracted by the US again and moved to the Las Vegas campus of the University of Nevada where she is still teaching and performing research as a Professor of Kinesiology.

Over her career, Gabriele Wulf has made important scientific contributions, especially to the field of the optimization of motor learning processes. She has addressed a variety of related research topics such as variability of practice, feedback frequency, contextual interference, implicit learning, and self-controlled learning procedures. In 1997, a study on the role of instructions about physical principles in motor learning (conducted in collaboration with Cornelia Weigelt) showed that instructing participants to focus on the feet instead of on the force exerted to the platform impaired performance in acquisition and retention on a ski-simulator task (Wulf & Weigelt, 1997). This finding – surprising as it was at that time – was put to direct empirical test by Wulf, Höß, and Prinz (1998) who were the first to theoretically work out and experimentally confirm the prediction of better learning as a consequence of an external (= movement-effect related) compared to an internal (= body-movement related) focus of attention. Within the research line that has been stimulated by this work and evolved throughout the following years, Wulf's contribution on this issue has had a remarkable impact (see Table 1) and has found its way into a current textbook describing the constrained action hypothesis from a more applied perspective (Wulf, 2007).

In the following main article, Gabriele Wulf gives a comprehensive overview of her own work on the interaction of attentional focus and motor learning over the last 10 years. Subsequently, her review is annotated in 21 peer-reviewed commentaries from internationally recognized experts in the field. We are very glad to have received submissions not only from German sport scientists but from all over the world, i.e., Austria, Canada, Hong Kong, Ireland, the Netherlands, United Kingdom, and United Stated and also from other disciplines such as psychology and musicology. The commentaries vary from more theoretical issues to methodological and also applied remarks, giving this target article the character of an international and interdisciplinary endeavor. Both the commentaries and Gaby Wulf's response highlight new and interesting research questions in the field of attentional focus and motor behavior which still need to be addressed.

Table 1. Citation Numbers of Issue-Related Articles Published by Wulf and Colleagues in ISI-Web Listed Journals 1997-2005 and Cited in the Editorial, Main Article, Commentaries, or Response of the Target Article 2007, Retrieved August 6, 2007, From ISI-Web of Knowledge (ISI), and Scholar-Google (SG)

Publication	ISI	SG
Wulf, & Weigelt (1997)	46	33
Wulf, Höß, & Prinz (1998)	54	55
Shea, & Wulf (1999)	32	39
Wulf, Lauterbach, & Toole (1999)	41	41
Park, Shea, McNevin, & Wulf (2000)	1	0
Wulf, McNevin, Fuchs, Ritter, & Toole (2000)	16	21
Wulf, McNevin, & Shea (2001)	30	31
Wulf, & Prinz (2001)	39	40
Wulf, Shea, & Park (2001)	18	15
McNevin, & Wulf (2002)	21	28
Wulf, McConnel, Gärtner, & Schwarz (2002)	18	23
McNevin, Shea, & Wulf (2003)	18	25
Totsika, & Wulf (2003)	5	3
Wulf, Weigelt, Poulter, & McNevin (2003)	10	18
Vance, Wulf, Töllner, McNevin, & Mercer (2004)	3	2
Wulf, Mercer, McNevin, & Guadagnoli, (2004)	7	8
Landers, Wulf, Wallmann, & Guadagnoli (2005)	3	0
Zachry, Wulf, Mercer, & Bezodis (2005)	0	0

We thank Gaby Wulf as well as all the authors of the commentaries for their inspiring contributions to this E-Journal and hope that this issue will stimulate further research in Sport Science.

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Wulf, G., & Weigelt, C. (1997). Instructions about physical principles in learning a complex motor skill: To tell or not to tell... *Research Quarterly for Exercise and Sport, 68*, 362-367.

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Individual articles (main article, commentaries, response) may be cited as follows (e.g., Wulf's main article):

Wulf, G. (2007). Attentional focus and motor learning: A review of 10 years of research. In E.-J. Hossner & N. Wenderoth (Eds.), Gabriele Wulf on attentional focus and motor learning [Target article]. *E-Journal Bewegung und Training*, *1*, 4-14. Retrieved month day, year, from http://www.ejournal-but.de.

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Target article published: 26.09.2007

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MAIN ARTICLE

ATTENTIONAL FOCUS AND MOTOR LEARNING: A REVIEW OF 10 YEARS OF RESEARCH

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Es wird ein Überblick über die empirische Befundlage zum Einfluss der Aufmerksamkeitsfokussierung auf motorische Ausführungs- und Lernleistungen gegeben. Die zu dieser Frage im Laufe der letzten Dekade durchgeführten Studien zeigen konvergierende Evidenz für die größere Effizienz eines externalen Aufmerksamkeitsfokus (d.h. Fokussierung des Bewegungseffekts) gegenüber einem internalen Fokus (d.h. Fokussierung der Bewegungen selbst). Vorteile eines durch Instruktionen oder Rückmeldungen induzierten externalen Fokus wurden für eine Vielzahl unterschiedlicher Bewegungsfertigkeiten, Fertigkeitsniveaus und Populationen demonstriert (einschließlich Personen mit motorischen Defiziten). Darüber hinaus werden empirische Befunde präsentiert, die die „constrained action"-Hypothese als Erklärungsansatz für die genannten Fokuseffekte unterstützen. Nach diesen Befunden fördert ein externaler Fokus die Automatisierung der Bewegungskontrolle und damit effektive Bewegungsdurchführungen. Von Bedeutung sind schließlich Befunde, nach denen Aufmerksamkeitsfokussierungen nicht nur temporär auf die Bewegungsqualität einwirken, sondern auch die langfristig überdauernden Lernergebnisse beeinflussen. Der Übersichtsbeitrag schließt mit einigen Anregungen für die zukünftige Forschung.

Schlüsselwörter: Aufmerksamkeitsfokus, motorisches Lernen, begrenzte Aufmerksamkeitsleistung, Anweisungen, Rückkopplung

Studies examining the influence of an individual's focus of attention on motor performance and learning are reviewed. Those studies, conducted over the past decade or so, provide converging evidence that an external focus of attention (i.e., focus on the movement effect) is more effective than an internal focus (i.e., focus on the movements themselves). Advantages of adopting an external focus, induced by instructions or feedback, have been shown for a variety of motor skills, skill levels, and populations (including persons with motor impairments). Evidence in support of the constrained action hypothesis, which has been put forward as an explanation for the attentional focus effects, is presented. These findings indicate that an external focus promotes automaticity in movement control, with the consequence that the effectiveness and efficiency of motor performance is enhanced. Importantly, there is evidence to suggest that an individual's focus of attention not only influences performance temporarily, but that it affects the learning of motor skills. The review ends with suggestions for future research.

Keywords: attentional focus, motor learning, limited attentional capacity, instructions, feedback

As observant practitioners and researchers have known for a quite long time, an individual's focus of attention has an important influence on the performance of motor skills (e.g., Bliss, 1892-1893; Boder, 1935; Gallwey, 1982; Schneider & Fisk, 1983). That is, the accuracy and quality of the movement depends to a great extent on what the performer focuses on while executing the skill. This has been confirmed by a series of newer studies (e.g., Beilock & Carr, 2001; Beilock, Carr, MacMahon, & Starkes, 2002; Gray, 2004). Importantly, not only performance, but the whole learning process seems to be affected by what the learner focuses on while practicing a skill (for a comprehensive review, see Wulf, 2007). That is, how fast a skill is learned, and how well it is retained, is largely determined by the individual's focus of attention that is induced by the instructions or feedback given him or her. The present article reviews the findings from studies, conducted over the past decade, that have specifically examined an internal versus external focus of attention. As originally defined by Wulf, Höß, and Prinz (1998), an internal focus is one that is directed at the performer's own body movements, whereas an external focus is directed at the effects that his or her movement have on the environment. As I will demonstrate in this review, there is considerable evidence that an external focus of attention is more effective for performance and learning.

The review begins with an overview of experimental studies that have compared the effectiveness of different attentional foci, using a variety of motor skills. While some studies have manipulated the learners' attentional focus through instructions, other studies have used feedback to examine attentional focus effects. An explanation for the differential effects of internal versus external foci – the "constrained action hypothesis" – as well as related evidence is presented in the subsequent section. The question whether the observed differences between focus conditions are simply temporary effects on motor performance, or whether they

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constitute relatively permanent or learning effects, is addressed next. The following two sections deal with "special" tasks and populations. Specifically, the effects of attentional focus on supra-postural tasks and postural control are reviewed. Also, a few studies have begun to look at focus effects in participants with motor impairments, including those with Parkinson's disease or stroke. The review ends with suggestions for future research.

Instructions

In almost any training situation where motor skills are to be learned, performers are given instructions about the correct movement pattern, or technique. Those instructions typically refer to the coordination of the performer's body movements, including the order, form, and timing of various limb movements. Instructions that direct individuals' attention to their own movements induce an internal focus of attention. As I will demonstrate, these instructions are relatively ineffective, especially when compared to those that induce an external focus by directing the individual's attention to the effect of his or her movements on the environment, such as an apparatus or implement. A number of studies that examined the influence of internal versus external focus instructions have used balance tasks, while others have used sport skills, such as hitting golf balls, shooting basketballs, or jumping.

Balance

The balance tasks used in studies on attentional focus include a ski simulator (Wulf et al., 1998, Experiment 1), stabilometer (e.g., McNevin, Shea, & Wulf, 2003; Wulf et al., 1998, Experiment 2; Wulf & McNevin, 2003; Wulf, Shea, & Park, 2001), Pedalo (Totsika & Wulf, 2003), and tasks requiring participants to stand still on compliant surfaces (e.g., Wulf, Mercer, McNevin, & Guadagnoli, 2004). The stabilometer, for example, is a platform that tilts to the left or right, and the participant's goal is to keep the platform (on which he or she stands) in a horizontal position. Markers, such as dots or short lines, are put on the platform, often directly in front of the performer's feet or at a short distance from the feet. These markers, while present under all conditions, serve as "focal points" for participants in the external focus conditions. Specifically, participants are either instructed to focus on keeping their feet horizontal (internal focus group), or to focus on keeping markers horizontal (external focus group). It is important to note that participants are typically instructed not to look at their feet or the markers – to avoid possibly confounding influences of visual information – but rather to look straight ahead. As a number of studies have shown, participants instructed to adopt an external focus generally demonstrate more effective learning than those provided with internal focus instructions (e.g., McNevin et al., 2003; Wulf et al., 1998; Wulf & McNevin, 2003; Wulf, McNevin, & Shea, 2001).

Other studies using balance tasks have yielded similar results. For instance, when riding a Pedalo, movement speed has been found to increase when participants are instructed to focus on pushing the boards under their feet forward (external focus), as compared to pushing the feet themselves forwards (internal focus) (Totsika & Wulf, 2003). On the ski simulator, focusing on the force exerted on the wheels under the platform on which the participant is standing has been demonstrated to produce larger movement amplitudes than focusing on the force exerted with each foot (Wulf et al., 1998, Experiment 1). Finally, postural sway is typically reduced when individuals standing on a moving platform focus externally (e.g., on rectangles under their feet) rather than internally (e.g., on their feet) (e.g., Landers, Wulf, Wallmann, & Guadagnoli, 2005; Wulf et al., 2004).

Golf

A few studies have used golf tasks (Perkins-Ceccato, Passmore, & Lee, 2003; Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007). In two of these studies (Wulf, in press-a; Wulf et al., 1999), participants had no prior golf experience. Therefore, they were first given basic instructions regarding the stance, grip, and posture, as well as a demonstration. Subsequently, two groups of participants were given slightly different attentional focus instructions: The internal focus group participants were asked to focus particularly on the swing of their arms, while the external focus group was asked to focus on the swing of the club. The target was a circle (diameter: 90 cm), placed on a lawn surface at a distance of 15 m. Concentric circles around the target demarcated zones used to assess the accuracy of the shots, and points between 5 (*target hit*) and 0 were awarded for each shot.

Figure 1 shows the results of the study by Wulf (2007, Experiment 1) which also included a control group without specific focus instructions. On a retention test without instructions, which was conducted one day after the practice phase, the external focus group showed a significantly greater accuracy in their shots compared to both the internal focus and control group. Thus, while internal focus instructions were relatively ineffective, the

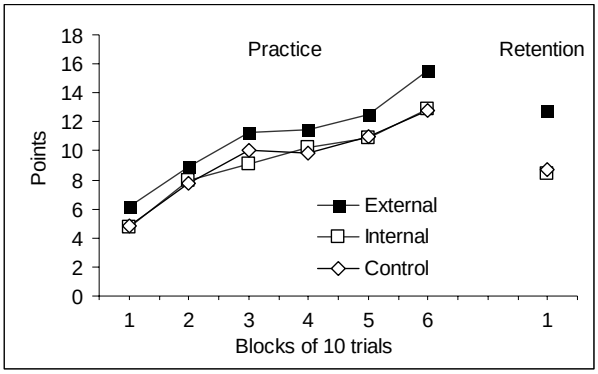

Figure 1. Accuracy scores for the external focus, internal focus, and control groups during practice and retention in the study by Wulf and Su (2007, Experiment 1).[1]

[1]Reprinted/adapted with permission from *Research Quarterly for Exercise and Sport, 78,* 384-389, Copyright 2007 by the American Alliance for Health, Physical Education, Recreation, and Dance.

external focus instructions clearly enhanced the learning of this task.

Another recent study (Perkins-Ceccato et al., 2003) appeared to come to a different conclusion. Even though this study only examined performance, not learning, as a function of attentional focus, the authors argued that an internal focus might be more advantageous than an external focus for novice golfers. However, differences between internal and external focus conditions were only found in the trial-to-trial variability of the shots, not in accuracy. Furthermore, no retention test was conducted, and performance differences between groups were observed only when those subgroups were considered that performed under the respective attentional focus conditions first (not second). Most importantly, the instructions given in the Perkins-Ceccato et al. study differed from those used in most studies on attentional focus in that they were relatively vague: In the internal focus condition, participants were asked to "concentrate on the form of the golf swing and to adjust the force of their swing depending on the distance of the shot". In the external focus condition, they were instructed to "concentrate on hitting the ball as close to the target pylon as possible" (Perkins-Ceccato et al., 2003, p. 596). While the external focus instructions were relatively unambiguous, it is questionable how participants may have interpreted the internal focus instructions. With the emphasis being put on the force of the swing, it is possible that individuals actually focused on the impact the *club* had on the ball. If this were the case, this would, in fact, constitute an external focus, and the performance advantage seen under this condition as compared to the *target* condition would actually be in line with the results of an earlier study (Wulf, McNevin, Fuchs, Ritter, & Toole, 2000). That study showed that, for novices, a focus on the swing of the club was indeed more effective than a focus on the ball trajectory and target (possible reasons for this result are discussed by Wulf and Prinz, 2001). At any rate, the Perkins-Ceccato et al. study indicates the need to give specific focus instructions, with clear references to body movements (internal) or movement effects (external), to allow for unequivocal interpretations.

Perkins-Ceccato et al. (2003) also had experienced golfers with an average handicap of around 4 perform the same task. Those golfers performed with greater accuracy under the "external" focus condition. Yet, this finding is also compromised due to the reasons outlined above. Another study using expert golfers with an average handicap of 0 demonstrated that external focus instructions can indeed enhance performance at a high level of expertise (Wulf & Su, 2007, Experiment 2). Similar to the study with novices described above (Wulf & Su, 2007, Experiment 1), the expert golfers were asked to hit golf balls at a target, although the target area was considerably smaller (25 cm) than that used in the novice experiment. Interestingly, similar to the novices, the experts hit the balls with greater accuracy when they were instructed to focus on the club motion as opposed to the arm motion. Almost surprisingly, when the experts were allowed to adopt their "normal" focus under control conditions, accuracy was similar to that seen in the internal focus condition. This indicates that the external focus benefits generalize to high skill levels.

Basketball

Two studies have examined the effects of attentional focus on shooting accuracy in basketball (Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002; Zachry, Wulf, Mercer, & Bezodis, 2005). Even though those studies varied in several respects, including the instructions and experimental design, both came to similar conclusions. In the study by Zachry and colleagues, participants with some basketball experience performed free throws, in a within-participant design, while focusing either on their wrist motion (internal focus) or the rim of the basket (external focus). Two sets of 10 trials were performed under each attentional focus condition, and the order of conditions was counterbalanced across participants. The scores awarded for each shot varied between 5 (*ball went through the hoop*) and 0 (*missed shot*). The results showed that free throw accuracy was significantly higher when performers focused externally (M = 2.6) rather than internally (M = 2.1).

In the study by Al-Abood et al. (2002), demonstrations by an expert model were combined with attentional focus instructions. Participants watched a video of an expert model perform a basketball free throw. While one group of participants, the movement dynamics group, was instructed to pay attention particularly to the model's movement form, another group, the movement effects group, was instructed to focus on how the model scored a basket. Al-Abood and colleagues (2002) did not provide participants with physical practice trials between model presentations. Rather, they compared the performances of the two groups on a pretest conducted before the video demonstrations relative to a posttest performed after the video presentations. The authors found that, in contrast to the movement dynamics group which showed no improvement from pre- to posttest, the movement effect group demonstrated a significant improvement. Thus, despite the vast methodological differences between the Zachry et al. and Al-Abood et al. studies, both found advantages of instructions that directed performers' attention to the anticipated movement effect.

Dart throwing

Effects of attentional focus on dart throwing were examined by Marchant, Clough, and Crawshaw (in press). These researchers instructed one group of novice dart throwers (internal focus) to "1) feel the weight of the dart in their hand; 2) think about drawing the dart back to the ear; 3) feel the bend in the elbow; and 4) feel the dart as it left the fingertips". In contrast, participants in another group

(external focus) were instructed to "1) focus on the centre of the dart board; 2) slowly begin to expand upon perspectives on the dart board; 3) then refocus on the centre of the dart board, expanding the centre, and making it as large as possible; and 4) toss the dart when so focused". A third group (control) was not given any focus instructions. The results showed that individuals who were given external focus instruction were more accurate than those who were given internal focus instructions. Even though a potential drawback of this study is that the internal and external focus instructions directed attention to different aspects of the skill, the external focus advantages are in line with previous studies. In contrast to other studies that included control groups without attentional focus instructions (e.g., Wulf et al., 1998; Wulf & McNevin, 2003; Wulf & Su, 2007; Wulf, Weigelt, Poulter, & McNevin, 2003), however, the control group's performance was similar to that of the external focus group, and more effective than that of the internal focus group. One potential reason for the relatively effective performance of the control group in that study is related to the task which, as the authors acknowledged, might have promoted an external focus in and of itself, even in the control condition without specific focus instructions: "the task itself advocates an external focus during execution through the emphasis on accuracy, therefore leading to an external focus possibly being induced in the control group even without specific instructions".

American Football

Zachry (2005) examined the effectiveness of internal versus external focus instructions for American football place kicking (field goal kicking). Participants, who had never kicked a football before, were first given a demonstration and general instructions about the technique. Then they performed kicks into a net that was hung from the ceiling at a distance of 5 m. A 10 x 10 inch target was marked in the center of the net. The goal was to kick the ball so that it hit the square. Participants performed under each of the three following conditions (with the order being counterbalanced among participants): (a) focus on the part of the foot that would be contacting the ball (internal focus condition), (b) focus on the part of the ball that they would be contacting with their foot (external focus condition), and (c) no attentional focus instructions (control condition). The results showed that kicking accuracy was significantly higher in the external focus condition compared to the other two: The percentage of successful kicks was 80% in the external focus condition, 68% in internal focus condition, and 66% in the control condition.

Jumping

Most studies examining attentional focus effects have used relatively complex motor skills that required the coordination of multiple degrees of freedom, were fairly challenging, and often showed considerable improvement across trials. In contrast to those studies, Wulf, Zachry, Granados, and Dufek (2007) examined whether the external focus benefits would generalize to a task that most adult participants already have in their repertoire of motor skills, and that mainly seems to depend on maximum force production, namely, a vertical jump-and-reach task. Participants in that study performed a jump-and-reach task using a Vertec™ measurement device (see Figure 2). The goal of this task was to jump straight up and touch the highest rung on the Vertec that they could reach. Participants performed under each of the following conditions: In the control condition, no attentional focus instructions were given; in the internal focus condition, participants were instructed to concentrate on the tips of their fingers, with which they touched the rungs; and in the external focus condition they were instructed to concentrate on the rungs to be touched. Individuals indeed reached higher rungs when they adopted an external focus. Relative to their standing reach height, jump-and-reach height was 24.5 cm with an external focus, compared to 23.2 cm with an internal focus, and 23.7 cm under control conditions (Wulf, Zachry, et al., 2006, Experiment 2). Importantly, the center of mass also showed a greater displacement (from baseline to maximum jump height) when partici-

Figure 2. Participant performing a jump-and-reach task using the Vertec™ measurement system in the study by Wulf, Zachry, Granados, and Dufek (2007).

pants were instructed to adopt an external focus. This indicates that participants actually *jumped* higher with an external focus (rather than simply exhibiting different kinematic patterns while airborne resulting in greater stretch, for example). Perhaps most interestingly, instructing participants to adopt an external focus increased jump height above and beyond what participants achieved under "normal" conditions (i.e., control conditions without instructions).

Feedback

Aside from instructions, learners' focus of attention may also be affected by the feedback given to them. Feedback – as opposed to instructions, which refer to the basic movement pattern – is based on an individual's actual performance. For example, based on what a coach, instructor, physical therapist, or experimenter considers to be the major flaw, he or she provides information about that aspect of the movement to the learner. As with instructions, it seems fair to say that feedback given in practical settings typically refers to the performer's movement coordination, thus inducing an internal focus. Some studies have examined the question whether the type of attentional focus induced by feedback has an influence on the learning process. These studies used balance tasks and sport skills, such as soccer kicks and volleyball serves, and are reviewed next.

Balance

Balance tasks are usually performed without augmented feedback. On the stabilometer, for example, the performer can feel (and see) the position of the platform relative to the horizontal. Thus, additional feedback would seem to be redundant. Nevertheless, Shea and Wulf (1999) provided participants with augmented visual feedback, presented on a computer monitor, concurrently with their performance. The feedback consisted of two horizontal reference lines on the left and right side of the screen, and two lines (which was actually one line with a gap in the middle) representing the actual position of the platform. To examine whether the focus of attention induced by the feedback would have an influence, one group of participants was instructed to think of the moving lines as representing their feet (feedback/internal focus group); another group was instructed to think of the lines as representing two lines on the stabilometer platform in front of their feet (feedback/external focus group). In addition, two control groups without feedback were included. These were instructed to try to keep either their feet horizontal (no feedback/internal focus group) or the lines in front of their feet (no feedback/external focus group).

The most interesting findings were those seen on a retention test, which all groups performed without feedback (or instructions). Even though feedback provided concurrently with the movement typically has a detrimental effect when it is removed in retention (e.g., Vander Linden, Cauraugh, & Greene, 1993; Schmidt & Wulf, 1997; Winstein et al., 1996), this was not the case in the Shea and Wulf (1999) study. The groups that had received feedback during practice showed generally more effective balance than the groups without feedback. Furthermore, the external focus groups (feedback/external focus, no feedback/external focus) were superior to the internal focus groups (feedback/internal focus, no feedback/internal focus). These findings are interesting for at least two reasons. First, they demonstrated that feedback inducing an external focus was more advantageous than feedback inducing an internal focus – even though the feedback itself was identical in both conditions. Second, the augmented, concurrent feedback enhanced learning, rather than degraded it. The authors argued that feedback might have served as a remote focal point that generally tended to induce an external focus, independent of the focus instructions. As a consequence, learning was enhanced. These findings were the first indication that the attentional focus induced by feedback can affect the learning process.

Volleyball

In contrast to the concurrent feedback used in the Shea and Wulf (1999), in most practical situations feedback is provided *after* the movement. In addition, instructors usually comment on the quality of the movement pattern, rather than provide quantitative information. Two experiments by Wulf, McConnel, Gärtner, and Schwarz (2002) examined that type of feedback and asked whether feedback would vary in its effectiveness if it induced an external rather than internal focus. In their Experiment 1, they used a volleyball "tennis" serve. Based on volleyball textbooks, four different feedback statements were first selected, which invariably referred to the player's body movements. In a second step, these statements were "translated" into ones that contained essentially the same information but directed the learners' attention more to the movement effects. For example, rather than instructing learners to shift their weight from the back leg to the front leg while hitting the ball (internal focus), they were instructed to shift their weight toward the target (external focus). After every fifth practice trial, the performer was provided one of the four feedback statements that was deemed most appropriate based on his or her performance on the previous five trials. The results were clear in showing that both novices and advanced players benefited from the external focus feedback. After a one-week retention interval, participants who had received feedback that induced an external focus demonstrated a greater accuracy in their serves than those who had received the "textbook" feedback directed at the body movements. Interestingly, this benefit was seen for groups of novice players, as well as experienced players.

Soccer

In a second experiment, Wulf and colleagues (2002) had experienced soccer players perform lofted kicks at a target placed in a soccer goal. Similar to the volleyball experiment, the feedback statements were simply worded somewhat differently for the internal focus (e.g., "Position your foot below the ball's midline to lift the ball"; "To strike the ball, the swing of the leg should be as long as possible") and external focus groups (e.g., "Strike the ball below its midline to lift it, i.e., kick underneath it"; "To strike the ball, create a pendulum-like motion with as long a duration as possible"). One of five feedback statements was given after practice trials (either after each trial or after every third trial, depending on the group). The main finding of interest here is that, on a no-feedback retention test conducted one week later, participants provided with external-focus feedback were generally more accurate in their kicks than those who received internal-focus feedback. This finding replicated those of the volleyball study, showing that even experienced players benefited more from feedback that referred to the movement effects rather than to their own movements.

Constrained Action Hypothesis

To explain the advantages of focusing on the movement effect, relative to focusing on specific movements, we originally referred to Prinz's common-coding theory (Prinz, 1990, 1997) (see Wulf & Prinz, 2001). Prinz argues that there is a need for a commensurate coding system for afferent and efferent information. Specifically, he assumes that both perception and action planning are coded in terms of "distal events" (Prinz, 1992). As a consequence, actions would be predicted to be more effective if they were planned in term of such events, or intended movement effects. While the observed advantages of focusing on the movement effect are in line with this view, common-coding theory is rather abstract and "does not specifically predict the differential learning effects of external versus internal attentional foci" (Wulf & Prinz, 2001, p. 656).

In more recent years, we have put forward an account, termed the constrained action hypothesis, that more specifically addresses how motor processes are affected by internal versus external foci of attention (e.g., McNevin et al., 2003; Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001). According to this view, focusing attention on the movement effect promotes an automatic mode of movement control. Adopting an external focus allows unconscious, fast, and reflexive processes to control the movement, with the result that the desired outcome is achieved almost as a by-product. In contrast, when individuals try to consciously control their movements (i.e., adopt an internal attentional focus), they tend to constrain the motor system by intervening in the processes that would "normally" regulate the coordination of their movements. Thereby, automatic control processes that have the capacity to control movements effectively and efficiently are disrupted. (Findings showing that individuals typically perform similarly under internal focus and "normal" control conditions suggest that people may have a tendency to consciously control their movements when confronted with novel tasks.) There are several lines of evidence in support of the constrained action view. These are related to differences in the attentional capacity, frequency of movement adjustments, and the degree of muscular activity observed under different focus conditions. These findings are reviewed next.

Attentional Capacity

The attentional demands of a given task are often determined by using dual-task paradigms. In those paradigms, participants perform the task of interest (primary task) simultaneously with a secondary task, such as a probe reaction time task. Performance on the probe reaction time task, which may require the participant to press a key in response to a visual or auditory signal, is assumed to be related to the attentional demands of the primary task. That is, longer reaction times are interpreted as indicating that the primary task required more attention (e.g., Abernethy, 1988). Using this approach, Wulf, McNevin, and Shea (2001) found short probe reaction times for participants performing a balance task with an external as compared to an internal focus. Specifically, participants who performed the stabilometer task under external focus (markers on the platform) or internal focus (feet) conditions were asked to respond as fast as possible by pressing a response key when a tone was presented (about 8 times per 90-s trial). The results not only showed shorter probe reaction times across practice trials for both groups, indicating that with more experience less attention was required for balance, but also shorter probe reaction times for the external focus group relative to the internal focus group. This finding corroborates the view that an external focus promotes automaticity in movement control.

Frequency of Movement Adjustments

Analyses of the movement frequency characteristics in balancing, using Fast Fourier Transformations, have consistently shown higher frequency adjustments for external compared to internal focus participants (McNevin et al., 2003; Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001). In general, high-frequency movement adjustments allow the motor system to quickly respond to perturbations from the environment or the person's own actions. In the studies mentioned above, participants learning to balance on a stabilometer showed consistently higher mean power frequency values when they were instructed to adopt an external focus (i.e., markers) compared to an internal focus (i.e., feet). This suggests that external focus participants utilized more, and faster, reflex loops operating at an automatic level,

while those who focused internally used more conscious, and slower, feedback loops.

Interestingly, placing the markers at a greater distance from the feet has been found to result in even higher frequencies in responding, as well as greater stability, than focusing on markers directly in front of the feet (McNevin et al., 2003; Park, Shea, McNevin, & Wulf, 2000). This suggests that movement effects that occur at a greater distance from the body – and are more easily distinguishable from body movements that produced them – result in even greater automaticity.

Muscular Activity

While most attentional focus studies have examined effects at the behavioral level, a few studies have begun to look at how the nervous system operates to produce those effects. These studies have used electromyography (EMG) to determine possible correlates at a neuromuscular level that might explain the performance differences seen under external versus internal focus conditions (Marchant, Greig, Scott, & Clough, 2006; Vance, Wulf, Töllner, McNevin, & Mercer, 2004; Zachry et al., 2005). If an external focus indeed results in greater automaticity than an internal focus, one might expect to see more discriminate motor unit recruitment, or more efficient movements, under external focus conditions.

In a study by Vance et al. (2004), participants performed a biceps curl task and were either instructed to focus on the movements of the curl bar (external focus) or of their arms (internal focus). Two sets of 10 repetitions were performed under each focus condition. The results demonstrated that, in the external focus condition, EMG activity was significantly reduced relative to the internal focus condition. As the movement outcome (i.e., weight lifted) was identical under both conditions, this indicates greater movement efficiency under external focus condition. Interestingly, EMG activity was not only reduced in the biceps muscles (i.e., the agonists), but also in the triceps muscles (i.e., the antagonists). This suggests that movement efficiency was increased not only through a more effective recruitment of muscles fibers within a muscle (intra-muscular coordination; Hollmann & Hettinger, 2000), but also through enhanced coordination between muscles (inter-muscular coordination; Hollmann & Hettinger, 2000).

Recently, Marchant et al. (2006) extended the Vance et al. findings by showing that instructing participants to focus on the curl bar resulted in less EMG activity not only compared to instructing them to focus on their arms, but also compared to no focus instructions (control condition). That is, the external focus instructions reduced muscular activity even compared to the "natural" control condition.

Zachry and colleagues (2005) looked at EMG activity during basketball free throw shooting when participants adopted an external focus (basket) compared to an internal focus (wrist motion). As free-throw accuracy was enhanced under the external focus condition, the authors argued that an external focus of attention might not only increase movement efficiency, but might also reduce "noise" in the motor system that hampers fine movement control and makes the outcome of the movement less reliable. Interestingly, significant attentional focus differences in EMG activity occurred in muscle groups that participants were not specifically instructed to focus on, namely, in the m. biceps and m. triceps brachii. EMG activity in those muscles was greater under the internal compared to the external focus condition. This suggests that the effects of attentional focus tend to "spread" to muscle groups that are not even in the performer's focus of attention. In other words, an internal focus appears to constrain not only the action of the body part that the individual focuses on, but the action of other body parts as well.

Performance or Learning

An interesting question is whether the differential effects of attentional focus are simply temporary effects on performance (i.e., only present when the individual adopts the respective focus), or whether they represent relatively permanent, or learning, effects. Most attentional focus studies have used delayed retention tests without instructions or reminders to assess learning. A potential drawback of this procedure, however, is that, during retention, participants might still adopt the same focus they were instructed to use during the practice phase. That is, performance on retention tests may not necessarily be regarded as conclusive evidence that the observed group differences constitute learning effects. Therefore, Totsika and Wulf (2003) used a transfer test, in which performers were prevented from using the attentional focus they were instructed to adopt during practice. Specifically, participants were required to perform an attention-demanding secondary task (i.e., counting backwards in threes) while riding a Pedalo as fast as possible. The results showed that movement speed was greater for the group that was given external, as opposed to internal, focus instruction during practice – suggesting that the influence of the focus of attention adopted during practice is indeed relatively permanent in nature. Moreover, Totsika and Wulf (2003) found a similar advantage when participants had to perform a novel variation of the task, namely, riding the Pedalo backwards as fast as possible. Thus, the external focus advantages do not seem to be restricted to the specific task practiced, but appear to be generalizable to novel contexts.

Another line of evidence indicating that effects of attentional focus represent learning differences, and are generalizable to variations of the skill, comes from studies that examined how a performer's focus of attention of a supra-postural task affects her or his postural control. These are reviewed in the following section.

Supra-Postural Tasks

Many real-life tasks have "supra-postural" goals. These are tasks in which the postural system subserves a "higher" goal, such as holding an object still, pointing, reading, or juggling, while standing or walking. Sometimes the postural task itself can be challenging, for example, when it requires balancing on a compliant, moving, or small support surface. A few studies have examined whether the type of focus on a supra-postural task might not only influence supra-postural performance, but also postural control.

McNevin and Wulf (2002) measured participants' postural sway while standing still with their eyes closed and lightly touching a curtain with their fingertips. The goal of the supra-postural task was to move the curtain as little as possible. In one condition, participants were instructed to adopt an external focus, that is, they were asked to try to minimize movements of the curtain. In the internal focus condition, they were instructed to minimize curtain movements by focusing on minimizing their finger movements. In addition, there was a control condition without attentional focus instructions. McNevin and Wulf found higher-frequency and lower-amplitude postural adjustments in the external as compared to both the internal focus and control conditions. This is in line with the view that an external focus promotes greater automaticity in movement control. More importantly, this finding extended previous research by showing that postural control can not only be influenced directly by manipulating the attentional focus on the postural (or balance) task, but that it can also be influenced *indirectly* through the attentional focus adopted on a supra-postural task.

A shortcoming of the McNevin and Wulf (2002) study was that movements of the curtain or the finger were not measured in order to assess supra-postural task performance. A follow-up study (Wulf et al., 2004), however, looked at effects on postural and supra-postural task performance as a function of the attentional focus on the supra-postural task. In that study, the balance task was more challenging, as participants stood on a compliant surface (inflated rubber disk). The supra-postural task required them to hold a 2 m pole horizontal and as still as possible. The authors measured both the stability of the pole and the amount of postural sway. The results replicated that of the previous study (McNevin and Wulf, 2002) with regard to postural stability. When participants were instructed to focus on the pole (external focus), they demonstrated less postural sway than when they were instructed to focus on their hands (internal focus). Furthermore, the pole itself was more stable when they adopted an external as opposed to an internal focus. Thus, the external focus on the supra-postural task had a double advantage: It enhanced performance on the supra-postural task and improved postural stability.

The two previous studies (McNevin & Wulf, 2002; Wulf et al., 2004) used within-participant designs, in which all participants performed under all focus conditions. Thus, those studies were only concerned with immediate effects on performance, but not with learning effects. Another study addressed the question whether the type of focus on the supra-postural task would also affect the learning of a balance (postural) task (Wulf et al., 2003). In that study, participants practiced a balance task (stabilometer) while at the same time performing a supra-postural task (holding a wooden tube horizontal). The attentional focus instructions given to different groups were related only to the supra-postural task: Participants in the internal focus group were instructed to focus on keeping their hands horizontal, whereas participants in the external focus group were instructed to focus on keeping the tube horizontal. The most interesting results were those seen on a transfer test. On this transfer test, the supra-postural task was removed. Thus, without the presence of the object of attentional focus, any group differences on the balance task would have to be interpreted as being the result of differential learning effects due to the (previous) focus on the supra-postural task. The results were clear in showing that an external focus on the supra-postural task enhanced balance, compared to both internal focus and no focus instructions. That is, the type of focus on the supra-postural task indeed affected the learning of the balance task.

Individuals With Motor Impairments

While most studies have used young, unimpaired adults as participants, a few studies have also examined whether the benefits of an external focus might generalize to individuals with motor impairments, such as those resulting from Parkinson's disease or stroke. As in most training situations, the instructions given by physical therapists typically refer to the patient's movement coordination. Thus, any evidence for performance advantages resulting from instructions that induce an external focus could have important implications for clinical rehabilitation.

Parkinson's Disease

Two studies examined balance (postural stability) in persons with Parkinson's disease as a function of their focus of attention (Landers et al., 2005; Wulf, Landers, & Töllner, 2006). In the Landers et al. study, a NeuroCom Smart® Balance Master system was used. This system measures postural sway and quantifies an individual's ability to maintain balance. Participants in that study included persons with Parkinson's disease, with an average age of 72.7 years, who also had a history of falls. Participants stood on rectangular pieces of contact paper, one under each foot, that were placed on the force platform of the Balance Master. All participants performed under all of the following three conditions. In the external focus condition, they were instructed to concentrate on putting an equal amount of pressure on the rectangles, whereas in

the internal focus condition they were asked to concentrate on putting an equal amount of pressure on their feet. In the control condition, they were simply instructed to stand still. In a "sway-referenced" condition – where the platform and the walls surrounding the participant tilt forward or backward in accordance with the participant's center of pressure – significant attentional focus effects were found. Balance scores were higher (i.e., postural sway was reduced) when participants adopted an external focus than when they adopted an internal focus, or were not given focus instructions. The latter two conditions resulted in similar balance scores. This was the first piece of evidence that balance in persons with Parkinson's disease can be enhanced by external focus instructions.

The findings of another study corroborate this conclusion (Wulf, Landers, & Töllner, 2006). In that study, individuals with Parkinson's disease were asked to stand on an inflated rubber disk. (This is a very challenging task for persons with balance problems, such as those with Parkinson's disease.) When asked to focus on moving the disk as little as possible (external focus), their postural sway was significantly reduced compared to when they were asked to move their feet as little as possible (internal focus), or when they were simply asked to stand still (control) (see Figure 3). Thus, the results of both studies provide converging evidence that the attentional focus effects generalize to individuals with Parkinson's disease.

Stroke

Fasoli, Trombly, Tickle-Degnen, and Verfaellie (2002) investigated the effects of external versus internal focus instructions in persons who had a cerebrovascular accident, or stroke. In that study, stroke patients and non-impaired control participants performed daily-life activities, including taking a can from a shelf and putting it on a table, taking an apple from a shelf and putting it into a basket, and placing an empty coffee mug from a table onto a saucer. The instructions directed participants' attention either to the object they were to manipulate (e.g., "Pay attention to the can: Think about where it is on the shelf and how big or heavy it is"), or to their movements (e.g., "Pay attention to your arm: Think about how much you straighten your elbow and how your wrist and fingers move"). The results showed that both impaired and non-impaired participants had shorter movement times and greater peak velocities on all tasks when they were given external focus instructions. This suggests that even participants with stroke pre-planned their movements to a greater extent, and used more automatic control processes, when they were instructed to focus externally.

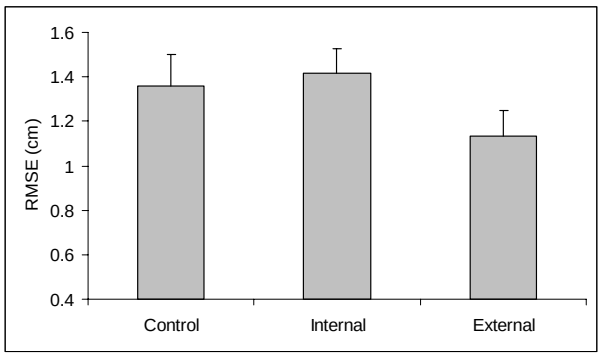

Figure 3. Magnitude of sway (root-mean-square error; RMSE) for participants with Parkinson's disease as a function of the type of attentional focus (control, internal, or external) in the study by Wulf, Landers, and Töllner (2006).

Conclusions and Directions for Future Research

After about 10 years of research, there can be little doubt that an individual's focus of attention plays a role in how well motor skills are performed and learned. Sometimes the beneficial effects of an external relative to an internal focus are seen almost immediately. But, more importantly, the type of focus an individual adopts while practicing a skill affects the learning process. Not only is a higher level of performance often achieved faster with an external relative to an internal focus; but the skill is retained more effectively. Performance advantages are seen on retention tests – when no focus reminders are given, and sometimes even when the individual is prevented from adopting the same focus – indicating that those advantages are relatively permanent. Furthermore, the benefits of an external focus have been shown to be generalizable to a wide variety of skills and skill levels, and have been found for young adults as well as for older individuals and those with physical impairments. We also have a fairly good understanding of how a person's focus of attention affects his or her performance. There is converging evidence that the adoption of an external compared to an internal focus promotes greater automaticity in movement control.

Yet, there are open questions as well. There are some areas, in which the evidence is not as strong as would be desirable, and others, in which research studies are still scarce or lacking altogether. For example, most studies have used performance outcome measures, such as movement accuracy, amplitude, speed, and measures of postural sway. Only very few studies have looked at how movement form is affected by the type of attentional focus. Expert ratings or motion analyses could perhaps be used in future studies to assess movement quality as a function of attentional focus. Furthermore, while some studies have looked at focus effects in the elderly and persons with Parkinson's disease or stroke, it would be interesting to examine whether the external focus advantages generalize to other populations with motor impairments, such as persons with cerebral palsy or incomplete spinal cord injury. Also, even though some researchers have started to examine attentional focus effects in children (e.g., Thorn, 2006), more studies are needed to determine at which age those effects begin to manifest themselves. Another fruitful direction for future research would be an examination of whether the optimal

(external) focus interacts with the performers' level of expertise. With increasing expertise, actions are assumed to be monitored at progressively higher levels (Vallacher, 1993). For a tennis player, such a hierarchy of levels – or movement effects – might be to "hit an ace", "give the ball a topspin", and "swing the racket forward and upward". While it makes sense to assume that novice performers would benefit more from focusing on lower-level movement effects (e.g., the swing of the golf club) than higher-level effects (e.g., the trajectory of a golf ball) (Vallacher, 1993; Vallacher & Wegner, 1987), would the opposite be true for expert performers (see also Wulf & Prinz, 2001)? Finally, performance decrements in stressful situations are often referred to as "choking under pressure". There is good evidence that a major cause of choking is self-focused attention (e.g., Baumeister, 1984; Gray, 2004). Could practicing with an external focus prevent, or at least reduce, choking?

Even though there are questions that still need to be answered, the research findings reviewed here have important implications for practical settings that involve motor skills, such as sports, the performing arts, and physical or occupational therapy: Changing the wording of instructions or feedback has the potential to enhance the performance and learning of motor skills, with the consequence that practice or rehabilitation procedures could become more effective and (cost-)efficient.

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COMMENTARY ON WULF

ATTENTIONAL FOCUS AND MOTOR LEARNING: POSSIBLE APPLICATIONS TO HEALTH PROFESSIONS EDUCATION

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In dieser Entgegnung diskutieren wir die Thematik der Aufmerksamkeitsfokussierung und des motorischen Lernens in ihrer – bislang unbeachteten – Bedeutung für die professionelle Ausbildung im Gesundheitssektor. Nach einer kurzen Einführung in dieses Feld präsentieren wir insbesondere Grundprinzipien der Anwendung aktueller Aufmerksamkeits- und Lernkonzepte in der Entwicklung von Curricula für den Erwerb technischer Fertigkeiten im klinischen Bereich.

Schlüsselwörter: Aufmerksamkeitsfokus, motorisches Lernen, motorische Fertigkeiten, antizipative Verhaltenskontrolle, Koordination

In this response we discuss how the issues reviewed regarding attentional focus and motor learning have not been addressed in the field of health professions education. We provide a brief introduction to the field of health professions education, and present a rationale for applying current concepts related to attention and learning to facilitate the development of technical clinical skills curricula.

Keywords: attentional focus, motor learning, motor skills, anticipatory behavior control, coordination

In her thorough review of the attentional focus literature, which she has made substantial contributions to through her own work, Wulf (2007) concludes with the suggestion that the attentional focus and motor learning model has important implications for practical settings. Some of these applied settings include sports, performing arts, and rehabilitation. In this response paper we would like to highlight the lack of similar research in the field of medical, and more specifically surgical, education. The process of teaching technical skills for the practice of medicine and other health professions has been going through an evolution in recent years. The educational approach has changed from an apprenticeship model, also termed “see one, do one, teach one”, towards a theory and evidence based approach. Formal training now takes place in highly specialized facilities that utilize various levels of simulation to teach technical skills in the absence of patients. This approach is rooted in the principles of motor learning that have been established in the fields of kinesiology and psychology (Dubrowski & Carnahan, 2003). Unfortunately, to date, most publications in this area have not referenced contemporary models or factors that influence motor skill acquisition. For example, the most recent model of motor learning that was cited in a current review of surgical education is almost 40 years old (see Fitts & Posner, 1967, as cited in Reznick & MacRae, 2006). As researchers with roots in kinesiology and now working in the field of medical education, we see it as part of our responsibility to update this applied literature with the most current and relevant models that describe the acquisition of motor skills (e.g., Guadagnoli & Lee, 2004).

What is so exciting about Wulf’s review is that her conclusions have direct application to the further development of research in medical education. At the Psychomotor Skills & Health Professions Laboratory at the University of Toronto, our research team is interested in studying the applicability of motor learning principles to learning technical skills for the practice of medicine. In particular, the world of surgery is an interesting environment for addressing issues of expertise and attention. The notion of maximizing the learning environment by providing optimal feedback to learners in the form of extrinsic and intrinsic focus of attention has not been addressed in the education of technical skills. To date, there is one model of learning within the surgical environment that describes the allocation of attentional resources, but it does not specifically address the learner’s foci of attention. This model does, however, address how the ability to share attentional resources changes as a function of surgical expertise (Gallagher et al., 2005). That is, it was suggested that successful “expert” performance within the operating room requires attending to various aspects of clinical performance such as perception, motor control, decision making, and communication, all of which demand and compete for limited attentional resources. Based on this model, only with extensive directed practice is the surgeon able to multi-task and divert his/her attentional processes appropriately. In our lab we have provided evidence to support this model. We have shown that as exper-

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tise develops, motor control strategies when performing a basic surgical skill (i.e., bone drilling) shift from on-line control to anticipatory control (Dubrowski & Backstein, 2004; Praamsma, Carnahan, Backstein, & Dubrowski, in press). Associated with this shift to anticipatory control is the ability to perform two tasks simultaneously. We have recently examined multi-tasking by having trainees perform the surgical procedure of pyloroplasty, which involves complex suturing of the stomach to alter its configuration, while also learning didactic information about the factors influencing ulcer complications. We found that pre-training on the technical skills of pyloroplasty improved the trainees' ability to divide their attentional resources when concurrently performing the pyloroplasty and listening to the didactic material, which resulted in superior recall of the ulcer-related information. Alternatively, we have shown that when a learner's attention is redirected during the learning process via a secondary task, the technical performance of individuals who are novice at the skill deteriorates, but the performance of individuals with experience is not affected. This was shown in a primary motor task involving interrupted wound closure (suturing), with a secondary task that required learning didactic material related to treatment of melanoma. These two studies show that pre-training, or prior experience with a motor skill, helps both with the learning of subsequent cognitive material and with the maintenance of motor performance when attention must be divided. Collectively these studies also demonstrate how a theoretical model can be implemented and validated within the realm of medical education.

Using the approach outlined above, we would like to apply the principles that Wulf has distilled from her review to extending the current state of research on attention in the field of health professions education. We would like to facilitate the process of knowledge translation in moving these concepts beyond the domain of sport skills, and into the clinical domain. This translation will result in the advancement of curriculum development for the education of health professionals, and may also feed back to the basic world, and help guide the formulation of appropriate theoretical questions (Brydges, Carnahan, Backstein, & Dubrowski, 2007).

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COMMENTARY ON WULF

ATTENTIONAL FOCUS AND MOTOR LEARNING: NOTES ON SOME PROBLEMS OF A RESEARCH PARADIGM

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Die Aufmerksamkeitsforschung zum motorischen Lernen scheint die Überlegenheit der Fokussierung distaler Effekte im Vergleich zur internalen Fokussierung schlüssig zu belegen. Weitergehende Befunde lassen jedoch Zweifel an der Generalität dieser Aussage aufkommen. Ferner mangelt es den theoretischen Erklärungsansätzen an Überzeugungskraft, wobei insbesondere (funktionale) Relationen zwischen Aufmerksamkeitsfokus und Aufgabenanforderungen berücksichtigt werden sollten.

Schlüsselwörter: Aufmerksamkeitsfokus, Verhaltenswirkung, Automatismus, funktionale Kopplung, Forschungsmethodologie

Research on attentional focus and motor learning seems to be conclusive: Directing attention to distal effects of movements is superior to an internal focus. However, looking at further evidence raises doubts about this general statement. On the other hand, the theoretical explanation of attentional effects is not convincing. Rather the (functional) relationship of attentional focus and task demands should be reconsidered.

Keywords: attentional focus, behavioral effect, automaticity, functional coupling, research methodology

In her target article, Wulf (2007) provides a concise and comprehensive review of research on attentional focus and motor learning available in English language. In our comment on the article we focus first on the studies and data and then on the theory.

Looking at the data, Wulf presents at first sight conclusive evidence for the beneficial effects of an external relative to an internal focus of attention. However, there are some shortcomings and open questions due to the design of the studies or, more general, due to the research paradigm. On some of these points, further studies, which are discussed later in this text, offer additional insights concerning methods and findings.

First of all, it is important to note that all studies reviewed by Wulf used indirect or behavioral treatments to manipulate the learner's attentional focus, mainly instructions or feedback. However, in some cases this information is rather vague (e.g., "focus on how the model scored a basket"; Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002) or address not the effect of the movement, but a (perceptional) target (e.g., the rim of the basket; Zachry, Wulf, Mercer, & Bezodis, 2005). Furthermore, the "basic instructions" given to all participants prior to the practice phase might "preconstitute" a certain focus, which is then interacting congruently or incongruently with the attentional focus induced by the treatment instructions. Finally, it is also possible that some of the experimental tasks by themselves lead to the adoption of a certain attentional focus, for example due to their (proximal or distal) outcomes or the perceptional conditions. Given all this, it is not clear which focus of attention the participants really adopt and the need for a validation of the focus-generating treatment becomes apparent.

Zentgraf (2005) validated her focus instructions by using a video-based three-dimensional movement analysis. She found that participants who were given external focus instructions on a juggling skill (e.g., "toss the balls to the same height"), in fact, showed significantly more consistent throws than those who were given internal focus instructions. On the other hand, internally focused learners (e.g., "keep your body still") did not demonstrate less postural sway while juggling than externally focused learners. Further options for a treatment validation are the application of questionnaires or interviews and, relating to future research, methods of Virtual or Augmented Reality.

An interesting, but still unanswered question is whether the effects of attentional focus are either (temporary) performance effects or (permanent) learning effects or both. In her review, Wulf (2007) postulates both short-term and long-term effects. However, a closer look at the results leads to a different (and more differentiated) view. A vote-counting of those attentional focus studies that (1) were mentioned by Wulf and (2) include practice sessions and retention/transfer sessions shows that the direction of attentional focus seems to affect rather the retention, or learning, of a motor skill than the practice: In 7 of 10 studies that have used instructions to induce an attentional focus, advantages of an external focus were only found in retention or transfer tests, but not during prac-

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tice. Only in 3 studies the external focus groups were superior to the internal focus groups already during practice. However, in 2 of these studies (Totsika & Wulf, 2003; Wulf, Lauterbach, & Toole, 1999) the group differences already occurred during the first trial(s) or trial block; thus, it is possible that they are not caused by the attentional focus instructions, but simply are the result of a sample bias. Surprisingly, in all studies in which no retention test was conducted, benefits of an external relative to an internal focus were observed already in the practice phase. The inconsistency of the findings shows that further research is needed on the problem under which conditions the effect occurs immediately or delayed. It is notable that the advantage of an external focus is frequently observed only during retention, when no focus information is given. Among other things, a theory of attentional focus has to address this point.

To explain the superiority of an external focus, Wulf proposes the constrained action hypothesis which assumes that external focus may provoke an automatic mode of movement control. This view is confirmed by three lines of evidence (faster RT under dual-task conditions, higher frequency of motor adjustments, and reduced EMG activity when adopting an external focus). We think that this explanation is not completely convincing, at best half of the truth. Generalizing this hypothesis leads to the expectation that any experimental treatment forcing subjects to adopt automatic control may lead to better learning. Why should this (unspecific) effect be associated with external focus? And why should it be superior in subjects learning a new skill? Research using the dual-task paradigm tells us that under dual-task conditions, there is a decrease in performance, particularly in early stages of practice.

Rather than assuming an unspecific control effect, the relationship of attentional focus and task should be (re-)examined in more detail (e.g., Hänsel & Seelig, 2003). Distal effects are normally much more closely related to the desired outcome, for example, keeping balance and hitting a target. This might be the reason why an external focus can be more informative to learners than an internal focus. On the other hand, if an internal focus can be adopted that closely corresponds to the task demands, this focus should be equivalent or superior to an external focus that shows a lower correspondence. For example, in a pedalo learning experiment, Körndle (1983) found that fast learners concentrate on concrete items representing an internal focus, like "bending forward", "keeping the trunk quiet" or "tensing the muscles of the thigh". Therefore, the functional relationship of attentional focus and task may be more important than the mode of control.

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COMMENTARY ON WULF

CONSTRAINING ACTION THROUGH ATTENTIONAL FOCUSING HAPPENS AT POINTS IN TIME

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Bei aller empirischen Evidenz für Aufmerksamkeitsfokuseffekte auf motorisches Fertigkeitslernen wird in dem Beitrag von Gabriele Wulf der überzeugende theoretische Rahmen für einen Mechanismus vermisst, der diese Effekte auf sensomotorischer Ebene erklären könnte. Auf Basis handlungstheoretischer Konzepte (bspw. Hoffmann, 1993) wird in diesem Kommentar ein solcher Theorierahmen vorgeschlagen, der zeitbezogene Effekte von Aufmerksamkeitsfokussierungen vorhersagt.

Schlüsselwörter: Aufmerksamkeitsfokus, Knotenpunkte der Bewegung, antizipative Verhaltenskontrolle, funktionale Kopplung, Muskelaktivität

Despite the empirical evidence for the effects of attentional focusing on the learning of motor skills reported in the target article, no convincing theoretical framework for a mechanism on a sensorimotor level behind these effects is provided. Such a framework is proposed based upon action-theoretical concepts (e.g. Hoffmann, 1993), that makes time-referenced predictions for the effects of attentional focussing.

Keywords: attentional focus, nodal points of the movement, anticipatory behavior control, functional coupling, muscular activity

The evidence for the superiority of an external focus of attention in motor learning gathered by Wulf and her collaborators over the last decade is very impressive. However, as sound as the empirical foundation may be, from a more theoretical perspective the assumptions of the constrained action hypothesis remain rather vague: How does an internal focus interfere with the "automatic processes" and how does this interference affect movement execution? These questions still lack convincing answers.

Addressing the latter issue, Wulf (2007) reports some studies that have looked beyond mere measures of movement outcome (e.g., McNevin, Shea, Wulf, 2003). These studies have at least shown that an internal focus condition negatively affects movement variability and that this may be caused by increased muscular activity (e.g., Zachry, Wulf, Mercer, & Bezodis, 2005). Still a precise mechanism is needed that connects the "cognitive level" of automatic and controlled processes and the "movement level" of disturbed movement execution. A proposal for a hypothetical mechanism on a level of motor control has been made by Beilock, Carr, MacMahon, and Starkes (2002, p. 8) that assumes that "the compiled real-time control structure of a skill is broken down into a sequence of smaller, separate, independent units – similar to how performance may have been organized early in learning. Once broken down, each unit must be activated and run separately, which slows performance and, at each transition between units, creates the opportunity for error that was not present in the 'chunked' control structure".

In an attempt to further specify the ideas put forward by Beilock et al. (2002) we have formulated and tested a nodal-point hypothesis of motor control (Hossner & Ehrlenspiel, 2007). It is based on the assumptions that movements are controlled by the anticipation of their sensory effects (overview: Kunde, 2006). If these effects (nodal points) are reliably anticipated the initially single behavioral units (stimulus-response-effect-triplets) are chunked over the course of learning to form chains. Within these chains the end-effect takes over control (e.g., Hoffmann, 1993) consequently reducing the necessity of checking the attainment of intermediate effects. On a phenomenological level, this is perceived as automatism. For example, when learning to drink from a cup, children will first attend to grasping after reaching was completed (intermediate effect). However, the reader of this comment may be drinking coffee while reading – thus without attending to the handle (chained control structure/automatism).

With respect to a hypothetical mechanism explaining the general disadvantage of internal focusing it can be assumed that "controlled" processes (caused by an "internal" focus) reflect an inversion of the serial chaining mechanism sketched above, as attention is directed towards intermediate effects. If the – adult and coffee drinking – reader focuses attention to the hand movement (internal focus) the well-learned and formerly fluid movement is split up into a grasping and a

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consequent transport movement of the cup to the lips.

On a sensorimotor level it can be assumed that the chaining of effects at certain nodal points coincides with a "freeing of degrees of freedom" in movement coordination (e.g., Vereijken, van Emmerik, Whiting, & Newell, 1992), accompanied by or resulting from reduced muscular activity. This reduction may be caused by decreased non-functional co-contractions of agonist and antagonist muscles. The "freeing" also allows the exploitation of task properties; thus, reactive phenomena and given properties of the sensorimotor system, e.g., compensatory variability (e.g., Müller, 2001), may be exploited more effectively in order to ensure stable and parsimonious performance and control. Summarizing, the nodal-point hypothesis thus provides two key features of a potential sensorimotor mechanism behind the effects of attentional focusing: First, this mechanism is clearly time-referenced as the focus of attention will be directed to nodal points of the movements. Secondly, this focusing on a nodal point will result in a reduced exploitation of task properties and a higher overall muscular activity at exactly and exclusively these points in time.

These predictions have been tested by us using a lever-sequencing task (Hossner, 2004) and a basketball free throw task (Ehrlenspiel, 2001). In the lever-sequencing task, participants learned to produce a sequence of seven states of two levers. After learning, participants had to focus their attention on a specific state while producing the entire sequence. In the basketball free throw task, expert basketball players had to either focus on the basket or on one of two nodal points within the movement. In both tasks, focusing on a nodal point resulted in an increased relative muscular activity at that nodal point compared to the other nodal points that were not in focus. It also resulted in reduced nodal-point specific task exploitation, i.e., reduced temporal covariation for the related succession of time intervals between lever states in lever sequencing and reduced spatial covariation of the throwing arm's joints in the free throw task.

Both experiments expand and render more precisely the findings reported by Wulf (e.g., McNevin et al., 2003; Zachry et al. 2005) by demonstrating time-referenced effects of attentional focusing that interrupt compensatory processes of the motor system. The nodal-point hypothesis thus appears to provide the framework for a mechanism behind the phenomenon of "paralysis by analysis" (Schmidt, 1982). This framework also allows for a more functional approach to the effects of attentional focus on motor learning and control: In order to allow "chaining" attention should be directed to relevant effects that are reliably attained and, thus, anticipated – whether "internal" (i.e., kinesthetic, proprioceptive) or "external" (exteroceptive, events in the environment). And relevance, in turn, depends on task constraints: If the handle of the cup is slippery it may be important to feel the grasp rather than only see it. But again, focusing will lead to the disruption of compensatory processes – and will be time-referenced.

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COMMENTARY ON WULF

FOCUSING ALONG MULTIPLE DIMENSIONS: SPATIAL, TEMPORAL, AND MODAL ASPECTS OF DISTALITY

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In vielen Studien des Überblicksbeitrags wird Distalität als Ausdruck der Effektnähe im Sinne eines räumlichen Bezugsrahmens konzeptualisiert. Hier wird hingegen für die Auffassung von Distalität als multidimensionales Konzept plädiert, so dass Aufmerksamkeit auch in anderen Dimensionen auf distale Effekte zu lenken ist und dies mit differentiellen Effekten der Aufmerksamkeitsfokussierung verbunden sein kann.

Schlüsselwörter: Aufmerksamkeitsfokus, Bewegungssteuerung, Verhaltenswirkung, Bewegungsaufgabe, funktionale Kopplung

In many studies reviewed in the target article, distality as a concept of effect vicinity is used in terms of a spatial frame of reference. It is argued here that by conceiving distality as a multidimensional concept, attention can also be directed towards distal effects along other dimensions as well yielding differential effects of attentional focusing.

Keywords: attentional focus, motor control, behavioral effect, movement task, functional coupling

Questions concerning the influence of an individual's attentional focus on processes of motor control and learning have led to a considerable amount of experimental work in human movement science. The empirical evidence reviewed by Wulf (2007) seems to indicate that it is generally more beneficial to direct a performer's attention to external, that is, distal effects of an executed movement, instead of directing attention towards more proximal aspects of the movement itself, such as for example, effects on the sensory surface of the body or patterns of muscle activation. These findings along with the constrained action hypothesis suggest that an effective focus of attention is most notably characterized by its distality.

The idea that distality as a prerequisite for successful attentional guidance should not be conceived in terms of distance from one's body but in terms of the vicinity to environmental action effects has already been articulated by Prinz (1997) and was subsequently supported by Wulf and colleagues who demonstrated that in order for an external focus of attention to be effective, attention needs to be directed not just away from movement execution, but towards the movement's actual effect (Wulf, McNevin, Fuchs, Ritter, & Toole, 2000, Experiment 1). Those effects, however, can be expressed within multiple frames of reference, e.g., by specifying its spatial location or its time of occurrence, so that attention can be directed towards distal effects along different dimensions. Based on the literature reviewed by Wulf (2007), it remains unclear if distal referencing is equally necessary or beneficial along different effect dimensions.

Hossner, Hegele, Erlacher, and Ehrlenspiel (2006) offered a systematic differentiation of distality along three dimensions: spatial, temporal, and modal. The first dimension relates to the spatial orientation of distality. In the majority of studies reviewed by Wulf (2007), the distinction between external and internal attentional foci can be mapped within a spatial frame of reference. For example, McNevin, Shea, and Wulf (2003) employed a balancing task and told participants to focus either internally on their feet or externally on markers, which were attached to a stabilometer platform and which were spatially more distant from the body. The superior performance of the external focus group supports the importance of distality along the spatial dimension. The second dimension relates to the temporal aspects of a movement. For example, in a study by Wulf and colleagues (2000), tennis players were instructed to focus either on the tennis ball approaching (antecedent) or the ball leaving the racket (effect). The better results of the effect group suggest that it should make a difference if the focus of attention is directed to an aspect of the movement which is temporally closer to the effect. Finally, the third dimension refers to the modality by which individuals attend to environmental effects or movement characteristics. This distinction has only received implicit experimental considerations and no direct comparisons have been made. For instance, in many studies that employed a balancing task (e.g., McNevin et al., 2003), subjects were instructed to focus visually on their feet or on markers attached to the stabilometer platform. Alternatively, subjects in a study by Vance and colleagues (Vance, Wulf,

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Töllner, McNevin, & Mercer, 2004) had to use proprioceptive information in order to attend to the instructed internal and external focus of attention. Since these are two different studies using different tasks and experimental procedures, it is difficult to directly compare their results, but one could argue that the visual modality might be conceived as a more distal way of attending to an action effect, because vision, as it is serving exteroception, is commonly directed to distal stimuli in the environment. Proprioception, on the other hand, is generally sensitive to stimuli intrinsic to the body and thus usually refers to more proximal aspects of an action.

Based on these considerations, Hossner et al. (2006) investigated the influence of various attentional foci on performing the golf putt. They differentiated the foci's distality to the intended action effect along the dimensions described above. Participants in their study always received combined instructions to focus their attention on performance- vs. effect-related aspects on the respective dimensions: "Feel vs. see (modal) the club grip vs. club head (spatial) at the moment you hit the ball vs. the turning point of your backswing (temporal)." Results revealed a significant main effect for the factor spatial, i.e. the performance was better when attention was focused on the golf club's head instead of the grip. This is in line with previous research supporting the importance of focusing attention on distal action features within a spatial frame of reference.

Furthermore, within the more beneficial focus on the spatially distal club head, there was a significant disordinal interaction of the two remaining factors temporal and modal. When focusing on the club head, it was better to concentrate on kinesthetic feedback when hitting the ball, but also better to concentrate on visual feedback during the backswing. Another experiment aiming to explain the origin of this interaction effect showed that by manipulating situational aspects of the task, the disordinal interaction between the modal and the temporal dimensions disappeared.

In conclusion, even though Wulf (2007) offered a number of important insights, it might be beneficial to recognize distality in terms of effect vicinity along different dimensions. Albeit a distal focus of attention along the spatial dimension led to superior performance, there is still room for optimizing pattern between the temporal and modal dimensions. Thus, it seems as if there exist dependencies from contextual and task constraints. Together, those define a functional relationship between the induced attentional focus and the intended action effect within a multi-dimensional workspace. Careful analyses of task and context might be helpful to discover these functionalities a priori and subsequently optimize attentional guidance in motor learning and control beyond the current standards.

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COMMENTARY ON WULF

SKILLFUL ATTENDING, LOOKING AND THINKING

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In diesem Kommentar geben wir einige forschungsmethodische Empfehlungen für die zukünftige Forschung zum Aufmerksamkeitsfokus und zur „constraint-action"-Hypothese. Insbesondere regen wir an: die Durchführung von Prä-Tests, die Kontrolle des Blickverhaltens, die Kalkulation von Effektgrößen, sorgfältige Vergleiche von Aneignungs- und Retentionsdaten bei vorliegenden oder fehlenden Instruktionen sowie – insbesondere im Könnensstadium – die Berücksichtigung von Kontrollbedingungen.

Schlüsselwörter: Aufmerksamkeitsfokus, Lernphase, Anweisungen, Sportpraxis, Hochleistungssport

In this commentary we recommend some research methods which would strengthen the design of future attentional focus research and give evidence for the constrained action hypothesis. In particular we encourage the use of pre-tests, control of visual gaze, calculation of effect sizes, careful comparisons of practice and retention data in the presence and absence of instructions, and consistent application of control conditions, especially when looking at skillful performance.

Keywords: attentional focus, learning stage, instructions, sports practice, elite sport

The research of Wulf and colleagues has increased our understanding of how an individual's focus of attention affects skill acquisition (see Wulf, 2007). The locus of attention has now become an important consideration in skill acquisition research. A direction to focus on a body-related feature has generally been shown to be detrimental to performance. This effect has been demonstrated mainly through comparisons with instructions which direct attention to features external to the action, rather than with control conditions (for exceptions see Wulf, Höß, & Prinz, 1998, Exp. 1; Wulf & McNevin, 2003). The constrained action hypothesis (Wulf, McNevin, & Shea, 2001) has been forwarded as an explanation for these attention effects. In this commentary we highlight some issues in the attentional focus literature that we feel warrant "attention" in future research.

According to the constrained action hypothesis, instructions which induce an internal focus intervene in coordination processes that normally occur "automatically", whereas an external focus does not interrupt these processes. This hypothesis would be more readily supported by stronger effects in acquisition, when instructions are given, rather than retention, when they are absent. However, differences between groups have more consistently been observed in retention. Exceptions to this are noted in studies when differences between groups were already present at the start of practice (Totsika & Wulf, 2003; Wulf, Lauterbach, & Toole, 1999; Wulf, Weigelt, Poulter, & McNevin, 2003, Exp. 1). The absence of pre-tests makes it difficult to know whether these groups were equally matched to start and hence the strength of the instructions.

Retention benefits related to an external focus, in the absence of acquisition differences, were also observed by Hodges, Hayes, Eaves, Horn, and Williams (2006). Two groups were required to watch and match either a model's movements (internal) or a model's ball flight (external) in a soccer kicking task. The advantage for the external group in retention was attributed to the need for this group to self-generate a movement solution during practice. It might be the case that an external focus requires the participant to be more actively involved in the learning process, at least when the instructions or feedback have information value (see also Hodges & Franks, 2000).

To date, there has been a lack of consistent differences between control and attentional focus conditions, as well as a lack of studies. Both are necessary for strong conclusions about the benefits or detriments associated with attentional focus. Also, control conditions enable investigation of what successful participants are doing when left to their own devices. One of the main assumptions of the constrained action hypothesis is that an external focus is commensurate with a more "automatic" or skilled mode of control. Therefore, there is a need for evidence showing that skilled performers spontaneously adopt an external focus and that external and control conditions are similar in terms of movement form, but different from internal conditions.

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In a recent study we have made these comparisons across conditions in a soccer kicking task (Ford, Hodges, Huys, & Williams, 2007; for similar research, see also Ford, Hodges, Huys, & Williams, 2006; Ford, Hodges, & Williams, 2005; Ford, Hodges, & Williams, in press). Although the attentional focus effects were not strong, both experts and novices generally performed more accurately when they focused on the ball (anticipate the desired trajectory) rather than the required body movements. However, the control condition was not different from either attention condition. Further, significant differences were only observed between these instruction conditions when feedback about ball trajectory was withheld. Perhaps as Wulf herself argues, feedback serves to encourage an external focus. When participants are asked to focus on the body, external feedback about outcome success competes with the instructed body focus. In this experiment movement kinematics were also measured. Correlations across the joints were higher and hence suggestive of more constrained movements under the body versus ball focus. Again, however, the control condition was not different from the two attention conditions. One finding which would suggest that an external focus was more akin to "normal" performance was that more experts than novices reported that focusing on the ball felt more "normal" than focusing on the body.

One of the major problems with the attentional focus research (and instruction research in general) is that if the effect is not found it can always be argued that participants were not using the instructions. Therefore failures to replicate would be considered methodologically flawed and evidence against the constrained action hypothesis would not be seen. It would be helpful to gather both published and unpublished data to determine effect sizes, so that from both a theoretical and applied viewpoint the meaningfulness of these attention manipulations can be determined. A meta-analysis would provide the opportunity to look at the dependency of attentional effects on such factors as feedback availability and task.

Finally, although there have been attempts to control where participants physically look during a trial, eye movement data would help to indicate whether vision attenuates or exaggerates attentional focus effects. Vickers (2007) has shown that eye fixations before a movement is executed affects performance and that for different skills, different focus areas are beneficial. For golf putting, the physical focus should be on the ball, whereas for shooting in basketball a focus on the rim of the basket is desired. In one study where one of us attempted to look at attentional focus effects during the acquisition of a golf chip (Hodges, Oakey, Mussell, & Franks, 2000) instructions to focus externally resulted in participants lifting their head up at the moment of impact, such that physically their gaze was not optimal. In future studies it will be necessary to clearly demonstrate that attentional focus effects are both strong and independent of visual gaze additionally prompted by the instructions.

In summary, for future attentional focus research we recommend research designs which include pre-tests, the consistent inclusion of control conditions, calculations of effect size both during practice and in retention as well as some form of control or measurement of visual gaze.

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COMMENTARY ON WULF

GOALS, ATTENTION, AND THE DYNAMICS OF SKILL ACQUISITION: COMMENTARY ON WULF

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Gabriele Wulf betont in ihrem Forschungsüberblick die Rolle der Aufmerksamkeit für das motorische Lernen. Wenngleich die empirische Befundlage deutlich zeigt, dass der Aufmerksamkeitsfokus von Bedeutung ist, bleiben die zugrunde liegenden Mechanismen noch weitestgehend unverstanden. Zukünftige Theoriearbeit sollte auf die Aufschlüsselung möglicher Kosten eines internalen Fokus und möglicher Gewinne eines externalen Fokus sowie auf die zeitliche Dynamik des Fertigkeitserwerbs gerichtet sein.

Schlüsselwörter: Aufmerksamkeitsfokus, interne Bewegungsrepräsentation, antizipative Verhaltenskontrolle, Verhaltenswirkung, Forschungsmethodologie

Gabriele Wulf discusses an interesting line of research and rightly emphasizes the importance of the attentional set in learning motor skills. However, while the empirical evidence clearly suggests that the attentional focus matters, the way how it does so is not yet well understood. Future theorizing needs to disentangle the possible costs of adopting an internal focus from the possible benefits of adopting an external focus, and to consider the temporal dynamics of skill acquisition.

Keywords: attentional focus, internal movement representation, anticipatory behavior control, behavioral effect, research methodology

Wulf's (2007) target article provides a thought-provoking overview of an impressively rich and creative line of research with important practical implications. Even though more research is certainly necessary to extend the theoretical approach to more, and especially more complex skills, it is fair to say that it already does a good job in accounting for a number of findings and for stimulating research in an interesting domain. But, as I will explain, there is both room and need for further improvement. My commentary targets three related issues with regard to that such improvement is necessary to make the theoretical approach more coherent, applicable, and useful.

First, the suggested constrained action hypothesis claims that adopting an external focus benefits motor learning by drawing (presumably unnecessary) attention away from movement-coordination processes and thus allowing them to operate in a more efficient automatic mode. Even though this is an interesting and attractive hypothesis, it remains unclear how the proposed mechanism actually works. Take the finding of Wulf, McNevin, and Shea (2001) that an external focus allows for faster probe reaction times than an internal focus. If we consider these reaction times as a measure of attentional capacity not absorbed by motor learning, we would need to conclude that external focusing is easier than internal focusing. However, this is little more than the learning data suggest anyway: If learning is easier (for whatever reason) it makes sense that it draws on lesser attentional resources. Whether this has anything to do with automaticity we simply do not know. It could just as well be that external focusing is more natural for subjects and therefore less interfering with the learning process.

More importantly, the way the constrained action hypothesis is presented suggests that there is nothing special about adopting an external focus in facilitating motor learning. All that is necessary to allow coordination processes to operate in an automatic mode would be to prevent learners from attending to their own body movements. Asking them to adopt an external focus would be one way to achieve that, but giving them a mental calculation task or asking them to think of or even report about their last vacation should work just as fine. This is by no means a far-fetched suggestion: Olivers and Nieuwenhuis (2005) were able to demonstrate that some cognitive processes indeed benefit from engaging subjects in distracting concurrent mental activities, such as free association on a task-irrelevant theme or listening to music. The important theoretical question thus is whether adopting an external focus is good, as is sometimes suggested, or whether adopting an internal focus is bad – which seems to be what the constrained action hypothesis suggests.

Second, it is possible that motor learning does not, or not only, benefit from preventing the adoption of an internal focus but (also) from inducing an external focus. In other words, focusing on distal action effects may be good for motor learning. This is actually the gist of Prinz's (1990) common coding hypothesis. His approach draws on ideo-motor logic in the tradition of Lotze (1852) and James

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(1890), who suggested that actions are represented in terms of their reafferent effects (Hommel, 1997). If one further considers that perceptual representations also comprise of the actions they afford, it makes sense to assume that perceived and produced events are cognitively coded in the same format and in the same way (Hommel, Müsseler, Aschersleben, & Prinz, 2001). Numerous experimental studies have supported this assumption and demonstrated that the preparation and selection of actions is mediated by representations of action effects (for an overview, see Hommel & Elsner, in press). This means that attentional focusing on the distal effects of actions is necessary for the processing of action-related stimuli up to the selection of specific responses. This renders it likely that the same kind of focus is also beneficial for acquiring the motoric means necessary to carry out the selected responses, that is, motor learning.

One of the attractive features of ideo-motor theories is that they provide a mechanism that explains how goals translate into actions (namely, by priming of the action whose anticipated distal effects overlaps most with the sensory representation of the goal). Indeed, goals are usually directly related to the distal effects of an action but bear little relationship to exactly how these effects were achieved (i.e., the proximal means). Indeed, almost all examples in Wulf's review refer to tasks and situations where the task goal and the distal action effects attended in the external-focus condition were indistinguishable. If so, the manipulation of external versus internal focus can thus be taken to reflect a manipulation of attention directed towards versus away from the action goal, which makes the outcome of the studies somewhat less surprising. In the absence of decisive data, this is just one of several possibilities, but it needs to be investigated – ideally independently of possible negative effects of internal focusing.

Third, almost all studies Wulf discusses were looking into rather short training sessions of a few hundred trials. It is impressive what focus manipulations can achieve in such a short time already, but we must not forget that real skill acquisition takes months or years. Accordingly, one wonders whether the optimal focus changes with experience and increasing level of skill. As Wulf points out in her conclusions, skills are likely to be cognitively represented in a hierarchical fashion, and it makes sense to assume that increasing learning experience moves the optimal focus from lower to higher, more integrative levels. Indeed, if ballet dancers integrate complex step patterns into a single dance figure and pianists chunk long sequences of finger movements into only a few sections, it is likely that this will drive their preferred attentional focus towards more abstract characteristics of their motor performance – presumably to a degree that makes it difficult to focus back on the local elements (Schwarz, 1927). However, shifts of the attentional focus may be more frequent and flexible than that. Even in a single training session, the optimal focus may vary, and it seems interesting to analyze and model the dynamics of this variability. It has also been suggested that success or failure in a single trial may change the focus, going more global after success and more local after failure (Vallacher & Wegner, 1985). Taking such dynamics into consideration is likely to help explaining empirical inconsistencies and tailoring training programs to the individual and his or her level of proficiency.

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COMMENTARY ON WULF

OPTIMAL ATTENTIONAL FOCUS IN PRACTICAL SPORT SETTINGS: ALWAYS EXTERNAL OR TASK SPECIFIC?

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In diesem Kommentar werden Wulfs empirische Befunde, die eine Überlegenheit eines externalen Fokus nahelegen, der zusammengefassten Meinung deutscher Spitzentrainer/innen gegenüber gestellt. Im Gegensatz zu Wulf schlagen die Trainer/innen einen aufgabenabhängigen, funktionalen Aufmerksamkeitsfokus vor. Anstelle einer generellen Regel könnte die in Wulfs Studien gefundene Überlegenheit eines externalen Fokus auf aufgabenabhängige Funktionalitäten zurückzuführen sein.

Schlüsselwörter: Aufmerksamkeitsfokus, Hochleistungssport, subjektive Theorie, Bewegungsaufgabe, funktionale Kopplung

In this comment, I compare Wulf's empirical findings suggesting the superiority of an external focus with the summarized opinions of Germany's elite athletes' coaches. Contrary to Wulf, the coaches rather suggest a task-dependent, functional attentional focus. The superiority of the external focus in Wulf's studies could be due to its task-dependent functionality and not due to a general rule.

Keywords: attentional focus, elite sport, subjective theory, movement task, functional coupling

In the closing words of her article, Wulf (2007) emphasizes the relevance of attentional foci for practical settings such as sports. She suggests that changing the wording of instructions or of feedback inducing a more external focus of attention in the athletes leads to a more effective practice. In my commentary, I concentrate on the practical implications of attentional focusing. To this end, I compare Wulf's research with a thorough investigation that was carried out by a group of colleagues among Germany's leading head coaches about 10 years ago (Roth, 1996). In half-standardized focused interviews, we surveyed the implicit theories of skill training among 31 expert coaches (Szymanski, Hossner, & Künzell, 1996). Their opinions were summarized into 10 principles (Hossner, 1996). In a questionnaire, these principles were validated by 152 federal coaches (Künzell & Schipke, 1996).

Indeed, the focus of the athlete's attention is one of the coaches' major concerns. The coaches follow an "optimal attention principle". They claim that it would depend on the circumstances what the optimal focus of attention is. 88% of the 152 coaches agreed that it is important for the athlete to focus on the "key points of the movement" in skill training. Key points are movement features that are necessary for the successful achievement of the movement's goal. However, in competition, this focus is disputed. 41% of the coaches suggested not to focus attention on anything but just to execute the movement in an automatic way, while 36% still recommended to focus on the key points. The rest advised an individual solution.

The coaches' advice "not to focus on anything" in competition and Wulf's advice to focus on external events share the same underlying considerations: The automaticity of the movement should not be disrupted by focusing on aspects of the movement itself during skill execution. However, in the coaches' opinion this should be done only in competition, but not in training. Both, the coaches in our investigation and Wulf in her article, do not define automaticity, but it can be inferred that they mean something different. In the coaches' opinion, automaticity is acquired by hundreds of repetitions in skill training, whereas Wulf argues that novices who practice the task for the first time have an automatic control mode that will be disrupted by an internal focus.

Strictly speaking, the coaches do not distinguish between an internal and an external focus. Though the focus on "key points of the movement" suggests an internal focus, this may not necessarily be the case. A "key point" could be a specific joint configuration at an important phase of the movement, but it could as well be a specific distal effect that is to be achieved (e.g., in skiing "bending the knees curve-inward" vs. "anchoring the edges of the skis in the snow"). Instead of distinguishing between external and internal focus, expert coaches emphasize the functionality of instruction and feedback. Instructions and feedback have to be given in a way that guides the athletes to focus on the part of the movement that is crucial for its function. The movement's function is to achieve the intended effect. So, to follow an example given by Wulf (2007, citing Zachry, 2005), it is crucial for the function of an American football place kick to hit the ball exactly central underneath

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its midline. It is not so crucial with which part of the foot the ball is hit. In her master's thesis, Zachry compared group A, which is being provided with less functional feedback ("focus on the part of the foot that would be contacting the ball", Wulf 2007, p. 7), with group B, which is being provided with a more functional feedback ("focus on the part of the ball that they would be contacting with their foot", Wulf 2007, p. 7). This example will not prove the superiority of an external vs. an internal focus, but it proves the superiority of a functional vs. a non-functional focus. In all tasks where an object has to be hit, thrown, or manipulated in a predefined way, it is of functional importance to put attentional focus on the object, i.e., an external focus. In hitting a moving object such as in volleyball, tennis, baseball, or many other sports it is obvious that the focus of visual attention must be at least for some time on the moving object, otherwise it is impossible to hit it correctly and to fulfill the ultimate movement goal. Wulf's finding of a superiority of an external focus might be confounded by the different functional importance of the external and the internal focus for performance.

It is obvious that Wulf deals with an important aspect of athlete's skill training. Summarizing my comment, I would suggest that an external focus might not generally be superior, but that the optimal focus of attention depends on the task at hand.

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COMMENTARY ON WULF

STAYING FOCUSED: ADDITIONAL QUESTIONS AND ISSUES FOR FUTURE ATTENTIONAL FOCUS RESEARCH

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Wulf beleuchtet in ihrem Übersichtsbeitrag zum Aufmerksamkeitsfokus und zu motorischen Lern- und Performanzeffekten eine Reihe anwendungs- und forschungsrelevanter Aspekte. In diesem Kommentar werden hierzu neuere Forschungsentwicklungen diskutiert, vor allem zu Instruktionen in praxisnahen Situationen, zu natürlicherweise mit Bewegungsaufgaben verbundenen Faktoren sowie zu „normalen" Bedingungen im Gegensatz zu experimentellen Instruktionen.

Schlüsselwörter: Aufmerksamkeitsfokus, Anweisungen, Muskelaktivität, Sportpraxis, Forschungsmethodologie

Wulf's review of the research carried out on attentional focus, motor performance and learning highlights a number of issues for application and research. This commentary covers recent research developments; in particular, the use of instructions in applied settings, the consideration of naturally occurring factors in movement settings, and the notion of "normal" conditions and participants' instruction use during experiments.

Keywords: attentional focus, instructions, muscular activity, sports practice, research methodology

The power of instruction to influence the actions of others is well documented, but often not fully understood. This review of research carried out by Gabriele Wulf and colleagues over the last 10 years (Wulf, 2007), and separate research subsequently influenced by their approach, highlights the significant impact that subtly different instructions can have on movement quality. Reading this review, two things become clear. Firstly, much has been achieved in demonstrating the effects of attentional focusing instructions on movement performance and learning, and that there are many possibilities for future application. Secondly, that there is still much to be done if we are to fully understand this area. As such, I propose some issues for consideration that fell outside the scope of the initial review, yet which may add to any subsequent discussion.

To start with, research in our labs (e.g., Marchant, Greig, & Scott, 2007) has supported the work of Wulf, Zachry, Granados, and Dufek (2007) where improved maximal force production is brought about by use of an external focus. Biceps curls carried out under external instruction produced increased force production when compared with those under internal instruction. This research, supporting both, Vance, Wulf, Töllner, McNevin, and Mercer (2004) and Zachry, Wulf, Mercer, and Bezodis (2005), also demonstrated increased muscular activity associated with an internal focus. Interestingly, increased muscular activity can often be an aim of some rehabilitative or training exercises; both to develop muscles and to overcome muscular atrophy. As such, these results may also see a utility of the internal focus in specific settings as well as highlighting the mechanisms by which they interfere with skill execution.

In light of this review, Wulf's suggestions for the promotion of more appropriate instruction in sports coaching settings are valid. However, not much is known of the instructions used by coaches in real-life settings. Is the success of a coach related to the types of instructions they use? Do successful coaches naturally use more externally focused instructions? Searching for the answers to these questions may prove fruitful in advancing the development of more successful coaching. Furthermore, as Wulf highlights, large gains can be made through the use of attentional focusing instructions in the movement rehabilitation from specific injuries and conditions. The physical therapist probably does not need reminding of the power that verbal instruction plays in their work. Yet as with sport coaches, little is known regarding the instructions used by physical therapists in practice. Regardless of this, the line of research proposed by Wulf is important, and one that requires the wealth of attention research has given to sporting skills to date.

Wulf rightly postulates the positive influence that externally focused instruction may have on the durability of skills performed under stress. This highlights a key consideration; researchers should seek to include more naturally occurring factors in their designs (both within sporting and rehabilitation settings). In addition to and expanding on

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stress, this most obviously includes fatigue (both mental and physical). Fatigue is a naturally occurring factor experienced in movement and sporting settings, often to the detriment of performance. Understanding the impact that different attentional instructions or learning approaches have under such naturally occurring conditions will lead to a better understanding of their application. In particular, such research would address the true dynamic nature of sporting situations.

On area of discussion hinted at by Wulf in this review is the notion of “normal” conditions. Although the control condition is necessary for comparisons between interventions, operationalizing a ”control/no-instruction” condition is problematic. Even when given no instructions, participants will at One area of discussion hinted at by Wulf in this review is the notion of “normal” conditions. Although the control condition is necessary for comparisons tempt their own strategies. As Wulf suggests here, when given no specific instructions, individuals may utilize an internal focus due to the caution provoked by novel and complex motor tasks. Related to this, participants in our studies regularly report that they do not use the instructions given at various points during their experimental trials (see Marchant, Clough, & Crawshaw, in press). Although this is not surprising in repetitive experiments, what are participants actually focusing upon at these times? And further, what are they focusing on when they are given no attentional instructions in “normal” conditions? Participant approaches to using or modifying a strategy may be related to the type of instruction they are given, the task, or their skill level. For example, in Marchant et al. (in press) participants reported that an internal strategy felt unsuccessful during a dart throwing task, and so they may have attempted to use or develop a more successful strategy of their own instead of persevering with the one they were given. To understand the flexible nature of attention during execution of skills, future research throwing task, and so they may have attempted to use or develop a more successful strategy of their should ad dress how and when participants utilize the instructions they are given, how this may change over time, and how attention is focused when no instructions are given in “normal” conditions.

In conclusion, this up-to-date review of the research on attentional focus and movement execution provides a timely indicator for the potential application of attentional focusing instructions in a number of settings. For researchers, it is clear that questions still remain that should see the area continue to develop.

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COMMENTARY ON WULF

ON THE HOW AND WHY OF THE EXTERNAL FOCUS LEARNING ADVANTAGE

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In diesem Kommentar wird für die zukünftige Forschung zu Aufmerksamkeitsfokuseffekten eine Stärkung der theoretischen Grundlegung angeregt. Nach unserem Verständnis beschreibt die „constraint-action"-Hypothese lediglich Performanzeffekte und bleibt die Erklärung von Lernvorteilen externaler Fokusbedingungen schuldig. Eine stärkere theoretische Orientierung sollte zum Verständnis der Mechanismen beitragen, auf denen aufmerksamkeitsgeleitetes motorisches Lernen basiert.

Schlüsselwörter: Aufmerksamkeitsfokus, antizipative Verhaltenskontrolle, Verhaltenswirkung, Spezifität, Lernphase

In this comment, the authors suggest to strengthen the theoretical basis for further research of the effects of attentional focusing. In our understanding, the current constrained action hypothesis merely describes performance but lacks explaining the learning benefits seen under external focus conditions. A more theoretical approach might help to identify explanatory mechanisms at work during attentionally guided motor learning.

Keywords: attentional focus, anticipatory behavior control, behavioral effect, specificity, learning stage

Directing attention to movement aspects by using instructions or feedback is a basic instrument in motor skill learning and, therefore, it is essential to address the issue to which aspects attention should be directed to support learning. It is indeed surprising that this question was of low interest in empirical motor research for a long time. The numerous studies of Wulf and colleagues resulted in a substantial amount of empirical data and stimulated a major scientific debate (Wulf, 2007).

However, it must be stated that an understanding of how and why an external focus of attention promotes motor learning is still lacking. As a consequence of a lacking theoretical background, it remains unclear which exact feature of an internal or an external focus of attention causes the respective compromising or enhancing learning effects. In our view, the constrained action hypothesis only provides a very general description: It is assumed that using an external focus promotes a more automatic mode of movement control while an internal focus constrains the motor system by intervening with "normal" control processes. To support this view, Wulf (2007) provided empirical data concerning attentional capacity, frequency of movement adaptations, and muscular activity. It remains unclear how these data can help to enlighten the learning mechanism when using an external focus. This understanding is, however, mandatory to generalize the results. In this comment, we will discuss the internal-external distinction from a motor learning perspective and make some suggestions concerning a theoretical framework for further research.

In search of a mechanism for Wulf's findings, we detected some interesting changes in her argumentation. In contrast to the Wulf and Prinz (2001) review, in the current paper no reference is made to the common-coding theory (Prinz, 1990, 1997) and the ideo-motor principle (Stock & Stock, 2004, for a review) to theoretically account for the empirical findings. We agree with Wulf that these theoretical approaches do not specifically predict the described learning differences. We would like to argue that the perspective of acquiring associations between movements and their effects provides a fruitful theoretical framework for further investigations of the effects of attentional focus on motor learning. The perspective of action-effect learning is highlighted in Prinz' approach as well as in computational internal-model concepts (e.g., Wolpert, Ghahramani, & Flanagan, 2001).

Movement effects can be temporally or spatially more proximal or distal (e.g., the trajectory of a racquet or the flight of a ball). Furthermore, movement effects consist of different sensory information – we see, hear, and feel hitting a ball (e.g., Kunde, Koch, & Hoffmann, 2004). It can be hypothesized that an external focus in movement execution accentuates exteroceptive (especially visual) sensory information while an internal focus highlights interoceptive sensations. It might be the case that an external focus promotes associations between movements and their exteroceptive effects, while an internal focus supports the link between movements and their tactile-kinesthetic sensations. If so, using an external focus in motor learning should result in a higher competence in producing external effects (e.g., an appropriate tra-

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jectory of a racquet), while using an internal focus should result in the ability to produce internal effects (the tactile-kinesthetic sensations in movement execution).

From this point of view, there are two possible explanations for the external learning advantage in Wulf's studies. First, in most skills it is inherent to produce external effects so that an external focus should be more appropriate to learn the characteristics of the task. The second possible advantage of the external focus in the existing studies goes back to stage models of motor learning. In classic stage models (e.g., Fitts & Posner, 1967; Gentile, 1972) as well as in recent neurophysiological models (e.g., Hikosaka, Nakamura, Sakai, & Nakahara, 2002), it is assumed that different aspects of the task are learned at different times (e.g., the spatial and motor code). In an initial "cognitive" stage, it is necessary to built up a first representation which allows successful execution (How and when do I have to move the racquet?). In the course of learning, the acquisition and refinement of a "motor" representation is increasingly important (How do the joints have to act together to achieve the desired outcome with high certainty?). Hence, in the beginning of the learning process focusing on spatio-temporal characteristics of the skill by accentuating visual information (external focus) should be adequate. In later learning stages, it might be more efficient to focus on critical aspects of movement execution by highlighting interoceptive sensations (internal focus).

In this comment, we would like to point out the necessity to embed the internal-external considerations into established theoretical concepts of motor learning. This is not only mandatory for a profound understanding of how different attentional foci influence motor learning. It would also help practitioners with formulating adequate instructions and feedback in different learning situations. Based on the well-established concept of action-effect learning in psychological research, we delineated a framework which allows to integrate the existing data and to identify further research perspectives (for a detailed description see Ehrlenspiel & Maurer, 2007).

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COMMENTARY ON WULF

HOW DOES THE DISTRIBUTION OF SPATIAL ATTENTION AFFECT THE QUALITY OF MOVEMENT PERFORMANCE?

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Es wird ein ein theoretischer Rahmen benötigt, der nicht nur die Vorteile eines externalen Fokus abdeckt, sondern – umfassender – die Struktur, Funktion und Mechanismen perzeptuell-kognitiver Strategien in der Bewegungskontrolle abbildet.

Schlüsselwörter: Aufmerksamkeitsfokus, kognitive Bewegungsrepräsentation, antizipative Verhaltenskontrolle, implizites Gedächtnis, bimanuelle Koordination

A theoretical framework is needed that covers not only the external focus advantage, but, more generally, the structure, function, and mechanisms of perceptual-cognitive strategies in movement control.

Keywords: attentional focus, cognitive movement representation, anticipatory behavior control, implicit memory, bimanual coordination

During the dancing lessons in my teenage time, I experienced a quite impressive phase transition from bad to good, or at least considerably improved, dancing. Just having struggled to get my feet right, virtually all of a sudden everything felt right. There were no feet any more, so-to-say, instead I felt our common centre of gravity like a flowing ball with the two of us gently moving with it and around it. Obviously, changing the focus of attention could make the difference in movement performance. But is there a general rule and strategy of how to distribute attention best?

Based on an impressive body of experimental results, Gabriele Wulf (2007) claims to have found such a general rule and strategy, namely that an external focus of attention was always advantageous for performance quality. If so, what might be the reason for this advantage? Wulf hypothesizes that the body could move more automatically and thus with less effort if attention is withdrawn from it.

Research on bimanual interference impressively adds to these results, but also puts some doubt on the generality of Wulf's conclusion. Diedrichsen and colleagues (Diedrichsen, Hazeltine, Kennerly, & Ivry, 2001) showed that higher reaction time costs, usually observed in asymmetrical as compared to symmetrical movements, fully disappeared if participants were not instructed with body-defined parameters (such as amplitudes and directions) but instead were directly presented with the to-be-reached targets. Moreover, overall reaction time was dramatically reduced in the direct reaching task. An external focus of attention may even render an "impossible" task into an executable one: Mechsner, Kerzel, Knoblich, and Prinz (2001) had participants circle two visible proxies with their circling hands hidden under the table. One of the tasks was to circle the proxies in symmetry. Due to an inbuilt gear system, this required circling the hands in a 4:3 frequency relationship – which is a virtually impossible task if instructed as such. Nevertheless, participants were well able to circle the proxies in symmetry, thereby circling the hands in that "impossible" frequency relationship.

When it comes to theory, i.e., unifying principles, one should, however, not consider the advantage of external focus to be the final word but also look for the unifying law under which this effect might be understood best. There are three issues that seem to point to the need to embed the external focus advantage in a broader theoretical context.

First, the advantage of external focus seems to be not a law but rather a rule of thumb that works in many cases but not in all. For instance, from the imagination techniques and wisdom of eastern material arts it seems obvious that in many tasks it is advantageous and indeed crucial to focus on one's centre of gravity – to the effect that the body works quite automatically and particularly efficiently. If so, internal and external focus advantages might be basically similar in nature, to be explained by a theory that covers both phenomena.

Second, the art of distributing one's spatial attention for the sake of optimal movement is probably not simply the art of choosing the focus. Obviously, the rest of the body and environment are not entirely "forgotten", so-to-say, or not at all attended to. A principle of "sparse but effective coding" seems to apply here, in the way that movement parameters like amplitude, direction etc. are

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not explicitly planned but implicitly and automatically tuned under the guidance of a more holistic perceptual representation of the moving body in the environment (Mechsner 2004a, 2004b). Addressing the question of how attention is best distributed outside the focus is obviously of high importance for achieving a more complete picture of movement control (for an investigation of distributed perceptual-cognitive representation structures in complex movements, see Schack & Mechsner, 2006).

Third, attention, and, more generally, the crucial perceptual and conceptual movement representations are certainly not only spatial in nature. Consider, for instance, the abundant anecdotal evidence that suitable metaphors sometimes crucially improve performance, in sports, dance, and playing music.

It might well be that the external focus advantage is best considered in the more general context of perceptual-cognitive strategies for movement control, i.e., finding the perceptual-cognitive representation that supports an intended movement best (Mechsner 2004a, 2004b). From the wisdom of movement practitioners it seems that such strategies cover and structure the whole "perceptual-phenomenal field" (Metzger, 1972), i.e., the mental representation of the moving person in the respective scene. There is still a long way to go until we have understood how such strategies are best conceived in a task-dependent way, as well as why and how they work in detail to bring about physical movement.

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COMMENTARY ON WULF

OPENING MUSICIANS' EARS TO ATTENTIONAL FOCUS

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Am Ende ihres umfassenden Forschungsberichts schlägt Gabriele Wulf vor, ihre Arbeit auch auf anderen Gebieten fortzuführen, und erwähnt dabei auch die aufführenden Künste. Dieser Kommentar folgt ihrer Aufforderung. Hierzu wird die Wichtigkeit der präsentierten Ergebnisse für die Musikpädagogik, für Übungsstrategien und das öffentliche Musizieren herausgestellt und eine Vorabinformation über eine Untersuchung gegeben, die gegenwärtig mit Konzertmusikerinnen und -musikern durchgeführt wird.

Schlüsselwörter: Aufmerksamkeitsfokus, motorisches Lernen, motorische Leistung, motorische Fertigkeiten, Anweisungen

At the end of this comprehensive review of motor learning research, Gabriele Wulf suggests that future work along these lines may extend to other disciplines, and mentions the performing arts. This short commentary answers this call. After stressing the importance of the findings presented when they are applied to music teaching, practice, and performance, there will be a sneak-preview of evidence resulting from a current study with concert musicians.

Keywords: attentional focus, motor learning, motor performance, motor skills, instructions

Gabriele Wulf's (2007a) review article offers insight into territory that musicians, music teachers, and music psychologists have not yet begun to explore (see also Wulf, 2007b; Wulf, Shea & Wright, 1998). To date, very little research has been done regarding motor learning and performance of instrumentalists or singers. Why? Because musicians tend to believe that the mystery of their art cannot be the subject of scientific analysis. They believe their work cannot be objectively studied, quantified, or explained. As a result the term "motor learning" is rarely used in connection with music education, and an empirical approach to musical performance is usually deemed irrelevant and ignored, even by professional music educators. The 10 years of research on attentional focus and motor learning presented in this article, however, is so clearly applicable to musicians' work that the time has come for them to take notice of concepts that have long been the subject of interest to sports scientists. In this commentary, I argue that the biggest argument for musicians to occupy themselves with these studies is the concept of "attentional focus", which is of interest to musicians as it may be able to provide a path towards understanding two vital questions: 1) How can music best be taught? And 2) Why do musicians make mistakes on stage?

Regarding the first issue, Wulf's target article presents studies that looked at the instructions, that is, the verbal messages that coaches use when teaching motor skills. The concept of "external focus of attention", or emphasis on the movement effect rather than the movement itself, proves to be more effective in learning (and retention) of new motor patterns across many sports activities. She makes an important distinction here between "performance" and "learning", which is often the subject of discussion among music teachers, many of whom suffer frustration on a regular basis when their students return one week later, unable to replicate the "success" of the previous lesson. Obviously, it could be very revealing to take some of the empirical studies mentioned in this article, and attempt to reproduce them to the music lesson setting. Based upon the evidence presented in the article it can be hypothesized that students who fail to adopt an external focus strategy will be less likely to practice correctly and will not retain what they "achieved" in the lesson, which was merely a temporary, or performance, effect.

Optimal performance in stress situations, the second issue, is a goal shared by both athletes and musicians. Evaluating the types of errors made in competition or on stage, is one approach to understanding human behavior "under pressure", and developing recommendations for effective preparation and performance strategies.

An on-going experiment at the University of Music and the Dramatic Arts in Graz uses the paradigm of many of Wulf's experiments applied to musical performance. The goal is to identify the attentional focus effects, or the effects of a shift of focus, during musical performance as a potential source of error. Graduate students of instrumental and vocal pedagogy, most of whom have already

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received their concert performance degree, are asked to play the same short composition three times after a run-through used to ascertain expertise. They each perform under three conditions: Control, internal focus, and external focus. Video recordings capture the musical expressiveness of their playing or singing and allow evaluation of accuracy and deviations across trials. After performance, interviews are conducted using the "Think-Aloud" retrospective report method (Eccles et al., 2005; Kirk & Ericsson, 2001). Preliminary evaluation of these exit interviews shows that musicians are very aware of the instructions they follow when performing – whether these are part of a self-dialogue, or were those given by the experimenter. Several of our participants remembered interference in the fluidity of performance induced by a shift from external to internal focus. In other words, they reported "choking under pressure" (Baumeister, 1984) and are aware of performance decrements that they ascribe to attention to those lower-level movement effects that Wulf reported. It appears as if this study will provide additional evidence for the constrained action hypothesis.

Some participants reported strategies to combat stage fright that included monitoring their actions by focusing on higher-level movement effects, which often are inseparable from the musical message they are trying to convey. Several even actively ignored the internal focus instructions and commented – unaware of the experimental design – that they preferred to "make music instead". Potentially, this study will provide further evidence for the effectiveness of external focus strategies, even, or especially, for complex motor activities.

No one seems to doubt that performing artists must deliver an optimum of accuracy and quality of movement on stage. Yet, expert motor control, fluidity of movement, balance, concentration, and focus are concepts that need to be discussed with regard to musicians, by musicians. Perhaps some of the questions left open at the end of the target article can be answered in the near future through complimentary studies of musicians' motor learning and performance.

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COMMENTARY ON WULF

DE-AUTOMIZATION IN MOTOR LEARNING? ANSWERS AND OPEN QUESTIONS

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Über zehn Jahre hinweg hat Wulf themenspezifische Befunde für die Bedeutung eines adäquaten Aufmerksamkeitsfokus beim motorischen Lernen angesammelt. Dieser Effekt wird mit der „constraint-action"-Hypothese (CAH) erklärt. Die CAH stimmt mit anderen Deautomatisierungsansätzen motorischer Kontrolle überein, liefert jedoch (bislang) keine Erklärung für Lernbeeinträchtigungen unter internalen Fokusbedingungen.

Schlüsselwörter: Aufmerksamkeitsfokus, motorisches Lernen, Lernphase, Automatismus, Forschungsmethodologie

Over 10 years Wulf has accumulated eclectic evidence for the importance of an adequate attentional focus in motor learning. This effect is explained by the constrained action hypothesis (CAH). The CAH is in line with other approaches assuming de-automization in motor control, but it provides no explanation (yet) for degraded learning under internal focus instructions.

Keywords: attentional focus, motor learning, learning stage, automaticity, research methodology

Gabriele Wulf's (2007) target article covers 10 years of extensive research on the effect of different attentional foci on motor learning. From this long standing perspective it is not appropriate to dwell exhaustively on all the minor problems on a technical level that might be raised against single studies. This comment lists only some potential objections of such kind. The major part instead will focus on some basic concepts relevant to this line of research.

Potential technical caveats are nicely presented in the discussion of the Perkins-Ceccato-study (Perkins-Ceccato, Passmore, & Lee, 2003). Wulf mentions i.) arbitrary choice of the dependent variable, ii.) lack of a retention test, iii.) sequence effects, iv.) dependency on skill level, and v.) vague instructions that leave open whether subjects actually used an external focus. These are listed as potential flaws of the one single study reported that is not in line with her overall picture. However, one definitely can not rule out that at least some of these objections can also similarly be raised against those studies taken as evidence for the benefits of an external focus. This can be exemplified with objection (i.): Wulf concedes that it might be helpful to look at other dependent measures, e.g., by quantifying movement form. Most of the studies presented up to now show a confounding asymmetry: The performance is often quantified by an effect-based measure which is closer to the external focus, i.e., the effect oriented focus. Under the internal focus condition, subjects are instructed to focus on, e.g., the golf swing. However, the quality or the variability of their swing is never assessed but rather the achievement of another – in the light of this instruction – secondary goal (e.g., distance to target).

Leaving behind those important, but primarily technical considerations, objection (v.) brings us to the core of the approach: Which processes are promoted by the different attentional foci? According to the constrained action hypothesis (CAH), an internal focus is associated with "conscious" control processes interfering with automatic control processes. By focusing internally, the actor intervenes in those latter processes that are normally capable of controlling the movement efficiently without drawing on limited attentional resources. This is comparable to the way specific emotional states (e.g., "choking under pressure", Beilock & Carr, 2001; Ehrlenspiel, 2006) might degrade performance, or "explicit" learning situations (Masters, 2000), respectively "rule-based" instructions (Liao & Master, 2001), might impair learning.

If one adopts the CAH, it is straightforward to search for any evidence confirming the pivotal assumption of cognitive interventions into an automatic process controlling the movement. Wulf references quite a few studies that are in support of this notion, but the majority or these studies is confined to a demonstration that movement control is affected in a negative way by an internal focus. However, those processes controlling a single movement are conceptually different from processes that change movement control over a number of practice trials. I will call this latter processes "learning processes", and it is not always obvious if and how these learning processes are affected by disrupted control processes.

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For me it is also not easy to derive this expectation from a theoretical perspective. How can de-automization, i.e., cognitive interventions in control processes be detrimental to learning in general? Or, to put it the other way round, are automated learning processes always the best basis for quick changes of coordination modes in motor learning? There is a huge amount of literature advocating different stages in motor learning, in which the automatic phase is the last stage. In this stage the learning process has reached its goal, the acquired movement is performed by automatic control processes. Disrupting these automatic processes by cognitive interventions will probably decrease performance. But how can de-automization bear on motor learning in earlier stages, where no automatic control processes might exist to interfere with? Of course, there are always automatic processes involved in any of our movements: We breathe, our heart is beating, and our postural control system keeps us from falling, but it is not always obvious which part of these hierarchically controlled systems is affected by conscious interventions. The CAH is based on the assumption that any interference with the automatic processes will be detrimental, because they offer the most efficient control. As I already tried to point out, the question here is not whether optimal automatic control processes are disrupted, but rather whether presumably optimal automatic learning processes are affected. It seems to me, that there is a large number of to-be-learned tasks, in which the automatic learning system will definitely not show the fastest learning rate: Without any cognitive interference, our postural control system will strongly resist in order to not allow our body to fall from a bridge; thus, one would never be able to learn to perform a bungee jump.

After 10 years of research on the role of different attentional foci on motor learning, the approach is now in line with other similar perspectives in motor control and learning, all dwelling on de-automization. It might probably take at least 10 more years to come up with answers on questions like: What are automatic learning processes? How are they involved in learning? Are they always optimal? Under which conditions should we intervene cognitively?

So, let us all pick up this challenge!

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COMMENTARY ON WULF

ATTENTIONAL FOCUS AND MOTOR LEARNING: SOME CAVEATS AND CAUTIONS

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Die von Gabriele Wulf in ihrem Überblicksbeitrag in beeindruckender Weise zusammen getragenen Fakten leisten einen signifikanten Beitrag für unser Verständnis des Einflusses von Aufmerksamkeitsfokussierungen auf motorische Lern- und Kontrollprozesse. In diesem Kommentar werden sowohl konvergierende Forschungsfelder betrachtet als auch einige potentielle Einschränkungen aufgezeigt, die in Theorie und Praxis bei der Interpretation dieser Fakten beachtet werden sollten.

Schlüsselwörter: Aufmerksamkeitsfokus, Automatismus, Anweisungen, Lernphase, Forschungsmethodologie

In her target article, Wulf reviews an impressive body of knowledge that has made a significant contribution to our understanding of the influence of attentional focus on motor performance and learning. This commentary highlights several convergent areas of research and some potential limitations that researchers and practitioners should consider when interpreting the attentional focus literature.

Keywords: attentional focus, automaticity, instructions, learning stage, research methodology

Over the last decade, Wulf and associates have produced an impressive body of evidence supporting the notion that focusing one's attention on the effects of body movements (external focus) rather than on the movements themselves (internal focus) is more effective for the performance and acquisition of motor skills. In her review, Wulf (2007) considers work from her own and other laboratories that supports the effectiveness of external focus strategies. It is not the intention to take issue with the results of the studies per se. However, there are a number of factors that potentially mediate the interpretation of the data that researchers and applied sport psychologists should consider. Before considering these limitations, it appears that there are parallels between the studies reviewed by Wulf and several other convergent areas of research, which Wulf acknowledged fell outside the scope of her review.

It is generally agreed that adopting an internal focus on body movements has a disruptive effect upon the learning and retention of motor skills. This finding is not new and has been well documented over the years (Baumeister, 1984; Bliss, 1893; Boder, 1935; Masters, 1992). There are similarities between Wulf's constrained action hypothesis (see McNevin, Shea, & Wulf, 2003) which predicts that an internal focus on body movements interferes with the automatic control processes that typically regulate well learned movements, and Deikman's (1966) deautomatization hypothesis, which emphasizes the "undoing of automatization, presumably by reinvesting actions and percepts with attention" (p. 31). Parallels can also be drawn between the constrained action hypothesis and the conscious processing hypothesis (Hardy, Mullen, & Jones, 1996; Masters, 1992) and Beilock and Carr's (2001) explicit monitoring hypothesis. At a more applied level, the direction of attentional focus literature also bears comparison with Kingston and Hardy's (1994) distinction between part and holistic oriented process goal setting strategies. Kingston and Hardy defined process goals as a focus on the behaviors that performers engage in during task performance. The use of process goals has been identified as an appropriate strategy to focus performers' attention to salient aspects of the task, and thus support skilled performance. Part process goals function by focusing attention on single elements of a skill, which may cause performance impairment in the same way as Wulf's internal focus. Holistic process goals, on the other hand, encourage performers to execute skills by focusing on global aspects of the movements using more automatic control structures that should discourage deautomatization, in the same manner as adopting an external focus. It will be interesting to see how these related avenues of investigation develop and whether some consensus can be reached as to the exact mechanisms that underpin effective attentional focus.

Despite the growing body of literature supporting the benefits of an external focus, there are some caveats that researchers and practitioners should consider. Several studies have not found any differences between internal and external task focus conditions during learning or retention (Maxwell & Masters, 2002; Perkins-Ceccato,

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Passmore, & Lee, 2003; Poolton, Maxwell, Masters, & Raab, 2006). However, as noted by Wulf, it does appear that some of the divergent findings can be explained by design inconsistencies and instructional nuances. A more fundamental problem with the attentional focus research relates to the absence of a post-experimental manipulation check to examine adherence to treatment conditions. This point is especially salient as Wulf, Shea, and Park (2001) reported that when given the opportunity to select their own focus of attention, learners chose to focus externally. Maxwell and Masters (2002) also provided evidence highlighting the seriousness of this limitation as in post-experimental interviews, participants indicated that they had discovered during practice that using an external focus had appeared more advantageous than their assigned strategy and adopted the external focus instead.

A further limitation may have occurred where studies have examined the effect of attentional focus upon the task execution of experts. It is highly probable that experts have automated performance routines that make it unlikely that treatment conditions are adhered to. Another concern relates to the lack of a pre-test in the skill acquisition studies (Schmidt & Lee, 2005). Participants in attentional focus studies could be pre-tested and matched on their ability to perform the various experimental tasks. A further limitation to the generalizability of the results relates to the number of trials completed by participants. Invariably, in the literature reviewed by Wulf, the number of trials does not exceed 100. It would be interesting to see how the effects of the attentional focus conditions compare over extended learning periods. For example, Masters (1992) and Hardy et al. (1996) used 400 practice trials, and Maxwell, Masters, and Eves (2000) gave participants 3000 trials.

Clearly, the work of Wulf and associates has gone some way to clarifying the effects of attentional focus upon the acquisition and performance of motor skills. However, as with all research, there are some caveats to the interpretation of the data. More work is required to address these limitations and integrate the convergent research approaches identified in this commentary.

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COMMENTARY ON WULF

AN OUTSIDE VIEW ON WULF'S EXTERNAL FOCUS: THREE RECOMMENDATIONS

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Wenngleich Wulf's Paradigma der Aufmerksamkeitsfokussierung einige unschätzbare Einsichten im Bereich der menschlichen Motorik hervorgebracht hat, möchten wir drei Empfehlungen abgeben. Im Besonderen empfehlen wir die Berücksichtigung von Schnittstellen zu anderen theoretischen Richtungen, von automatischen, reflexähnlichen Kontrollprozessen sowie von möglicherweise positiven Effekten eines internalen Fokus auf die Fertigkeitsdeautomatisierung als Vorbereitung zum Umlernen.

Schlüsselwörter: Aufmerksamkeitsfokus, implizites Gedächtnis, Automatismus, hierarchisch gesteuerte Modelle, Umlernen

Although Wulf's attentional focus paradigm has generated invaluable insights into motor control and learning, we would like to make three constructive comments. In particular, we recommend exploration of the interface with other theoretical approaches, most notably implicit versus explicit learning, elucidation of the notion of automatic, reflex-like control processes, and consideration of the possibility that an internal focus could in fact be beneficial in skill deautomatization and relearning.

Keywords: attentional focus, implicit memory, automaticity, hierarchical control models, re-learning

In more than a decade of research Wulf and colleagues have repeatedly demonstrated that adopting an external focus of attention is advantageous over an internal focus in skill learning and performance alike (see Wulf, 2007). Clearly, this is an invaluable insight with important theoretical and practical implications. Nevertheless, we would like to make three constructive recommendations for furthering, extending and refining Wulf's research program.

First, near the end of her review Wulf (2007) justly alludes to the need to investigate the role of direction of attention in choking under pressure, a phenomenon that has been intensively investigated in other frameworks, most notably that of implicit and explicit learning (Masters, 1992, 2000; Maxwell, Masters, Kerr, & Weedon, 2001). Thus far, however, Wulf has not really considered the interface between the external versus internal focus of attention dichotomy and other relevant cognitive dimensions of skill learning and performance. We believe this would be interesting to do as it may help to integrate different theoretical perspectives on skill learning. Minimally, such an endeavor would allow delineating the relative contributions of explicit and implicit learning, working memory and direction of attention to choking under pressure and possible interactions among those contributions, as evidenced by recent attempts in this direction by Maxwell and Masters (2002), Poolton, Maxwell, Masters, and Raab (2006) and ourselves (Koedijker, Oudejans, & Beek, 2007).

Second, when it comes to theoretical development, the key question is of course why an external focus of attention is superior over an internal focus of attention. Wulf proposes that an external focus "promotes an automatic mode of movement control", allowing "unconscious, fast, and reflexive processes to control the movement" (p.9). But what are those automatic and reflexive processes? To start unpacking those notions it may be useful to turn to other theories of motor control and learning (e.g., Anderson, 1982; Bernstein, 1996; Fitts & Posner, 1967). Bernstein (1996), for instance, attempted to explain motor skill acquisition in terms of a hierarchical organization of four levels of control, each supporting specific aspects of perceptual-motor performance, ranging from the regulation of muscular tone to the control of complex action sequences. Gradually, a person becomes more skilful with respect to a certain task when the "division of labor" between leading and subordinate levels of control implicated in the task becomes optimized to achieve the task goal. Following this theory, external and internal foci of attention would differ in this division of labor between levels of control at the beginning of learning and beyond. Automatization is seen as the result of the implementation of sensory correction mechanisms at lower levels of control, so-called "background corrections". Perhaps with an external focus of attention movement control is initiated at such a lower level, immediately passing by more conscious "foreground corrections" of the higher levels and resorting to more "background corrections" from the start (possibly in a similar way as implicit learning). An internal focus may induce a higher

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level of control making use of the more conscious foreground corrections. As noted by Beek (2000), "modern-day neuroscience has provided many facts and discoveries that are consistent with Bernstein's ideas" (p. 551), especially for the process of automatization. Coming back to our main point, theories of motor control may provide entry points for elucidating the underlying mechanisms of external and internal foci of attention in learning and performing perceptual-motor tasks.

Finally, Wulf emphasizes the negative effects of an internal focus of attention, suggesting that an external focus is always superior. However, in certain practical situations, resorting to an internal focus may be beneficial rather than detrimental (cf., Beek, 1989, 2000). For instance, adopting an internal focus of attention may be indispensable when an athlete seeks to replace a suboptimal technique by a more optimal one in order to reach a higher level of performance. In reshaping the imperfect automatisms it seems initially necessary to intentionally deautomatize movement control, that is, in terms of Bernstein's theory, to override these automatisms by resorting to a higher level of control. Precisely because a given skill is performed in a particular automatized manner, to change its execution, it may be necessary to consciously contrast it with an alternative manner of execution that is not yet automatized. This would imply that attention should first be directed internally at the automated manner of performance so that the actor can become aware of differences between the old (automated) and new (desired) way of execution. Indeed, some authors have argued that this is the only way to undercut the tendency to reject the "New Way" in favor of the "Old Way", a phenomenon known as proactive inhibition (Hanin, Korjus, Jouste, & Baxter, 2002). On this understanding, deautomatization of the "Old Way" paves the way to automatizing the "New Way" and thus lifting performance to another level.

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COMMENTARY ON WULF

MOVING WITH AN EXTERNAL FOCUS: AUTOMATIC OR SIMPLY LESS DEMANDING?

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Die von Wulf und Kolleg/innen vertretene „constraint-action"-Hypothese fußt auf der Annahme, dass ein externaler Fokus eine automatische Bewegungskontrolle erlaubt. Wir argumentieren hingegen, dass der Vorteil externaler gegenüber internaler Fokussierung aus verringerten Anforderungen an Informationsverarbeitungsprozesse resultiert. Darüber hinaus werden individuelle Neigungen zur Fokusanpassung an wechselnde Aufgabenbedingungen diskutiert.

Schlüsselwörter: Aufmerksamkeitsfokus, motorisches Lernen, Informationsverarbeitung, kognitive Prozesse, Anweisungen

Wulf and colleagues' constrained action hypothesis contends that an external focus allows automatic processing of movement. We argue that any benefits associated with an external focus may be a result of reduced information processing load, relative to internal focus instructions, rather than the promotion of automaticity. The propensity of individuals to adapt their focus of attention in the face of changing task demands is also discussed.

Keywords: attentional focus, motor learning, information processing, cognitive processes, instructions

The constrained action hypothesis makes two separate predictions. The first proposes that attending internally prompts conscious control of movement that "constrains" the motor system and disrupts performance. This closely resembles other established concepts in the motor learning literature (e.g., reinvestment theory, Masters, 1992). The second prediction is that attending externally "promotes an automatic mode of movement control" (Wulf, 2007, p. 9). Although we are sympathetic to a dual process account of the attentional focus effect, it is unlikely that either focus promotes the exclusive use of controlled or automatic processes. A more parsimonious explanation is provided by an information processing perspective that takes only explicit/controlled processing load into account.

Increasing the demands on explicit information processing resources, such as working memory, can be detrimental to learning (Maxwell, Masters, & Eves, 2000) and performance (Maxwell, Masters, & Eves, 2003). An external focus instruction may be effective because it reduces the demands on information processing relative to an internal focus instruction. An external focus cue encourages the performer to primarily process movement effect information, but an internal focus cue prompts conscious processing of both the movement effects and information from internal feedback sources (e.g., proprioceptive feedback loops). In other words, the information processing demands are greater for internal focus learners.

We recently provided empirical evidence supporting the information processing explanation of external focus advantages (Poolton, Maxwell, Masters, & Raab, 2006). Over 300 practice trials of a 2m golf putting task, participants were encouraged to focus their attention on the swing of their hands (internal focus) or on the swing of the club (external focus). The internal focus instruction resulted in the accrual of a substantial amount of internally and externally referenced explicit knowledge. Moreover, performance was disrupted under dual-task conditions (tone counting), implying significant dependence on working memory for motor processing. In contrast, the external focus instruction limited the report of explicit knowledge and resulted in stable performance under dual-task conditions. It appeared that directing learners' attention to the movement effect reduced the use of, and dependence on, information processing resources (i.e., working memory) to the extent that a concurrent cognitive task could be processed. A second experiment provided participants with either six external focus instructions or six internal focus instructions, so that the amount of explicit knowledge available in the two learning conditions was comparable. It was argued that if external focus instructions elicit automatic processing then dual-task conditions would continue to have little impact on performance in the external focus condition; whereas, if external focus instructions themselves carry a processing load then an additional cognitive task would disrupt performance. Support was shown for the latter hypothesis. The experiments suggested that, rather than promote automaticity of movement, a single external focus instruction is effective because it reduces the load

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on explicit or conscious information processing resources. Increased automaticity needs not to be seen as an inevitable consequence of the lowering of explicit load.

Closer examination of Wulf, McNevin, and Shea's (2001) probe reaction time study also supports the existence of some information processing under external focus conditions. As predicted, Wulf et al. showed shorter probe reaction times in the external focus condition and so argued for movement automaticity. However, the data implies that probe reaction times generally increased from baseline levels when the balance task was performed concurrently. Although the increases were slighter in the external focus condition (consistent with the explicit information processing stance), the results suggest that performance was not entirely automated.

A second problem with the attentional focus literature is a lack of manipulation checks; despite encouragement to maintain a particular focus of attention, participants may not conform to the instructions. The deployment of attention is generally a dynamic, rather than static, process influenced by individual preference, and performance conditions (e.g., pressure, fatigue, injury). Performers may prefer an external focus for well developed skills (e.g., balancing, Wulf, Shea, & Park, 2001) and an internal focus for novel tasks (e.g., golf putting, Wulf, 2007, p. 5). Errors in performance or injury may trigger a switch between loci of attention as the performer attempts to identify problems and formulate solutions (see Maxwell, Masters, Kerr, & Weedon, 2001). A switch to an internal focus, in the form of "reinvestment" (conscious control of one's skill by focusing attention on the explicit knowledge that underlies the movement coordination mechanics), can also occur in performers under pressure, with disruptive consequences (see Masters, 1992; Masters, Polman, & Hammond, 1993). Furthermore, patterns of internal focus are not constant in movement impaired populations (e.g., Parkinson disease or stroke patients). Masters, Pall, MacMahon, and Eves (in press), for example, show an association between the duration for which the patient has had Parkinson disease and the propensity for an internal focus of attention (again in the form of reinvestment). It is of particular interest that empirical work on such populations (see target article) suggests that an external focus may somewhat overcome any predisposition to focus internally, but it remains to be seen whether an external focus instruction has enough power to prevent reinvestment.

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COMMENTARY ON WULF

ON THE VALUE OF THE ATTENTIONAL FOCUS CONCEPT: ELABORATE AND SPECIFY!

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Dem Konzept internaler und externaler Aufmerksamkeitsfokussierung scheint es mehr an Elaboration und Spezifikation zu mangeln als an weiterer Formalisierung und Extension. Es werden zwei Argumentationslinien präsentiert, die eine Elaboration des Konzepts und dessen Spezifikation erlauben, insofern praktische Erwägungen in Betracht gezogen werden.

Schlüsselwörter: Aufmerksamkeitsfokus, Bewegungsaufgabe, Spezifität, Anweisungen, Sportpraxis

The concept of internal and external focus of attention seems much more in need of concept elaboration and specification than of a new formalization or extension. I will provide two arguments that enable elaboration of the concept and its specification if practical considerations are taken into account.

Keywords: attentional focus, movement task, specificity, instructions, sports practice

Gabriele Wulf (2007) provides a sound review of 10 years of research on attentional focus and motor learning, to which she has over the years valuably contributed. In this comment, I will focus on two aspects of attentional focus that require further elaboration to make the concept both theoretically and empirically sound as well as of practical use, namely, (a) the task-dependent effects and (b) the conceptual status if practical consequences are considered. The concept of internal and external focus of attention seems much more in need to be elaborated and specified than to be new formalized or extended as potential ways of theoretical refinements (see Kuhl, 1983).

Concerning task-dependent effects of attentional focus, the question is, how task specific the benefit of external focus of attention turns out to be. The answer given by Wulf (2007) in the target article is that it is not task-specific. Indeed a variety of motor skills, ranging from simple balance tasks to more complex tasks used in, for example, ball games, benefit from instructions using external focus of attention. However, classifications of motor skills (e.g., Schmidt & Wrisberg, 2000) list between extremes such as “maintaining standing balance” and “dribbling a soccer ball against a defender” much more tasks than used in the attentional focus literature so far. In the review, Wulf listed skills and sports such as balance, golf tasks, basketball, dart throwing, American football and jumping showing that attentional focus is not task-specific. Balance can be categorized as stationary with neither body transformation nor object manipulation. Tasks used in golf, basketball, dart throwing, and American football can be classified such that objects (e.g., the golf ball) are “not in motion” and there is “no change in the response” required from trial to trial. In fact, almost all the tasks used in the attentional focus literature require no body transportation (with the exception of jumping) and the object of the response is not in motion or can be self-controlled (e.g., volleyball “tennis” serve). Given standard classifications of motor skills (e.g., Gentile, Higgins, Miller & Rosen, 1975, with 16 different types of motor skills), tasks with unpredictable environments, complex body transportations, and object manipulations are certainly not overresearched in this field. Experiments using, for example, a volleyball smash (Raab & Haug, 2000) or unpredictable environmental conditions such as tracking a target on a computer display (Raab, Schorer, & Sessler, 2001) could not replicate the benefits of external focus but rather showed for the volleyball smash that at least during acquisition of the task (but not during retention) internal focus of attention outperforms external focus of attention. This effect may be the result of demands on working memory (Poolton, Masters, Maxwell, & Raab, 2006) or due to task-specific components that are different from tasks used in previous attentional focus research (both the volleyball smash and target tracking are visually guided skills). I conclude that further research may therefore concentrate on filling more of the 16 types of tasks Gentile et al. (1975) classified.

Secondly, concerning practical considerations, there is a myriad of learning concepts that guide methods and instructions for the learner of motor skills such as implicit and explicit learning, discovery learning, analogy learning, variability of practice, differential learning, and many more. Some of these concentrate more on the conditions of prac-

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tice, such as variability of practice, whereas others also rely on instructions to manipulate the specific type of learning. Unfortunately, there is no default task used in experiments investigating these different learning concepts, so that we are unable to compare the exact wording of the instructions used. For example, golf putting instructions have been used in studies on internal/external focus and implicit/explicit learning, and table tennis stroke instructions have been used in discovery learning, internal/external focus, and implicit/explicit learning conditions. For tennis and table tennis instructions, for instance, previous publications have demonstrated common and different components of these instructions using different theoretical concepts. Instructions in the attentional focus research ("concentrate on something other than your body movements (i.e., the ball)", Wulf, McNevin, Fuchs, Ritter, & Toole, 2000), in the explicit/implicit distinction ("rotate more for cross-court shots than shots down the line", Smeeton, Williams, Hodges, & Ward, 2005), or in the analogy paradigm ("strike the ball while bringing the bat up the hypotenuse of the triangle", Liao & Masters, 2001) may have similar effects.

I believe that more empirical work is needed to differentiate effects of these instructions. This should be accompanied by conceptual specificity of the concepts used. For instance, it still seems unclear whether the benefits of an external instruction are due to enhancing automaticity (Wulf, 2007), leading participants to "information rich areas" (Magill, 1998), reducing the load on working memory (Poolton et al., 2006), or reducing the reinvestment into the representation of the movement (Masters & Maxwell, 2004). More important for coaches is the question "Which instruction is the best?" given a specific learner and task. Previous research offers similar instructions based on different concepts and, therefore, this kind of debate on the effectiveness of instructions may not matter for coaches as much as we want it to.

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COMMENTARY ON WULF

ATTENTIONAL FOCUS ON THE INVARIANT CONTROL VARIABLES

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Anstelle der Unterscheidung zwischen externalem und internalem Fokus werden Aufmerksamkeitsbefunde reinterpretiert als Effekte der Fokussierung invarianter Kontrollvariablen im Gegensatz zur Fokussierung frei variierbare Variablen. Darüber hinaus wird die Demonstration langfristiger Lernvorteile in Frage gestellt.

Schlüsselwörter: Aufmerksamkeitsfokus, dynamisches System, koordinative Struktur, Kontrollparameter, funktionale Kopplung

Rather than the distinction between external and internal focus, attentional focus findings are re-interpreted as attention to the invariant control variables versus attention to variables that can be free to vary. The demonstration of long term learning benefits is also questioned.

Keywords: attentional focus, dynamic system, coordinative structure, control parameter, functional coupling

The target article by Wulf (2007) highlights the importance of considering the actor's focus of attention in the performance and learning of motor skills. While research appears to demonstrate short-term benefits for "external' versus 'internal' attentional focus, alternative distinctions to external and internal focus have not been addressed, and long term learning benefits have yet to be shown.

Previous findings are predicated on the distinction between internal focus, where the actor attends to his/her own body movements, and external focus, where the actor attends to the effects of their movement on the environment. The results appear to demonstrate consistent advantages for external focus of attention. Wulf (2007) has summarized those benefits as: better outcome performance, lower attentional demand, lower muscle activity and higher frequency adjustments.

Instead of considering the results of the research to be understood as the distinction between external and internal focus, I propose that the findings may be explained by the relevance of the variable to the control of the movement outcome. An external focus typically means that attention is paid to an aspect that is closely related to the outcome of the movement–while for internal focus, attention is further removed from the actual outcome. It is not surprising that the further attentional focus is from the outcome, the worse the performance. As with any complex system, if an effort is made to constrain one part this can have unintended influences on other parts.

It has long been known that characteristics close to the outcome of a movement are relatively invariant, while other parts, such as joint motions, are free to vary from repetition to repetition (Bernstein, 1967). Specifically, Bernstein showed that the trajectory of a hammer swung at an anvil by experienced blacksmiths was relatively invariant, but the joint trajectories were free to vary. This finding was supported by Arutyunyan, Gurfinkel, and Mirskii (1968), who revealed that expert marksmen minimized the movement of the endpoint of a pistol, while the wrist, elbow, and shoulder joints were free to move within a coordinative structure. Focusing on the movement of a joint may reduce its variability, but is likely to have unintended influences on the coordinative structure and outcome, as suggested by the research on attentional focus. Therefore, the reduced performance during internal focus may be a function of reducing variability of the wrong movement characteristics, rather than internal focus per se.

In addition to lower performance, focusing attention on specific movements of the body further from the actual outcome could explain the other research findings on attention, muscle activity, and frequency of adjustments. If the actor is at all concerned about the outcome, then attention is divided between the goal and the experimenter defined focus of attention. The further apart these two characteristics of the movement the greater the demands on attention. Internal focus on the body has also been claimed to increase muscle activity. In an effort to control the specific movements of a body part greater co-contraction can occur, along with concomitant increases in activation of other muscles. Finally, external focus has been associated with higher frequency responses in a stabilometer task. Again, this may arise because attention to an external cue emphasizes changes in optic flow, which have been shown to

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changes in optic flow, which have been shown to be important in postural control (e.g., Lishman & Lee, 1973). In contrast, internal focus encourages the actor to attend to the body which does not provide the relevant optical information. Therefore, the findings that have been offered to support the internal versus external distinction can be better explained by the focus on variables relevant to the performance of a task.

The foregoing emphasizes the need for further research to understand focus of attention and how it impacts not only the outcome, but also joint kinematics and other variables. Firstly, it is important to discover the relevant variables in the performance of different tasks. These variables may often prove to be considered external, according to the earlier definition, although they are likely to be properties of the relationship between the actor and environment. In addition, research must assess the influence of varying attentional focus on movement outcome, and kinematics of the endpoint and joint motions to better understand the role of attentional focus.

Finally, practitioners need to have alternative recommendations for correcting flaws in movement techniques and enhancing learning. The relevance of attentional focus has been emphasized because it appears to contradict the common instructional strategy of providing verbal knowledge of performance to correct movement errors. However, it is not clear how external focus can mitigate against problems in technique. While the research suggests that external focus leads to better learning, these studies have considered only short periods of practice, retention, and transfer. For long term learning benefits practitioners need efficient and effective strategies for making lasting changes to their action capabilities. Motor learning research needs to provide stronger evidence for these strategies.

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COMMENTARY ON WULF

THE INFLUENCE OF ATTENTIONAL FOCUS ON MOTOR PERFORMANCE AND LEARNING: A BRIEF CRITIQUE OF GABRIELE WULF'S ARTICLE

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In diesem Kommentar nehmen wir zu Gabriele Wulfs Artikel zum Einfluss des Aufmerksamkeitsfokus auf motorische Kontroll- und Lernprozesse Stellung. Obwohl die Einnahme eines bestimmten Aufmerksamkeitsfokus unser Verständnis für die Optimierung von Aneignungs- und Performanzprozessen motorischer Fertigkeiten bereichert hat, bleiben doch einige Punkte offen, die noch der Lösung harren.

Schlüsselwörter: Aufmerksamkeitsfokus, motorisches Lernen, Lernphase, Automatismus, Anweisungen

In this paper, we will comment upon Gabriele Wulf's article concerning the influence of attentional focus on motor performance and learning. Whilst the adoption of a particular focus of attention has contributed to our understanding of how motor skills may be most effectively acquired and performed a number of unresolved issues can be identified.

Keywords: attentional focus, motor learning, learning stage, automaticity, instructions

A key theme of Wulf's (2007) review is her proposal that the adoption of an external focus of attention will not only contribute to the effective acquisition of new skills but will also facilitate superior performance amongst experts. By contrast, the adoption of an internal focus apparently hinders the acquisition of new skills and disrupts expert performance. However, as we shall explain below, there are a number of unresolved theoretical and methodological issues relating to Wulf's approach.

Wulf contends that explicit instructions directing a novice learner's attention to his/her own movements will induce an internal focus, thereby hindering skill acquisition and performance. Wulf states that when "performers are given instructions about the correct movement pattern, or technique", that these instructions are "relatively ineffective" (2007, p. 5). In contrast, an external focus of attention involves focusing on the effects that one's body movements have on the environment. Wulf claims that the adoption of an external focus will encourage the motor control processes to "self-organize more naturally", thereby promoting automaticity (Wulf, Shea, & Park, 2001, p. 342). Unfortunately, these claims run counter to traditional theories of motor skill acquisition that describe learning as progressing from explicit or conscious modes of processing to implicit or automatic modes of processing (Anderson, 1982; Fitts & Posner, 1967). It may be inferred from these theories that novice learning and performance will benefit most from skill-focused attention. In line with traditional theories and contradicting Wulf's findings, recent studies have found that an internal focus will be more beneficial to novice performance than an external focus. For example, Castaneda and Gray (2007) found that an internal focus produced superior performance amongst less-skilled baseball players. Likewise, Beilock, Carr, MacMahon, and Starkes (2002) found skill-focused attention to be more beneficial for novice performance of a golf putting task than a condition distracting attention from the task at hand.

In addition, Poolton, Maxwell, Masters, and Raab (2006) found no learning and performance advantages for external focus instructions when compared with either internal focus or no instructions, when novices completed a golf putting task under secondary task load. These authors suggest that both internal and external focus of attention instructions produced working memory overload, thereby debilitating learning and performance. This suggestion is contrary to Wulf's explanation that the performance of participants who adopt an external focus should remain robust under secondary task loading, owing to the increased compatibility of an external focus with planning and action, resulting in reduced attentional demands (Wulf, McNevin, & Shea, 2001).

Given such factors, a major theoretical limitation of Wulf's approach is the suggestion that all performers, regardless of skill level, should be encouraged to adopt an external focus of attention. It would seem that the optimal focus of attention a novice may adopt whilst learning or performing a motor skill remains an unresolved issue, warranting further research.

Whilst the sole use of external focus of attention instructions amongst novices may not be the most efficacious instructional approach, encourag-

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ing experts to adopt an external focus has met with considerable support in the motor performance literature (Beilock et al., 2002; Castaneda & Gray, 2007). There appears to be little doubt that when experts adopt an internal focus of attention, the automaticity of performance is severely disrupted. Wulf has proposed that attending to the effects of one's actions or to that which is external to the performer (e.g., putter club-head) will prevent the disruption of expert performance. While this method has provided a possible means of preventing the breakdown of expert performance, issues relating to the methodology employed by Wulf to encourage an external focus must be addressed. It would appear that the instructions given to participants in order to induce an external focus actually constitute internal focus instructions. For example, to encourage an external focus amongst expert golfers, Wulf instructs participants to focus on the "swing of the club". Beilock et al. (2002) have suggested that focusing on the swing of the club represents a mechanical action and thereby an internal focus. A more suitable method of preventing experts from consciously attending to their actions may be to encourage them to focus solely on the effects that their actions have on the environment (e.g., ball leaving the club-head). Castaneda and Gray (2007) found that this approach produced superior performance from experts in a baseball batting experiment than either internal or external (focusing on bat movement) instructions. The authors claim that this environmental condition produced best results as it prevented interruption of procedural knowledge and the connection between the action and its effects are strengthened. This suggests that an external focus is most effective when it makes no reference to movement mechanics but prevents experts from attending to any aspect of the movement itself.

Wulf's external focus has provided a possible means of preventing the breakdown of expert performance, but appears to require amendments to ensure its most effective use. Despite the preceding difficulties, Wulf's paper raises important theoretical and practical issues concerning the relationship between attention, learning, and skilled performance.

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COMMENTARY ON WULF

ATTENTIONAL FOCUS EFFECTS HIGHLIGHT THE ROLE OF MENTAL REPRESENTATIONS IN MOTOR CONTROL

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Der vorliegende Kommentar bezieht die Effekte verschiedener Aufmerksamkeitsfoki auf die Bedeutung mentaler Repräsentationen für die Kontrolle komplexen Bewegungshandelns. Wir schlagen dabei vor, zwei bislang nur unzureichend berücksichtigte Forschungsrichtungen zu beachten, die für ein besseres Verständnis von Aufmerksamkeitseffekten für die Kontrolle willentlichen Verhaltens hilfreich sind. Hierzu bedarf es auch der Untersuchung proximaler Bewegungsrepräsentationen.

Schlüsselwörter: Aufmerksamkeitsfokus, Bewegungssteuerung, antizipative Verhaltenskontrolle, kognitive Bewegungsrepräsentation, Forschungsmethodologie

The present commentary relates the effects of different foci of attention to the role that mental representations play in the control of skilled motor actions. We suggest considering two lines of research that have not been sufficiently addressed by the focus of attention literature, but which can help to better understand the effects of attentional focus on the control of voluntary behavior. This also requires investigating the role of proximal movement representations.

Keywords: attentional focus, motor control, anticipatory behavior control, cognitive movement representation, research methodology

The target article by Gabriele Wulf (2007) provides an impressive review of research on the importance of the focus of attention for motor learning and performance. There is no doubt that this topic has become a major theme in motor learning research, which is nicely reflected by the large number of authors and recent studies cited in this review. In our commentary, we want to point out, that the reported effects of attentional focus on motor skill learning warrant the investigation of mental representations that underlie motor performance. We briefly note two lines of research, not directly handled in Gabriele Wulf's review, which in our opinion nicely corroborate her main approach and the reported findings.

When examining the reviewed studies under closed scrutiny, we noted some findings that came as a surprise to us, while other findings were not surprising. The latter relate to studies in which the external focus of the performer was confounded with his/her focus on the particular performance score. For these studies, it is not surprising that the performance of an individual deteriorates when he/she is instructed to focus on a criterion that is different from the criterion being measured, such as when the focus of attention in basketball shooting is not directed to the target (i.e., the basket), but rather to the performer's own body movement (i.e., the arms) (e.g., Al-Abood, Bennet, Hernandez, Ashford, & Davids, 2002; Zachry, Wulf, Mercer, & Bezodis, 2005). Much more interesting are those studies without this confound. For example, it is striking that the same information (e.g., two feedback lines in a balance task, Shea & Wulf, 1999) affects performance differently depending on how participants interpret this feedback. Such findings show, that performers have considerable degrees of freedom regarding the way how a certain action is mentally represented, and most importantly, this has a strong impact on the individual's performance (Wulf, McConnel, Gärtner, & Schwarz, 2002).

These findings and the basic idea of this kind of studies accord with two lines of recent research: The first line is concerned with the role that action effects play in the control of voluntary movements, while the second one is interested in the cognitive representations underlying the organization of complex sport skills.

The first line of research bears on the so called ideo-motor principle, which has become an intensively studied idea in experimental psychology over the past few years (cf., Hoffmann, Stöcker, & Kunde, 2004, for a recent review). The ideo-motor principle states that voluntary behavior is exclusively planned in terms of the intended sensory consequences following any goal-directed motor action. Many findings, which have been related to the ideo-motor principle, accord well with the findings reported in the focus-of-attention literature. For example, Kunde and Weigelt (2005) demonstrated that anatomical and neuro-muscular constraints affect the production of bimanual object manipulations only under conditions in which performers are instructed to focus on the movements of their arms and hands, but not under condi-

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tions in which they focus on the to-be-manipulated objects. Also, serial learning of repetitive key-pressing sequences is much more effective, as long as these key presses produce predictable action effects (i.e., contingent tone-effects), rather than when no external effects are provided (Hoffmann, Sebald, & Stöcker, 2001). The link between the effects of attentional focus in motor skill learning and the ideo-motor principle has not been made to a sufficient degree. This link, however, is necessary to understand how voluntary behavior (the production of sport skills) is affected by the performer's attention to the intended (sensory) consequences of his/her motor action.

The second line of research investigates the coding of motor actions. Here, it has been assumed that the sensory consequences of motor actions are coded in representational networks of so called Basic Action Concepts (BACs, Schack, 2004). BACs are cognitive chunks of movement postures and movement events concerning common features in the realization of action goals. Importantly, BACs code both internal and external effects of motor actions. With the help of new experimental methods, it is possible to measure such representational structures (cf., Schack & Hackfort, 2007, for a recent review). As we know from a number of studies, expertise in the motor domain is characterized by well integrated networks, organized in a hierarchical tree-like structure (e.g., Schack & Mechsner, 2006). We assume that different attentional foci are important for the development and change of such representational structures, in ways of shaping proximal and/or distal movement representations. Currently, the relative effects of different attentional foci on the formation of such representational structures during the acquisition of sport skills are unknown and should be investigated in future studies.

Another important question for future research relates to the role that proximal movement representations (typically emphasized by internal focus instructions) play in the production of motor actions. The question is if the "automatic mode of movement control" (Wulf, 2007, p. 9) prompted by an external focus of attention, renders any representation of proximal movement effects dispensable? There is evidence suggesting that this is not the case. Take for example a study by Kunde (2001) on action-effect compatibility, demonstrating that performance suffers when certain motor actions produce sensory effects that are incompatible to the movements causing these effects (e.g., when pressing a key softly produces a loud instead of a quiet tone). These action-effect compatibility effects arise even when the instructions refer exclusively to the external effects of a movement (Kunde, Müsseler, & Heuer, 2007).

These results suggest that not only distal effect representations of one's own movement (attended to with an external focus) affect the production of motor actions, but also proximal effect representations (attended to with an internal focus). The latter seem to be almost insurmountably created during the generation of voluntary behavior and will almost inevitably interfere with distal effect representations (cf., Kunde, Koch, & Hoffmann, 2004, for more details).

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COMMENTARY ON WULF

AN APPLIED SPORT PSYCHOLOGICAL PERSPECTIVE ON THE RELATIVE MERITS OF AN EXTERNAL AND INTERNAL FOCUS OF ATTENTION

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In diesem Kommentar wir die Generalisierbarkeit der von Wulf (2007) vorgenommenen Setzung hinterfragt, nach der ein externaler Fokus für das Erreichen sportlicher Höchstleistungen von Vorteil ist. Der zukünftigen Forschung wird empfohlen, a) Fokuseffekte bei kontinuierlichen Fertigkeiten und/oder bei präzisen Formbewegungen (bspw. Kunstspringen) zu untersuchen, und b) einen „internalen Fokus" stärker über das Bewegungsgefühl anstelle spezifischer mechanischer Eigenheiten zu definieren.

Schlüsselwörter: Aufmerksamkeitsfokus, Sportpraxis, Hochleistungssport, Bewegungsvorstellung, Bewegungsaufgabe

In this paper, the generalizability of Wulf's (2007) premise that an external attentional focus is preferable for elite athletic performance is questioned. It is recommended that future researchers a) examine attentional focus during the execution of continuous sport skills and/or those emphasizing the production of precise movement form (e.g., springboard diving), and b) re-conceptualize the definition of "internal focus" to emphasize the general feel of the motion rather than the specific mechanics.

Keywords: attentional focus, sports practice, elite sport, mental image of movement, movement task

The majority of sport skills examined in the research reviewed by Wulf (2007) have had as a performance goal the accurate projection of an object toward a target. These skills include place kicking in American football (Zachry, 2005), kicking a soccer ball (Wulf, McConnel, Gärtner, & Schwarz, 2002), hitting a golf ball (Wulf & Su, 2007), throwing darts (Marchant, Clough, & Crawshaw, in press), serving a volleyball (Wulf et al., 2002), and shooting a basketball (Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002; Zachry, Wulf, Mercer, & Bezodis, 2005). From an applied sport psychological perspective it is not surprising that an external focus has been found to be effective for this type of task because it directs performers' attention to cues that are relevant to *goal achievement* (e.g., ways of projecting the object toward the target). On the other hand, an internal focus (at least the way it has been defined in these studies) directs performers' attention to sensory information that is at best tangential to goal achievement (e.g., the mechanics of muscle and joint activity). Therefore, based on Wulf's review, it would seem more precise to conclude that the available research on attentional focus during sport skill execution suggests a focus on goal achievement is preferable to a focus on joint mechanics if the performer's goal is to accurately project an object toward a target.

What, then, might be said about the relative merits of an external and internal focus for sport skills involving other types of goals? Unfortunately, little direct examination of this question has been attempted to date. One line of inquiry that is suggestive, however, is that dealing with the perspective used by elite athletes during mental imagery of their performance (see Hardy, 1997, for a discussion). This research suggests that athletes engage in *both* visual and kinesthetic imagery and, with respect to the former, do so from *either* an internal or external perspective (Jowdy, Murphy, & Durtschi,1989). For example, a rhythmic gymnast might use an external visual perspective to "see" her performance from the judges' perspective, or an internal visual perspective to "see" aspects of the environment the way she does during an actual performance (Orlick & Partington, 1988). At the same time, the gymnast might kinesthetically image the "feel" of various components of her routine. Thus, it is plausible to presume that, depending on the sport skill being performed, athletes could adopt an attentional focus that is similar to any of these imagery perspectives.

For athletes performing skills requiring the precise execution of movement form (e.g., springboard diving) or a sequence of continuous (e.g., swimming, distance running) or discrete (e.g., balance beam routine, figure skating program) movements, an internal focus might be more effective than an external focus. In some cases *both* types of focus might be effective at the same or different times. One elite swimmer I currently work with focuses on "easy speed" (a term originally coined by a U.S. Olympic swimmer; see Newburg, 1995) during the swimming phase of her races but shifts her focus to "hot walls" when executing her

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turns. “Easy speed” represents an internal focus while “hot walls” is a type of external focus. Each contributes to goal achievement at different points in the swimmer’s race (i.e., relaxed and rapid strokes in the swimming lane and rapid turns at the walls). It should be emphasized, however, that this athlete’s internal focus is *different* from the “internal focus” defined in most of the research on attention and motor performance. Rather than focusing on the *specific mechanics* of the action, the athlete focuses on the *general feel* of the swimming motion (i.e., easy speed). Other athletes I have worked with have used *both* an external and internal focus almost simultaneously during movement execution. For example, a former national champion javelin thrower focused on “standing tall and sticking it” during each attempt. “Standing tall” represented the feel of the posture he wanted to achieve immediately prior to releasing the javelin. “Sticking it” referred to his intended result (or as Wulf puts it, the “movement effects”).

From an applied sport psychological perspective, I encourage future investigators to expand on the current research by examining the relative merits of an external and internal focus during the execution of sport skills emphasizing movement form (e.g., diving) and/or the production of a sequence of continuous (e.g., swimming) or discrete (e.g., gymnastics) movements. I also encourage a reconceptualization of the operational definition of “internal focus”. Based on the research examining the mental imagery of elite athletes and on anecdotal evidence obtained by sport psychology consultants who work with them (e.g., Orlick & Partington, 1986), it would appear that an emphasis on the general *feel* of the action rather than on specific muscle and joint *mechanics* would constitute a more ecologically-valid definition.

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COMMENTARY ON WULF

EFFECT CODES ARE IMPORTANT FOR LEARNING AND CONTROL OF MOVEMENT PATTERNS

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Wulf (2007) legt beeindruckende Evidenzen für Leistungsverbesserungen durch Aufmerksamkeitsfokussierung auf distale Bewegungseffekte vor. Dieser Vorteil eines externalen Fokus beruht mutmaßlich auf der Funktion von Effektcodes für die motorische Kontrolle. Leistungssteigerungen beruhen danach auf dem Erlernen von Effekten, die eine effiziente Bewegungskontrolle ermöglichen, und deren Integration in motorische Handlungsrepräsentation.

Schlüsselwörter: Aufmerksamkeitsfokus, interne Bewegungsrepräsentation, antizipative Verhaltenskontrolle, Verhaltenswirkung, Bewegungsentwurf

Wulf (2007) provides impressive evidence that focusing of attention on the distal movement effects improves performance. The reason for this advantage of an external focus of attention presumably results from the functions of effect codes in motor control. It is argued that performance will improve if those effects that allow an efficient control of the movement are learned and become part of the representation of the motor action.

Keywords: attentional focus, internal movement representation, anticipatory behavior control, behavioral effect, motor plan

Wulf (2007) provides impressive evidence for an advantage of an external focus of attention in motor learning and control. Participants perform better if they focus on the external, distal effects of their movements rather than the movement itself. For example, participants practicing a golf swing were either instructed to attend to the swing of their arms or to the swing of the club. The latter group showed better performance than the first during the training session and better retention in a later test session. Similar outcomes were reported for other tasks such as balancing, basketball throws, darts, etc. Thus, rewording of the instruction can change the attentional focus of the performer and consequently affect the performance. The focus of attention also depends on the feedback. Effect-related feedback usually results in better performance than movement-related feedback.

Wulf's (2007) explanation of the advantage of the external focus of attention is based on her constrained action hypothesis. The hypothesis states that an internal focus of attention would disrupt the automatic and unconscious processes controlling the movement. In contrast, adopting an external focus would allow unconscious, fast and reflexive processes to control the movement. With other words, better performance with external focus of attention is explained by a disadvantage of the internal focus. From a theoretical point of view this is not convincing. Not considering the general problems of differentiating between conscious and unconscious or automatic and controlled processes, what exactly happens if the internal focus of attention intervenes in the automatic control processes and why should that not happen with an external focus of attention? Instead it seems much more interesting to ask if and how effects are incorporated in learning and control of voluntary movements. The advantage of focusing on distal effects should result from the function of effect codes in movement control. At least three different functions are discussed in the literature. Firstly, it has been suggested that effect codes are necessary for the selection of motor programs. It is assumed that participants learn the effects of their movements by random movement execution. Then the acquired movement-effect relations can be reversed so that an activation of the effect codes in memory automatically activates the movement (Harleß, 1861; James, 1890; Lotze, 1852). Modern versions of this ideo-motor principle are the common coding principle (Prinz, 1992, 1997) and the theory of event coding (Hommel, Müsseler, Aschersleben, & Prinz, 2001). Secondly, knowledge of effects might be necessary for monitoring of response execution. For example, the schema theory (Schmidt, 1975, 1982) states that effects of the designed motor program are anticipated to enable the cognitive system to check whether the program is executed correctly. Thirdly, the schema theory also states that the anticipation of effects of a designed motor program enables an internal test of the program in advance of its execution. The action can be executed if the anticipated effect is identical with the desired effect.

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Recent evidence from psychological experiments clearly indicates that effect codes are activated as part of motor planning, even if only simple key-pressing responses are required. For example, Elsner and Hommel (2001) found evidence that learned response effects can activate the response if they were later used as stimuli. Furthermore, response times depended on the overlap between features of the required responses and their effects (Koch & Kunde, 2002; Kunde, 2003; Kunde, Hoffmann, Zellmann, 2002). Ziessler and Nattkemper (2002) and Ziessler, Nattkemper, and Frensch (2004) reported that information about response effects presented during response planning facilitated the response.

Thus, the activation of effect codes is obviously a mandatory part of the planning of motor responses. This should be even more important for more complex motor actions. Explicitly focusing attention to the effects of the movement might support the learning of the effects and their use in motor control. Theoretically, any kind of movement effects (proximal and distal) could be used for the selection of movements, the internal test of the motor program and the monitoring of movement execution. The advantage of focusing on external, more distal effects can probably be explained by two points. First, the distal effects are directly comparable with the desired effects which consist usually in intentional changes in the environment. Second, the perceptual system might be much better in differentiating between external stimuli than between internal stimuli. For example the seen position of the club might be much more accurate than the perceived kinesthetic feedback of the golf swing. For an efficient training procedure it is important that the learners learn those effects that are commensurable with the desired effects and that can be differentiated with sufficient accuracy. This applies for most of the movement pattern discussed in target paper to external, distal effects.

To summarize, the critical point is not whether there is an internal or external focus of attention when performing a movement pattern. Instead performance depends on if the learned movement effects are appropriate to fulfill their functions in motor control. For the movements reported in the revview paper these are obviously the distal effects, however other movement patters could probably rely more on proximal effects.

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AUTHOR'S RESPONSE

METHODS, FINDINGS, EXPLANATIONS, AND FUTURE DIRECTIONS: RESPONSE TO COMMENTARIES ON "ATTENTIONAL FOCUS AND MOTOR LEARNING"

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Die zu dem Hauptbeitrag „Attentional Focus and Motor Learning: A Review of 10 Years of Research" (Wulf, 2007a) abgegebenen Kommentare kreisen hauptsächlich um vier Themenbereiche: methodologische Fragen, experimentelle Befunde, Erklärungsansätze für Aufmerksamkeitseffekte und zukünftige Forschungsrichtungen. Genau diese Themenbereiche bilden die Gliederung für meine Erwiderung. Methodologische Fragen, die in den Kommentaren aufgebracht wurden, betreffen beispielsweise Forderungen nach Manipulationsüberprüfungen und Kontrollbedingungen. Einige Kommentator/innen argumentierten, dass die für einen externalen Fokus gefundenen Lernvorteile nicht mit den Resultaten anderer Studien oder mit traditionellen Konzeptualisierungen des Lernprozesses in Übereinstimmung zu bringen sind. In anderen Kommentaren wurden Vorschläge für alternative Erklärungen (z.B. funktionale Relevanz, „common-coding"-Theorie) für die Unterschiede zwischen internalen und externalen Fokusbedingungen unterbreitet. Und schließlich steuerten einige Kommentator/innen Anregungen für zukünftige Forschungsarbeiten bei oder gaben eine Vorschau auf aktuell in ihren Labors durchgeführten Studien.

Schlüsselwörter: Aufmerksamkeitsfokus, motorisches Lernen, Forschungsmethodologie, Automatismus, antizipative Verhaltenskontrolle

Commentaries on the target article, "Attentional Focus and Motor Learning: A Review of 10 Years of Research" (Wulf, 2007a), centered mainly around four themes: Methodological issues, experimental findings, explanations of the attentional focus effects, and directions for future research. My response to the commentaries is organized around those themes. Methodological issues raised in the commentaries included, for example, suggestions to use manipulation checks and control conditions. Some commentators argued that learning advantages of an external focus were not in line with findings of other studies, or with traditional conceptualizations of learning. In other comments, alternative explanations (e.g., functional relevance, common coding theory) for the learning differences between internal versus external foci were proposed. Finally, several commentators made suggestions for future research, or gave a preview of ongoing studies in their laboratories.

Keywords: attentional focus, motor learning, research methodology, automaticity, anticipatory behavior control

Over the past few years, considerable research has been directed toward examining the effects that an individual's focus of attention has on motor performance and learning, and toward understanding the mechanisms underlying these effects (for a review, see Wulf, 2007b). One type of attentional focus that has been demonstrated to enhance the learning of motor skills – across a variety of skills, levels of expertise, age groups, as well as for healthy individuals and those with motor impairments – is an external (movement-effect related) focus. Compared to an internal (body-movement related) focus, which arguably is often induced by instructions provided to learners in applied settings, an external focus has been shown to produce more effective and efficient performance. These findings are not only theoretically interesting, but also have important implications for practical settings, where a speedy, cost- and time-efficient (re-)acquisition process, effective retention, and transfer to novel situations (including stressful conditions) are crucial.

My review of research on attentional focus and motor learning has elicited a number of interesting commentaries. While each commentary is unique and often based on the authors' own research interests and perspectives, several common themes have emerged. My response to the commentaries is therefore organized around those themes. Several authors raised issues related to the experimental methods used, or commented on experimental findings; others were more concerned with the theoretical explanation of the external focus advantage. Finally, a number of authors suggested issues to be examined in future studies. I address these groups of issues in turn.

Methodological Issues

The methodological issues raised in some commentaries referred primarily to the use of manipulation checks, control conditions, and pre-tests.

Manipulation Checks

Few variables in the motor learning domain have produced effects as reliable as those seen under internal versus external focus conditions. Nevertheless, some authors have criticized the lack of manipulation checks, such as participant interviews, to determine if participants followed the in-

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structions (Bund, Wiemeyer, & Angert, 2007; Marchant, 2007; Mullen, 2007; Oudejans, Koedijker, & Beek, 2007; Poolton, Maxwell, Masters, & van der Kamp, 2007). Such manipulation checks are certainly an option if one is interested in finding out to what extent participants actually adopted the instructed attentional focus. Studies that have used such manipulation checks (e.g., Marchant, Clough, & Crawshaw, in press; Thorn, 2006) have shown that, even though participants may not have adhered to the instructions on all trials, they did so most of the time. The best evidence that participants generally adhered to the attentional focus instructions is the fact that attentional focus effects have been shown to be very reliable in numerous studies that used a wide variety of motor tasks, types of instructions or feedback, skill levels, and populations. Yet, process analyses, verbal protocols (e.g., Kaakinen & Hyönä, 2005), and post-experimental interviews may provide interesting additional insights into performers' focus of attention. Such procedures may be particularly useful for control conditions, as suggested by Marchant (2007). Although the majority of studies that included control conditions have shown very similar performances for internal focus and control conditions/groups (see below) – perhaps suggesting that participants "naturally" tend to adopt an internal focus – evidence for this view, or alternative views, would certainly be welcome.

Control Conditions

Numerous studies have included control conditions without attentional focus instructions (Landers, Wulf, Wallmann, & Guadagnoli 2005; Marchant et al., in press; Marchant, Greig, Scott, & Clough, 2006; McNevin & Wulf, 2002; Wulf, Höß, & Prinz, 1998; Wulf, Landers, & Töllner, 2007; Wulf & McNevin, 2003; Wulf & Su, 2007; Wulf, Töllner, & Shea, 2007; Wulf, Wächter, & Wortmann, 2003; Wulf, Weigelt, Poulter, & McNevin, 2003; Wulf, Zachry, Granados & Dufek, 2007). In all cases – with only one exception (Marchant et al., in press) – control and internal focus conditions produced essentially identical results, while external focus conditions consistently demonstrated superior performances to both. Thus, the view that there is a "lack of consistent differences between control and attentional focus condition" (Hodges & Ford, 2007, p. 23) is one that I do not share. Rather, there is considerable evidence that an external focus is *beneficial* to performance and learning.

Pre-Tests

Pre-tests are not typically used in motor learning experiments. Rather, a random assignment of participants to different groups is used to ensure comparable skill levels at the beginning of practice. Our studies have been no exception. Nevertheless, some commentators pointed out the lack of pre-tests in our studies (Bund et al., 2007; Hodges & Ford, 2007; Mullen, 2007). This concern might have been triggered by the fact that attentional focus effects – in contrast to those of other learning variables, such as contextual interference or feedback frequency (e.g., Schmidt & Lee, 2005) – sometimes appear almost immediately. This is also seen in studies that have examined performance effects as a function of attentional focus, using within-participant designs, which often involved only a few trials per condition (e.g., Landers et al., 2005; Marchant et al., 2006; McNevin & Wulf, 2002). While (non-significant) group differences were seen early in practice in a few learning studies (Totsika & Wulf, 2003; Wulf, Lauterbach, & Toole, 1999), sampling bias can certainly not explain consistent findings in 50 or so studies.

Findings

Some commentators took issue with the findings nonetheless – either because of apparent discrepancies between practice and retention results (Bund et al., 2007), because the findings appear not to be in line with the findings of other researchers (Toner & Moran, 2007), or because of anecdotal evidence that seems to suggest otherwise (Künzell, 2007; Mechsner, 2007; Oudejans et al., 2007; Wrisberg, 2007).

Practice Versus Retention Results

According to Bund et al. (2007), "an interesting, but still unanswered question is whether the effects of attentional focus are either (temporary) performance effects or (permanent) learning effects or both" (p. 17). In their subsequent discussion of extant findings, the authors unfortunately confuse temporary/performance effects with those seen during practice. How different variables affect performance during practice is generally considered to be relatively uninteresting, compared to the more permanent, or learning, effects that are measured in retention. This also holds for studies on attentional focus. Whether or not focus effects are already observable during practice presumably depends on the task and the exact instructions (e.g., McNevin, Shea, & Wulf, 2003). The important question, which I addressed in the section "Performance or Learning" of the target article (Wulf, 2007a), is whether the effects seen in *retention* are temporary – which they could be if performers still adopted the focus they were instructed to use during practice – or relatively permanent. Because of the nature of the attentional focus manipulation, the independent variable employed during practice cannot easily be removed in retention tests. However, as I argued in the target article, there is strong evidence to suggest that the effects of different foci used during practice indeed constitute learning effects.

Inconsistencies With Other Studies and Traditional Views of Learning?

Toner and Moran (2007) claimed that our findings are inconsistent with those of other researchers (e.g., Beilock, Carr, MacMahon, & Starkes, 2002; Castaneda & Gray, 2007) and that our view of the

learning process is different from traditional views (Anderson, 1982; Fitts & Posner, 1967). These assertions are incorrect. They reflect a misunderstanding of the attentional focus work, at best, or a misrepresentation, at worst. Toner and Moran (2007, p. 49) begin their commentary with a quote that is taken out of context: "Wulf states that when 'performers are given instructions about the correct movement pattern, or technique', that these instructions are 'relatively ineffective'". What Toner and Moran did not quote was that I was referring to internal focus instructions, namely those referring "to the coordination of the performer's body movements, including the order, form, and timing of various limb movements" (Wulf, 2007a, p. 2). This specification is important in the light of Toner and Moran's (2007) subsequent comparison of our work with that of others. What Beilock, Gray, and colleagues have shown repeatedly is that "skill-focused" attention is more effective for performance in novices than are dual-task conditions in which participants are distracted by a secondary task (e.g., Beilock & Carr, 2004; Beilock et al., 2002; Gray, 2004). Frankly, this is not very surprising. However, Beilock et al. do not distinguish between internal or external foci of attention. "Skill-focused" attention could imply either focus. The internal and external-focus instructions (or feedback) we have provided in our studies were all "skill-focused". The important difference between our and their studies is that our instructions were either movement- or effect-related, respectively. Neither Beilock and colleagues (2002, 2004) nor Gray (2004) have compared the effectiveness of internal versus external foci. Therefore, the claim that their studies "indicate that an internal focus will be more beneficial to novice performance than an external focus" (Toner & Moran, 2007, p. 49) is completely unsubstantiated.

Furthermore, Toner and Moran (2007; see also Müller, 2007) claimed that our conceptualization of the learning process is not in line with traditional views that "describe learning progressing from explicit or conscious modes of processing to implicit or automatic modes of processing (Fitts & Posner, 1976; Anderson, 1982)" (Toner & Moran, 2007, p. 49). This is not the case either. When the learner adopts an external as compared to an internal focus, it is assumed that the learning process is *speeded*, and that a state of automaticity is achieved sooner (see Wulf, 2007b, Chapter 4). Thus, one might argue that the length of the initial stages of learning is shortened by the adoption of an external focus. In a related point, Müller (2007, p. 38) asked, "how can de-automization bear on motor learning in earlier stages, where no automatic control processes might exist to interfere with?" Or, worded differently, how can an external focus promote automaticity if an individual has never, or rarely, performed a particular skill before? The answer to this question is relatively simple. People typically do not learn new skills as a *tabula rasa*. Even though we might not have performed a given skill before, we might have had previous experience with similar skills. For example, over most of our lifetime, our postural system has learned to make automatic adjustments that prevent us from losing our balance. If we were required to stand on a compliant, or even a moving, support surface, we would still be able to use some of the same control mechanisms. In other cases, a learner might have performed components of a novel skill in the context of another skill. For example, experience with throwing and catching balls might transfer to juggling, so these aspects of the skill should be performed more or less automatically. Nevertheless, as our studies indicate, individuals often appear to choose a more conscious mode when confronted with a new skill (as seen by the typical absence of differences between control and internal focus conditions; see above). An external focus seems to counteract this tendency.

Anecdotal Evidence

Several commentators pointed out apparent discrepancies between the internal-focus disadvantages, compared to an external focus, and the opinions of experts, such as coaches, athletes, or physical therapists (e.g., Künzell, 2007; Marchant, 2007; Mechsner, 2007; Oudejans et al., 2007; Wrisberg, 2007). For example, Oudejans et al. (2007) consider it necessary to direct attention internally in the reshaping of imperfect automatisms. Mechsner refers to the "wisdom" of practitioners and martial arts experts ("it seems obvious that in many tasks it is advantageous and indeed crucial to focus on one's center of gravity"; Mechsner, 2007, p. 33). I do not want to discount the wisdom of practitioners. Yet, those comments are exclusively based on *anecdotal* evidence. Until there is convincing *experimental* evidence indicating that an internal focus is more effective than an external focus, the discussion of these claims is moot. What these comments do indicate, though, is that there is a need for more research related to expert performance, re-learning in cases in which the technique is flawed, as well as re-learning of motor skills in rehabilitation settings.

Explanations for the Attentional Focus Effects

In several commentaries, alternative explanations for the effects of an external relative to an internal focus have been proposed. For example, it has been suggested that visual information might have a mediating role in this context (Hodges & Ford, 2007; Maurer & Zentgraf, 2007; Russell, 2007). Also, a number of commentators suggested that an external focus may be more related to the goal of the task, compared to an internal focus, and that an external focus may be therefore more "functional" (e.g., Hommel, 2007; Künzell, 2007; Maurer & Zentgraf, 2007; Russell, 2007; Wrisberg, 2007; Ziessler, 2007), that attention should be directed at "key points" (Ehrlenspiel, 2007; Künzell, 2007), or that learning might be "easier", when an external focus is adopted (Hommel, 2007; Poolton et al.,

2007). Finally, several authors referred to the ideomotor principle and Prinz's common coding theory as explanations for the attentional focus effects (Hommel, 2007; Maurer & Zentgraf, 2007; Weigelt, Schack, & Kunde, 2007; Ziessler, 2007).

Effects of Vision

Differential influences of visual information cannot explain the performance and learning differences between external and internal focus conditions (Hodges & Ford, 2007; Maurer & Zentgraf, 2007; Russell, 2007). As we have pointed out repeatedly in our papers, as well as in the target article (Wulf, 2007a), it is essential that attentional focus not be confounded with visual information. [Nevertheless, it is often still falsely assumed that vision is confounded with attentional focus (see Hegele & Erlacher, 2007).] In our balance studies, for example, participants are always instructed to look straight ahead while focusing their attention on their feet or markers in front of their feet (e.g., McNevin et al., 2003; Wulf et al., 1998; Wulf, McNevin, & Shea, 2001). In some cases, participants were even required to keep their eyes closed (e.g., McNevin & Wulf, 2002). Thus, differences in optic flow (Russell, 2007) or visual information about the movement outcome (Maurer & Zentgraf, 2007) cannot explain the performance differences between focus conditions.

Functional Relevance

The idea that an external focus might have greater functional relevance than an internal focus (e.g., Hommel, 2007; Künzell, 2007; Maurer & Zentgraf, 2007; Russell, 2007; Wrisberg, 2007; Ziessler, 2007) might seem more appealing, at least at first glance. For example, Russell (2007, p. 48) claimed that our findings "can be better explained by the focus on the variables relevant to the performance of a task". Hommel (2007, p. 26) pointed out that, in most of our studies, "the task goal and the distal action effects attended in the external-focus condition were indistinguishable". Similarly, Künzell (2007) suggested that the functional importance of the instructions may have been confounded with the attentional focus manipulation. As examples, advocates of the functional-relevance explanation typically used "goal-related" tasks that involved targets, arguing that the external focus instructions might have directed more attention to the outcome of their actions in terms of goal achievement (e.g., Hommel, 2007; Künzell, 2007; Wrisberg, 2007; Ziessler, 2007). However, with the exception of perhaps two studies (Al-Abood, Bennett, Hernandez, Ashford, & Davids, 2002; Zachry, Wulf, Mercer, & Bezodis; 2005), I am not aware of any focus manipulations that may have directed more attention to the movement outcome under external focus conditions. If the functional importance of the instructions could explain the differential effects on performance and learning, the results would not be very impressive. Therefore, one of our main objectives has always been to ensure that internal and external focus instructions were as similar as possible and did not differ in information content.

Any alternative hypothesis for the effects of attentional focus should be able to explain the full set of findings. In terms of the functional-relevance hypothesis, there are several lines of evidence that argue against this view as a possible explanation. First, outcome information, such as deviations from a target, were available under all focus conditions (e.g., Wulf et al., 1999; Wulf, McConnel, Gärtner, & Schwarz, 2002; Wulf & Su, 2007; Zachry et al., 2005), and there is little reason to assume that participants under internal focus conditions were less inclined to hit the target compared to external focus conditions. Second, and more importantly, how would the functional-relevance hypothesis explain attentional focus differences in balance performance? In a number of our studies, we have used balance tasks in which participants were to focus on keeping either their feet (internal focus) or the support surface still (external focus) (e.g., McNevin et al., 2003; Wulf et al., 1998; Wulf et al., 2001). Similarly, in the Totsika and Wulf (2003) study using a Pedalo task, participants focused on pushing either their feet forward, or the boards on which they were standing (while looking straight ahead). In those cases, movements of the support surface are a direct function of movements of the feet. How can one focus be argued to be more "functional" than the other? Furthermore, how can the differential effects on EMG activity in biceps curls (Marchant et al., 2006; Vance, Wulf, Töllner, McNevin, & Mercer, 2004) – with identical movement amplitudes and frequencies – be explained by this hypothesis? Finally, in the Shea and Wulf (1999) study, attentional focus effects were seen on a balance task (stabilometer), even when the visual feedback on a screen was *identical* and only the participants' interpretation of it (internal versus external) was manipulated. Overall, convincing evidence is lacking for "functional relevance" as a mediating factor, or even as an encompassing explanation, for the attentional focus effects.

Information-Processing Demands

Poolton et al. (2007) suggested that information-processing demands may be reduced with an external relative to an internal focus. While I agree with the notion that an external focus requires less conscious processing of movement-related information – as motor control is shifted to a more automatic level – I do not agree with the rationale for this view: "An external focus cue encourages the performer to primarily process movement effect information, but an internal focus cue prompts conscious processing of both movement effects and information from internal feedback sources (e.g., proprioceptive feedback loops)" (Poolton et al., 2007, p. 43). On balance tasks, for example, where – especially when visual information about the "outcome" is precluded visual (e.g., McNevin & Wulf, 2002; Wulf et al., 2001) – performers need to process proprioceptive information under both in-

ternal and external focus conditions. Furthermore, outcome information also needs to be processed under either condition when the task requires hitting a target, for instance (Wulf et al., 1999, 2002; Zachry et al., 2005). The finding by Poolton, Maxwell, Masters, and Raab (2006, Experiment 2) that Poolton et al. (2007) cite as evidence for their hypothesis, does not show convincing support for this idea. In the absence of significant differences between internal and external focus conditions, it is difficult to argue that the accumulation of more explicit knowledge under the internal focus condition is responsible for performance/learning differences in other studies. [The lack of attentional focus effects in the Poolton et al. (2006) study is likely due to the unusual, and probably overwhelming, amount of information participants had to process under each condition (i.e., six sets of instructions), which may have nullified any attentional focus effects.] Thus, in my view, reduced information-processing demands are a consequence, or side-effect, of an external focus; but it is not the reduced information-processing demands that make an external focus effective.

In a similar vein, Hommel (2007) suggested that an external focus might be "easier", "more natural", and "less interfering" than an internal focus. He concluded: "Whether this has anything to do with automaticity we simply do not know" (Hommel, 2007, p. 25). Again, I agree with the view that an external focus might make performance "easier". Yet, I believe this is a function of the automaticity that is promoted by an external focus. How else could the fast movement adjustments (e.g., Wulf et al., 2001) and the reduced EMG activity (e.g., Vance et al., 2004) be explained? Hommel also suggested that "there is nothing special about adopting an external focus in facilitating motor learning. All that is necessary to allow coordination processes to operate in an automatic mode would be to prevent learners from attending to their body movements" (Hommel, 2007, p. 25). As we have shown, it is *not* enough to prevent learners from adopting an internal focus (Wulf & McNevin, 2003). Having individuals perform a secondary task (i.e., shadowing a story) while learning a balance task did not provide any learning benefits. Thus, it is not just the prevention of an internal focus, but the adoption of an external focus, that enhances learning.

Ideo-Motor Principle and Common Coding Theory

When we first discovered differences in motor learning as a function of the individual's focus of attention (Wulf et al., 1998), we referred to Prinz's common coding theory (1990, 1997) as a possible explanation for those effects (see also, Wulf & Prinz, 2001). As indicated earlier (Wulf, 2007a; Wulf & Prinz, 2001), though, common coding theory does not specifically predict the attentional focus effects. Therefore, a search for a more specific account of the differential influences on motor performance and learning was necessary, and the constrained action hypothesis is the result of that search. Yet, several commentators (Hommel, 2007; Maurer & Zentgraf, 2007; Weigelt et al., 2007; Ziessler, 2007) refer back to the ideo-motor principle (James, 1890) and Prinz's common coding hypothesis, arguing that this might be a more "fruitful theoretical framework" (Maurer & Zentgraf, 2007), as it is the associations of movements and their effects that need to be learned. Indeed, there is plenty of experimental evidence indicating that "the preparation and selection of actions is mediated by representations of action effects" (Hommel, 2007, p. 26). Ziessler (2007, p. 56) also refers to evidence showing that "learned response effects can activate the response if they were later used as stimuli", and Weigelt et al. (2007, p. 51) point out the "role that action effects play in the control of voluntary movements".

The evidence for the importance of action effects in the preparation of responses is undeniable, and I am certainly sympathetic to the ideas put forward by Prinz and his collaborators. Yet, I do not see how this theoretical framework provides a "better" explanation for the effects of internal versus external foci. As the quotes above indicate, anticipated action effects seem to be important for the *selection* and *planning* of actions in response to stimuli. But how can this account explain the effects of attentional focus on *motor control*, such as the frequency of movement adjustments in balance, or EMG activity in a biceps curl task? Frankly, it appears to me that action effect and common coding views – while certainly in line with our results – do not provide a specific explanation for those effects. In contrast, the constrained action hypothesis does provide such an explanation.

Key Points

Ehrlenspiel (2007) and Künzell (2007) refer to a "key-point" ("nodal-point") hypothesis to explain primarily the negative effects of an internal focus (Hossner & Ehrlenspiel, 2007). While a concise definition of "key points" is missing in those commentaries, Künzell (2007, p. 27) indicated that a key point "could be a specific joint configuration at an important phase of the movement, but it could as well be a specific distal effect that is to be achieved". Based on this description, a focus on key points of the movement could be either internal or external. Notwithstanding this difference between the key-point idea and the attentional focus work, their conceptualization of the learning process – where increasingly larger "units" are controlled and control shifts to higher hierarchical levels as learning progresses – is in line with Vallacher's (1993; Vallacher & Wegner, 1987) view of action control. It is also in line with suggestions as to how the optimal focus of attention might shift to higher-level effects as a function of expertise (see Wulf, 2007b, Chapter 5). It will be interesting to see how the effectiveness of focusing on different key points might relate to the internal-external focus distinction.

Future Directions

Several commentators had interesting suggestions for future research. Some of these suggestions were aimed at elucidating further the concomitant changes in motor control and learning as a function of attentional focus (Russell, 2007; Weigelt et al., 2007), or at examining the role of different types of effects (Hegele & Erlacher, 2007); others were more directed to examining the generalizability of the findings to different categories of skills (Raab, 2007), or to complex skills that are required in settings that have received little attention as of yet, such as surgery or music (Brydges, Dubrowski, & Carnahan, 2007; Mornell, 2007).

Functional Variability

Russell's (2007) suggestion that an external focus might lead to greater functional variability than an internal focus – with the result that the intended outcome is achieved with greater accuracy and reliability – is interesting. In fact, we have hinted at this possibility in an earlier paper: "It is conceivable that adopting an external focus of attention, that is, focusing on the movement effect, facilitates compensatory variability in various movement parameters to ensure that the effect is achieved, whereas focusing on the movements themselves interferes with such processes" (Wulf & Prinz, 2001, p. 657). Currently, a study is underway in our lab, in which we examine variability in joint angles, etc. under different focus conditions in high-jumping.

Movement Representations

Another intriguing idea for future research is Weigelt et al.'s (2007) proposal to examine potential differences in movement representations as a function of the attentional focus adopted during practice. Based on the assumption that an external focus speeds up the learning process (Wulf, 2007b), an obvious prediction would be that this type of focus should result in memory representations that show greater resemblance to those of advanced performers than those developed with an internal focus. The examination of mental representations would certainly add a novel aspect to this research area, which has predominantly used performance outcome (e.g., accuracy scores) or production measures (e.g., EMG) as dependent variables.

"Dimensions" of Movement Effects

Hegele and Erlacher's (2007) commentary on "dimensions of distality" goes back to a finding showing that directing attention to a movement effect that occurs at a greater (spatial) distance from the body can be more effective than focusing on an effect that occurs closer to the body (McNevin et al., 2003). Hegele and Erlacher's suggestion that "temporal" and "perceptual" dimensions of movement effects should be considered, in addition to the spatial dimension, is interesting. Examining those factors independently would appear to be challenging, however. Often effects that occur at a greater spatial distance from the body also occur later in time (e.g., the anticipated trajectory of a ball versus its landing point). [The "perceptual" dimension seems to be more related to different types of sensory feedback, rather than planned movement effects – and the respective instructions in the Hossner, Hegele, Erlacher and Ehrlenspiel (2006) study cited by Hegele and Erlacher (2007) would actually seem to induce more of an internal focus.] Nevertheless, examining different dimensions of movement effects – including those at different hierarchical levels (see Wulf, 2007b) – would seem like a worthwhile endeavor, as it may provide more insight into the effects of attentional focus on motor control.

Generalizability

Even though a variety of tasks have been used to examine the effects of attentional focus, Raab (2007) pointed out that tasks requiring body transport and those taking place in variable environments (Gentile, 1987) were underrepresented. [A table with examples of various tasks, based on Gentile's classification, and external versus internal focus instructions was provided in Wulf (2007b, Chapter 2).] Several studies have used tasks that involved body transport (e.g., Maddox, Wulf, & Wright, 1999; Totsika & Wulf, 2003; Wulf et al., in press) or tasks requiring responses to objects in motion (e.g., Maddox et al., 1999; Wulf, McNevin, Fuchs, Ritter, & Toole, 2000; Wulf, Wächter, & Wortmann, 2003), and the typical benefits of focusing on the movement effect were observed in those studies as well. While I presently do not see any reason to assume that the effectiveness of external versus internal foci would depend on the type of task, a fruitful direction for future research may be to examine the generalizability of the external focus advantages to other tasks along the lines suggested by Raab (2007).

Both Brydges et al. (2007) and Mornell (2007) have provided interesting insights into how the findings related to attentional focus effects might apply to areas that most motor learning researchers do not usually "think of". Motor learning research often involves tasks that are relatively simple and that place relatively modest demands on attention, memory, and/or processing capacity. [This has obvious advantages, such as the ease and objectivity in measuring performance.] Yet, if the goal is to understand motor skill learning, in general, and to provide recommendations for the training of motor skills in more applied settings (e.g., in music or surgery), it seems to be necessary to study the learning of more complex skills which, at least initially, pose greater challenges to the learner (Wulf & Shea, 2002). It is therefore exciting to see that Brydges et al. (2007) and Mornell (2007) have accepted the challenge of conducting studies that involve the learning of complex motor skills with high accuracy demands – which, moreover, are often performed under stressful conditions – such as those required in surgery or music. It will be interesting to see their results.

Conclusions

A broad range of issues has been brought forward in the commentaries. While some commentaries presented an opportunity to provide clarification, others challenged our theoretical assumptions and presented interesting alternative accounts, whereas yet another group highlighted important practical implications for real-life settings. Most certainly, different viewpoints will continue to exist. But, of course, it is exactly those differing views, and the challenges we present to each other, that drive the field forward and advance our understanding of how motor skills are best learned or taught. Our fascination with motor learning is obviously something that we all share.

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