E-JOURNAL Bewegung und Training

Bewegung und Training, 2007, preprint www.ejournal-but.de

TARGET ARTICLE – MAIN ARTICLE

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

GABRIELE WULF
DEPARTMENT OF KINESIOLOGY, UNIVERSITY OF NEVADA, LAS VEGAS

Abstract

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.

Zusammenfassung

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.

Keywords

focus of attention, motor skills, performance, instruction, 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, in press-a). 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 sec-

Correspondence Address:
Gabriele Wulf (gabriele.wulf@unlv.edu)
Department of Kinesiology
University of Nevada, 4505 Maryland Parkway
Las Vegas, NV 89154-3034
United States of America

E-Journal *Bewegung und Training*
Offizielles Organ der Sektionen Biomechanik, Sportmotorik und Trainingswissenschaft in der Deutschen Vereinigung für Sportwissenschaft.
ISSN 1612-5770

tion. The question whether the observed differences between focus conditions are simply temporary effects on motor performance, or whether they 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 makers – 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, in press-b; Wulf, Lauterbach, & Toole, 1999). In two of these studies (Wulf, in press-b; 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.

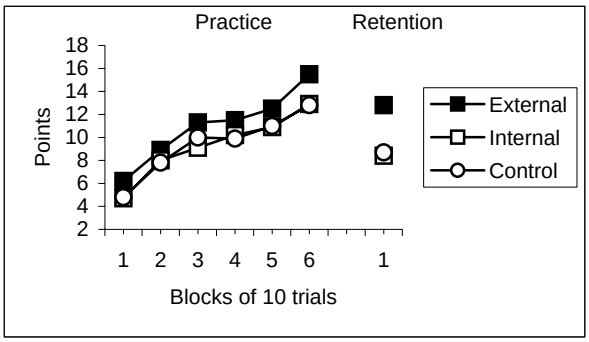

Figure 1. Accuracy scores for the external focus, internal focus, and control groups during practice and retention in the study by Wulf (in press-b, Experiment 1).

Figure 1 shows the results of the study by Wulf (in press-b, 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 ex-

ternal 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 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, pg. 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, in press-b, Experiment 2). Similar to the study with novices described above (Wulf, in press-b, 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 (2.6) rather than internally (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, in press-b; Wulf et al., 1998; Wulf & McNevin, 2003; 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 (2006) 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.

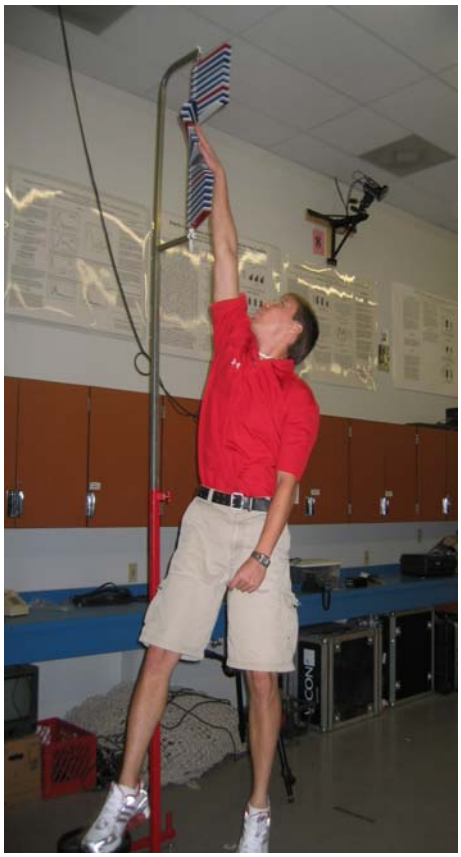

Figure 2. Participant performing a jump-and-reach task using the Vertec™ measurement system.

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 participants 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, pg. 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, Shea, & Wulf, 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 corrobo-

rates 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 (McNevin et al., 2003; Wulf, McNevin, & Shea, 2001; Wulf, Shea, & Park, 2001), 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, Shea, & Wulf, 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 con-

stitute 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, Weigelt, 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.

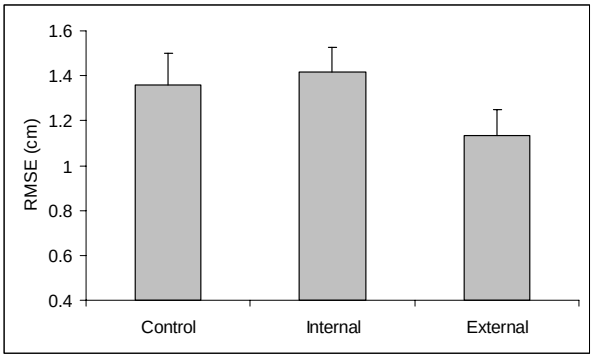

Figure 3. Magnitude of sway (root-mean-square error; RMSE) for participants with Parkinson's disease as a function of the type of attentional focus (control, internal, or external) in the study by Wulf, Landers, and Töllner (2006).

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 preplanned their movements to a greater extent, and used more automatic control processes, when they were instructed to focus externally.

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 advan-

tages 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.

References

Abernethy, B. (1988). Dual-task methodology and motor skills research – Some applications and methodological constraints. *Journal of Human Movement Studies, 14,* 101-132.

Al-Abood, S. A., Bennett, S. J., Hernandez, F. M., Ashford, D., & Davids, K. (2002). Effects of verbal instructions and image size on visual search strategies in basketball free throw shooting. *Journal of Sports Sciences, 20,* 271-278.

Baumeister, R. F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. *Journal of Personality and Social Psychology, 46,* 610-620.

Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General, 130*, 701-725.

Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: Impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied, 8*, 6-16.

Bliss, C. B. (1892-1893). Investigations in reaction time and attention. *Studies from the Yale Psychology Laboratory, 1,* 1-55.

Boder, D. P. (1935). The influence of concomitant activity and fatigue upon certain forms of reciprocal hand movements and its fundamental components. *Comparative Psychology Monographs, 11* (Serial No. 4).

Fasoli, S. E., Trombly, C. A., Tickle-Degnen, L., & Verfaellie, M. H. (2002). Effect of instructions on functional reach in persons with and without cerebrovascular accident. *American Journal of Occupational Therapy, 56,* 380-390.

Gallwey, W. T. (1982). *The inner game of tennis.* New York: Bantam Books.

Gray, R. (2004). Attending to the execution of a complex sensorimotor skill: Expertise differences, choking, and slumps. *Journal of Experimental Psychology: Applied, 10,* 42-54.

Hollmann, W., & Hettinger, T. (2000). *Sportmedizin – Grundlagen für Arbeit, Training und Präventivmedizin* (4th ed.) [Sports medicine – Fundamentals for work, exercise, and preventative medicine]. Stuttgart: Schattauer.

Landers, M., Wulf, G., Wallmann, H., & Guadagnoli, M. A. (2005). An external focus of attention attenuates balance impairment in Parkinson's disease. *Physiotherapy, 91,* 152-185.

Marchant, D., Clough, P. J., & Crawshaw, M. (in press). The effects of attentional focusing strategies on novice dart throwing performances and their experiences. *International Journal of Sport and Exercise Psychology*.

Marchant, D., Greig, M., Scott, C., & Clough, P. (2006, March). *Attentional focusing strategies influence muscle activity during isokinetic bicep curls.* Poster presented that the annual conference of the British Psychological Society, Cardiff, UK.

McNevin, N. H., Shea, C. H., & Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. *Psychological Research, 67,* 22-29.

McNevin, N. H., & Wulf, G. (2002). Attentional focus on supra-postural tasks affects postural control. *Human Movement Science, 21,* 187-202.

Park, J.-H., Shea, C. H., McNevin, N. H, & Wulf, G. (2000). Attentional focus and the control of dynamic balance. *Journal of Sport and Exercise Psychology, 22*, S85.

Perkins-Ceccato, N., Passmore, S. R., & Lee, T. D. (2003). Effects of focus of attention depend of golfers' skill. *Journal of Sport Sciences, 21*, 593-600.

Prinz, W. (1990). A common coding approach to perception and action. In O. Neumann & W. Prinz (Eds.), *Relationships between perception and action* (pp. 167-201). Berlin: Springer.

Prinz, W. (1992). Why don't we perceive our brain states? *European Journal of Cognitive Psychology, 4,* 1-20.

Prinz, W. (1997). Perception and action planning. *European Journal of Cognitive Psychology, 9,* 129-154.

Schmidt, R. A., & Wulf, G. (1997). Continuous concurrent feedback degrades skill learning: Implications for training and simulation. *Human Factors, 39,* 509-525.

Schneider, W., & Fisk, A. D. (1983). Attention theory and mechanisms for skilled performance. In R. A. Magill (Ed.), *Memory and control of action* (pp. 119-143). Amsterdam: North-Holland.

Shea, C. H., & Wulf, G. (1999). Enhancing motor learning through external-focus instructions and feedback. *Human Movement Science, 18,* 553-571.

Thorn, J. (2006). *Using attentional strategies for balance performance and learning in nine through 12 year olds.* Unpublished doctoral dissertation, Florida State University, Tallahassee.

Totsika, V., & Wulf, G. (2003). The influence of external and internal foci of attention on transfer to novel situations and skills. *Research Quarterly for Exercise and Sport, 74,* 220-225.

Vallacher, R. R. (1993). Mental calibration: Forging a working relationship between mind and action. In D. M. Wegner & J. W. Pennebaker (Eds.), *Handbook of mental control.* Englewood Cliffs, NJ: Prentice Hall.

Vallacher, R. R., & Wegner, D. M. (1987). What do people think they're doing? Action identification and human behavior. *Psychological Review, 94,* 3-15.

Vance, J., Wulf, G., Töllner, T., McNevin, N. H., & Mercer, J. (2004). EMG activity as a function of the performer's focus of attention. *Journal of Motor Behavior, 36,* 450-459.

Vander Linden, D. W., Cauraugh, J. H., & Greene, T. A. (1993). The effect of frequency of kinetic feedback on learning an isometric force production task in nondisabled subjects. *Physical Therapy, 73,* 79-87.

Winstein, C. J., Pohl, P. S., Cardinale, C., Green, A., Scholtz, L., & Waters, C. S. (1996). Learning a partial-weight-bearing skill: Effectiveness of two forms of feedback. *Physical Therapy, 76,* 985-993.

Wulf, G. (in press-a). *Attention and motor skill learning*. Champaign, IL: Human Kinetics.

Wulf, G. (in press-b). An external focus of attention enhances golf shot accuracy in beginners and experts. *Research Quarterly for Exercise and Sport.*

Wulf, G., Höß, M., & Prinz, W. (1998). Instructions for motor learning: Differential effects of internal versus external focus of attention. *Journal of Motor Behavior, 30,* 169-179.

Wulf, G., Landers, M., & Töllner, T. (2006). *Postural instability in Parkinson's disease decreases with an external focus of attention.* Manuscript submitted for publication.

Wulf, G., Lauterbach, B., & Toole, T. (1999). Learning advantages of an external focus of attention in golf. *Research Quarterly for Exercise and Sport, 70,* 120-126.

Wulf, G., McConnel, N., Gärtner, M., & Schwarz, A. (2002). Enhancing the learning of sport skills through external-focus feedback. *Journal of Motor Behavior, 34,* 171-182.

Wulf, G., & McNevin, N. H. (2003). Simply distracting learners is not enough: More evidence for the learning benefits of an external focus of attention. *European Journal of Sport Science, 3* (5), 1-13.

Wulf, G., McNevin, N. H., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *Quarterly Journal of Experimental Psychology, 54A,* 1143-1154.

Wulf, G., McNevin, N. H., Fuchs, T., Ritter, F., & Toole, T. (2000). Attentional focus in complex motor skill learning. *Research Quarterly for Exercise and Sport, 71,* 229-239.

Wulf, G., Mercer, J., McNevin, N. H., & Guadagnoli, M. A. (2004). Reciprocal influences of attentional focus on postural and supra-postural task performance. *Journal of Motor Behavior, 36,* 189-199.

Wulf, G., & Prinz, W. (2001). Directing attention to movement effects enhances learning: A review. *Psychonomic Bulletin & Review, 8,* 648-660.

Wulf, G., Shea, C. H., & Park, J.-H. (2001). Attention in motor learning: Preferences for and advantages of an external focus. *Research Quarterly for Exercise and Sport, 72,* 335-344.

Wulf, G., Weigelt, M., Poulter, D. R., & McNevin, N. H. (2003). Attentional focus on supra-postural tasks affects balance learning. *Quarterly Journal of Experimental Psychology, 56,* 1191-1211.

Wulf, G., Zachry, T., Granados, C., & Dufek, J. S. (2006). *Increases in jump-and-reach height through an external focus of attention.* Manuscript submitted for publication.

Zachry, T. (2005). *Effects of attentional focus on kinematics and muscle activation patterns as a function of expertise*. Unpublished master's thesis, University of Nevada, Las Vegas.

Zachry, T., Wulf, G., Mercer, J., & Bezodis, N. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin, 67,* 304-309.

Original main article received: 16.11.2006
Revised main article received: 10.12.2006
Main article accepted: 14.12.2006
Main article published for comments: 31.01.2007