frontiers in PSYCHOLOGY

ORIGINAL RESEARCH ARTICLE
published: 11 November 2010
doi: 10.3389/fpsyg.2010.00190

Frequent external-focus feedback enhances motor learning

Gabriele Wulf[1]*, Suzete Chiviacowsky[2], Eduardo Schiller[2] and Luciana Toaldo Gentilini Ávila[2]

[1] Department of Kinesiology and Nutrition Sciences, University of Nevada, Las Vegas, NV, USA
[2] School of Physical Education, Federal University of Pelotas, Pelotas, Rio Grande do Sul, Brazil

Edited by:
Jared Porter, Southern Illinois University, USA

Reviewed by:
Jared Porter, Southern Illinois University, USA
Mathias Hegele, Justus Liebig University Giessen, Germany

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

The present study examined the hypothesis that feedback inducing an external focus of attention enhances motor learning if it is provided frequently (i.e., 100%) rather than less frequently. Children (10- to 12-year-olds) practiced a soccer throw-in task and were provided feedback about movement form. The feedback statements, provided either after every (100%) or every third (33%) practice trial, were similar in content but induced either an internal focus (body-movement related) or external focus (movement-effect related). The results demonstrated that learning of the movement form was enhanced by external-focus feedback after every trial (100%) relative to external-focus feedback after every third trial (33%) or internal-focus feedback (100%, 33%), as demonstrated by immediate and delayed transfer tests without feedback. There was no difference between the two internal-focus feedback groups. These findings indicate that the attentional focus induced by feedback is an important factor in determining the effectiveness of different feedback frequencies. We argue that the informational properties of feedback cannot sufficiently account for these and related findings, and suggest that the attentional role of feedback be given greater consideration in future studies.

Keywords: focus of attention, knowledge of performance, soccer

INTRODUCTION

Feedback is one of the major factors in the process of motor skill learning (typically referred to as knowledge of results or knowledge of performance in the literature). Therefore, it is not surprising that research related to how augmented feedback functions, and how it can be optimized to facilitate learning, has a long history. After early disquisitions on the subject (e.g., Thorndike, 1914, 1927), and more systematic inquiries in the 1950s (e.g., Bilodeau and Bilodeau, 1958; Bilodeau et al., 1959), another resurgence in interest was seen in the mid-1980s, inspired by Salmoni et al.'s (1984) influential review of the literature and their theoretical ideas regarding the informational role of feedback. Another 30 years later, it may be opportune to take a fresh look at this important variable. In the past few years, it has become clear that learning is not simply a function of the task information provided to the learner, but that it is subject to a variety of social–cognitive–affective influences (Lewthwaite and Wulf, 2010a) – that may also, intentionally or unintentionally, be conveyed through feedback. For instance, aside from the volume or accumulation of information about the task that feedback provides, its valence may also affect learning. In the present study, our goal was to examine whether the effect of feedback frequency might be explained through its impact on the induction of beneficial or detrimental performance strategies or movement control in the form of feedback regarding attentional focus. Attentional focus is one variable that has consistently been shown to affect motor learning (see Wulf, 2007), perhaps in part due to its influence on the performer's cognitive–affective states. We were particularly interested in how the focus of attention induced by the feedback would interact with the frequency of its delivery.

The "guidance hypothesis" proposed by Salmoni et al. (1984) clearly addressed the informational role of feedback. The basic tenet of the guidance idea is that the information provided by feedback guides the learner to the correct movement pattern, facilitating performance during practice. Yet, frequent feedback (e.g., feedback after every trial) is assumed to have negative effects on learning. Specifically, learners are thought to become dependent on the feedback and neglect the processing of intrinsic feedback. Furthermore, frequent feedback is believed to result in excessive variability in performance ("maladaptive short-term corrections") and to prevent the learning of a stable movement pattern. In contrast, a reduced relative frequency of feedback supposedly allows learners the opportunity to process their own intrinsic feedback, making them relatively independent of the augmented information, and promotes greater movement stability.

Numerous studies have been conducted to examine the effects of different types and schedules of feedback (for reviews, see Schmidt, 1991; Swinnen, 1996; Wulf and Shea, 2004). Undoubtedly, research examining the assumptions of the guidance hypothesis has provided us with a better understanding of how feedback functions. Wulf and Shea (2004) termed this "the good" of the feedback literature. However, they also pointed out that not all findings were consistent with the guidance view ("the bad"), and that a theoretical framework to guide future research was lacking ("the ugly"). Some of the findings inconsistent with the guidance view have come from studies examining one of the most popular feedback manipulations, namely, the relative frequency of feedback. Several studies have demonstrated learning advantages of practice conditions with a reduced feedback frequency, compared to 100% feedback (e.g., Wulf and Schmidt, 1989; Winstein and Schmidt, 1990; Nicholson and Schmidt, 1991; Weeks and Kordus, 1998). However, a number of other studies failed to replicate these findings (e.g., Sparrow and Summers, 1992; Dunham and Mueller, 1993; Sparrow, 1995; Wishart and Lee, 1997; Lai and Shea, 1998; Wulf et al., 1998). Based on their review of that literature, Wulf and Shea (2004) concluded that there appeared to be little evidence that feedback provided after every practice trial causes learners to become dependent on it.

Another challenge for the guidance view, and in particular the assumption of dependency-producing effects of feedback, comes from studies showing that feedback inducing an external relative to an internal focus of attention resulted in more effective learning (Shea and Wulf, 1999; Wulf et al., 2002). Instructions or feedback promoting an external focus (i.e., a focus on the movement effect) have been shown to enhance learning, compared to those inducing an internal focus (i.e., a focus on the performer's body movements). In numerous studies conducted over the past dozen years or so, learning advantages of an external focus have been found consistently for a variety of skills, age groups, levels of expertise, and non-impaired as well as impaired populations (for a review, see Wulf, 2007). The adoption of an external focus has been shown to facilitate automaticity in movement control (e.g., Wulf et al., 2001) as well as movement efficiency (e.g., Marchant et al., 2009; Lohse et al., 2010; Wulf et al., 2010; see Marchant, in press), whereas directing attention to one's movements tends to result in conscious control attempts that constrain the motor system, disrupt automaticity, and lead to superfluous muscular activity. Recently, Wulf and Lewthwaite (2010) argued that, by referring to the performer's body movements, internal focus instructions or feedback may promote a focus on the self, leading to concerns and worries about one's performance, and subsequently "micro-choking" events.

Wulf et al. (2002) argued that the feedback provided in most experiments examining feedback frequency effects may have induced internal foci of attention, and that the benefits of reducing feedback could have been due to the relief this manipulation offered from the constant internal focus induced by every trial feedback. They therefore predicted an interaction between the frequency of feedback and the attentional focus induced by it: Specifically, if the feedback promoted an internal focus, a reduced feedback frequency should be more effective than feedback after every trial; in contrast, if it induced an external focus, frequent feedback should be more effective than a reduced frequency. The results of Wulf et al.'s Experiment 2 were in line with this prediction. Participants practicing a lofted soccer kick generally benefited more from external focus than from internal-focus feedback. Importantly, while 33% feedback was more effective for learning than 100% feedback in the internal-focus conditions, the opposite pattern of results was seen in the external-focus conditions. *Post hoc* analyses of the interaction effect showed that only the difference between the two internal focus groups was significant, while the difference between the two external focus groups did not reach significance. We therefore deemed it important to further investigate whether a high frequency (100%) of feedback can be more effective than a reduced frequency if the feedback induces an external focus of attention. Such a finding would be important from both theoretical and practical perspectives.

In Wulf et al.'s Experiment 2, the feedback referred to different aspects of the movement technique; yet, movement form was not assessed. It is possible that form ratings are a more sensitive measure of performance, compared with accuracy scores, when feedback is directed at movement form. Therefore, movement form scores as a function of feedback were of primary interest in the present study. Our study was designed after a previous one in which the effects of different feedback frequencies on the learning of a soccer throw-in skill in 12-year-old children were examined (Weeks and Kordus, 1998). The feedback statements that were used in that study mostly referred to movements of various body parts (i.e., induced an internal focus). One of eight feedback statements (see **Table 1**, left) was provided either after every trial (100% group) or after every third trial (33% group). The reduced feedback frequency resulted in a more effective learning of the movement form, compared to feedback after every trial. In the present study, the same age group, task, and similar procedure (with the exception of 72 h retention and transfer tests) were used. However, we added two groups (100% and 33% feedback) that received feedback statement that were translated into ones that induced more of an external focus (see **Table 1**, right). That is, while providing the same information, we tried to avoid references to the learners' body movements and to direct more attention to the movement effect. In a 2 (feedback frequency: 100% versus 33%) × 2 (attentional focus: internal versus external) design, we examined possible interaction effects of those variables. While

Table 1 | Feedback statements used in the Weeks and Kordus (1998) study (left) and the present study (right).

	Feedback statements	
	Internal-focus feedback (same as in Weeks and Kordus, 1998)	**External-focus feedback**
1	The feet, hips, knees, and shoulders should be aimed at the target, feet shoulder-width apart	The sneakers should point at the target; keep them apart
2	The back should be arched at the beginning of the throw	Produce a "C" at the beginning of the throw
3	The grip should look like a "W" with the thumbs together on the back of the ball	The grip should look like a "W" on the back of the ball
4	The ball should start behind the head at the beginning of the throw	The ball should be behind you at the beginning of the throw
5	The arms should go over the head during the throw and finish by being aimed at the target	Propel the ball forward and release it in front of you, aiming at the target
6	There should not spin on the ball during flight	There should not spin on the ball during flight
7	The ball should be released just in front of the head	The ball should be released just in front of you
8	Feet should remain on the ground	The sneakers should remain on the ground

we did not predict group differences in movement accuracy (similar to Weeks and Kordus, 1998), as movement outcome information was always available, we expected to see learning differences in movement form. Specifically, in contrast to the two internal-focus feedback groups, we predicted learning advantages for the 100% relative to the 33% external-focus feedback group.

MATERIALS AND METHODS

PARTICIPANTS

Participants were 48 children (18 boys, 30 girls) between the ages of 10 and 12 years, without physical or mental disabilities. All participants were naïve as to the purpose of the experiment. All children provided assent, and the school and parents/guardians provided informed consent. They were also informed that the data gathered in the present study would be kept completely confidential. The university's institutional review board approved the study.

APPARATUS AND TASK

A regulation size soccer ball (circumference: 69 cm; weight: 440 g), made of leather, was used. The task required participants to perform throw-ins to a target area consisting of a 2.5 m^2 piece of colored cloth laying flat on the ground. It was placed at a distance of 75% of the participant's maximum throwing distance, which was determined in a pre-test. In the center of the target area was a 35 cm^2, considered the primary target, in which a rubber cone (60 cm high) was placed. The participant's goal was to throw a regulation soccer ball so that it hit the center square on the fly, which yielded a score of 5 points. Fewer points (3, 2, 1) were given if the ball hit one of the zones (35 cm in width) surrounding the target, or missed the target area completely (0 points).

PROCEDURE

Participants were assigned quasi-randomly to one of four experimental groups, with 12 participants and an equal number of boys and girls in each group. Each participant performed the task individually. Before the beginning of the practice session, the (male) experimenter, who was skilled at performing the throw-in, provided a verbal description and demonstration of the skill to each participant. The participant was then given a pre-test consisting of one throw-in to determine his or her maximal throwing distance. A distance of 75% of the participant's throwing distance was then calculated and used as the target distance during practice session.

Two groups of participants received internal-focus feedback (see **Table 1**, left), whereas two other groups received external-focus feedback (see **Table 1**, right). One group under each attentional focus condition was provided with feedback after every practice trial (100%), while the other group was given feedback only after every third trial (33%). The experimenter provided participants with one of the eight feedback statements listed in **Table 1** (right) after the respective trials. The feedback statement chosen by the experimenter reflected the aspect of performance that needed the most improvement. In addition, participants could see the outcome of their throw but were also given their accuracy score by the experimenter after each trial. Before the practice session, participants were informed that they would have to perform retention and transfer tests without feedback, and that they were to attempt to exhibit proper form in each session. Each participant performed 30 practice trials. Immediately following the practice phase and 24 h later, all participants performed retention and transfer tests, each consisting of five trials without feedback. On the retention tests, the target was placed at the same distance that was used during practice (i.e., 75% of the distance the participant reached on the pre-test). During the transfer tests, the target was placed at a distance of 50% of the individual's pre-test distance.

DEPENDENT VARIABLES AND DATA ANALYSIS

We analyzed movement form, using the same procedure as Weeks and Kordus (1998), and throwing accuracy. In order to assess the quality of participants' movement form, they were videotaped during all phases of the experiment. The video camera was placed at an angle of 45° from behind the participant. Two judges, naïve to group assignment, viewed the tapes independently and rated the movement form on each trial, based on the criteria used for the feedback statement (**Table 1**). Specifically, the raters awarded 1 point for each of the eight aspects of the technique that was performed correctly. If it was not executed correctly, 0 points were recorded. Thus, the maximum form score for each trial was 8. The average measure intraclass correlation was high (0.951, $p < 0.001$). Therefore, the scores of both raters were averaged.

The distribution of the movement form data did not differ significantly ($p = 0.846$) from a normal distribution. Therefore, we used an analysis of variance (ANOVA). Both movement form and accuracy scores were averaged across blocks of five trials for the practice phase as well as the retention and transfer tests. All scores were analyzed in 2 (attentional focus: internal, external) × 2 (feedback frequency: 100%, 33%) × 6 (blocks of five trials) ANOVAs with repeated measures on the last factor for the practice phase. The immediate and delayed retention as well as transfer test data, respectively, were analyzed in separate 2 (attentional focus) × 2 (feedback frequency) × 2 (days) ANOVAs.

Maximum throwing distances, a percentage of which was used for practice, retention (75%), and transfer (50%), were compared in a 2 (attentional focus) × 2 (feedback) ANOVA.

RESULTS

MAXIMUM THROWING DISTANCE

The maximum throwing distances reached by participants on the pre-test did not differ among the external focus 100% (6.9 m), external focus 33% (6.4 m), internal focus 100% (6.5 m), and internal focus 33% (6.4 m) groups. Neither the main effects of attentional focus or feedback frequency, nor their interaction were significant, $Fs\ (1, 44) < 1$.

MOVEMENT FORM

Practice

The form scores achieved during practice can be seen in **Figure 1** (left). All groups showed an increase in form scores, with the external-focus groups having higher scores than the internal-focus groups at the end of practice (external focus: 6.0; internal focus: 5.6). The main effect of block, $F\ (5, 220) = 10.70$, $p < 0.001$, $\eta^2 = 0.20$, was significant. Furthermore, the interaction of block and attentional focus was marginally significant, $F\ (1, 44) = 4.01$, $p = 0.05$, $\eta^2 = 0.08$. The main effects of attentional focus, feedback

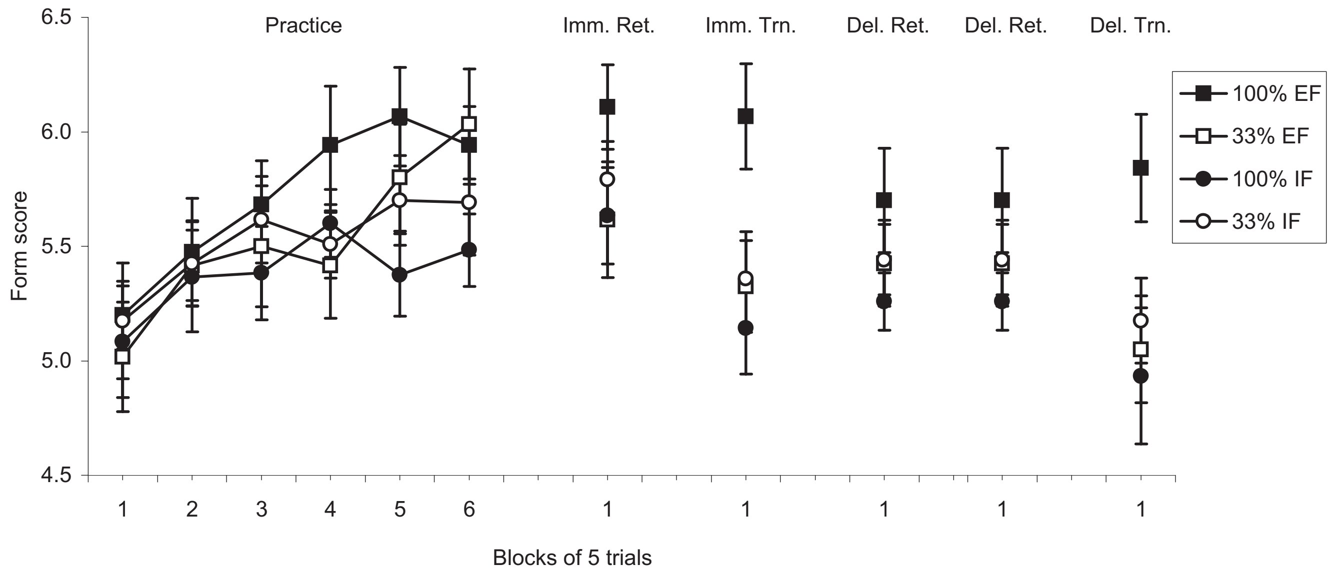

FIGURE 1 | Movement form scores of the groups receiving external focus (EF) or internal focus (IF) feedback on 100% or 33% of the practice trials, respectively, during practice, immediate and delayed retention, and immediate and delayed transfer. (Error bars represent standard errors).

frequency, and the interaction of attentional focus and feedback frequency, *F*s (1, 44) < 1, were not significant. Also, none of the other interactions were significant.

Retention

Form scores generally decreased somewhat from the immediate to the delayed retention test 1 day later (see **Figure 1**). This was confirmed by a significant main effect of day, $F(1, 44) = 8.95$, $p = 0.001$, $\eta^2 = 0.17$. The external focus 100% group tended to demonstrate higher form scores than the other groups, although the interaction of attentional focus and feedback frequency did not reach significance, $F(1, 44) = 1.37$, $p > 0.05$. None of the other main or interaction effects were significant, *F*s (1, 44) < 1.

Transfer

Form scores generally decreased from the immediate to the delayed transfer test, $F(1, 44) = 5.16$, $p < 0.05$, $\eta^2 = 0.11$. Importantly, the external focus 100% group outperformed all other groups on both the immediate and delayed transfer test (see **Figure 1**). This was reflected by a significant Attentional Focus × Feedback Frequency interaction, $F(1, 44) = 4.62$, $p < 0.05$, $\eta^2 = 0.10$. *Post hoc* tests indicated that the external focus 100% group (5.95) had significantly higher form scores than all other groups (external focus 33%: 5.25; internal focus 100%: 5.05; internal focus 33%: 5.30) (*p*s < 0.05). Also, the main effect of attentional focus was marginally significant, $F(1, 44) = 3.80$, $p = 0.058$. No other main or interaction effects were significant.

THROWING ACCURACY

Practice

All groups showed a consistent increase in throwing accuracy across practice blocks (see **Table 2**). The main effect of block was significant, $F(5, 220) = 9.80$, $p < 0.001$, $\eta^2 = 0.18$. The other main or interaction effects were not significant.

Retention

Accuracy scores tended to be slightly lower on the delayed compared to the immediate retention test, although the main effect of day failed to reach significance, $F(1, 44) = 2.78$, $p = 0.10$. None of the other main or interaction effects were significant either.

Transfer

None of the main or interaction effects were significant.

DISCUSSION

We tested the hypothesis that a high frequency of feedback (100%) would be more beneficial to learning than a reduced feedback frequency (33%) if the feedback statements induced an external rather than internal focus of attention. The prediction that feedback after every trial would result in more effective skill learning than feedback on only a portion of practice trials is contrary to the generally accepted view regarding the function of augmented feedback for learning, which was originally formulated in the guidance hypothesis (e.g., Salmoni et al., 1984; Schmidt, 1991). Yet, our assumption was based on evidence for the learning advantages of instructions inducing an external relative to an internal focus of attention (for a review, see Wulf, 2007), as well as previous indications that external-focus feedback facilitated learning (Shea and Wulf, 1999; Wulf et al., 2002).

The results of the present study confirmed the prediction that external-focus feedback provided after every trial (100%) would result in more effective learning than less frequent feedback (33%). In fact, the external focus 100% group outperformed all other groups on both transfer tests. That is, when the feedback statement were worded in a way that promoted an external focus – by foregoing references to the performers' body movements (e.g., of feet, arms, shoulders, thumbs, head) and directing more attention to the movement effects (e.g., on the ball) – a high feedback frequency was

Table 2 | Accuracy scores of the groups receiving external-focus or internal-focus feedback on 100% or 33% of the practice trials, respectively, during practice, immediate and delayed retention, and immediate and delayed transfer.

Group								
Experimental phase	**Ext. 100%**		**Ext. 33%**		**Int. 100%**		**Int. 33%**	
Practice	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
Block 1	2.93	0.24	3.12	0.28	3.07	0.27	3.48	0.26
Block 2	3.80	0.17	3.35	0.24	3.40	0.26	4.23	0.16
Block 3	3.63	0.23	3.77	0.20	3.43	0.25	3.85	0.31
Block 4	3.65	0.16	3.95	0.13	3.82	0.24	3.73	0.19
Block 5	3.88	0.13	3.98	0.14	3.55	0.21	3.72	0.20
Block 6	3.98	0.16	4.12	0.11	3.80	0.19	3.73	0.26
Immediate retention	3.83	0.21	3.92	0.13	3.67	0.24	3.95	0.19
Delayed retention	4.20	0.10	4.13	0.15	3.92	0.24	4.08	0.30
Immediate transfer	3.77	0.18	3.77	0.20	3.45	0.15	3.60	0.18
Delayed transfer	4.25	0.14	4.23	0.15	3.92	0.16	4.25	0.09

beneficial and resulted in superior learning compared to any other feedback condition. Trends in the same direction were observed for the retention tests. It is not unusual for significant group differences to emerge only on transfer tests, as these often present greater challenges to performers and tend to be more sensitive measures of learning (e.g., Wrisberg and Wulf, 1997; Lai and Shea, 1998; Chiviacowsky and Wulf, 2002, 2005; Fairbrother et al., 2009). There were no differences between the 100% and 33% internal-focus groups. Even though the 33% internal-focus feedback group tended to outperform the 100% group in retention and transfer, these differences was not significant – underscoring the fragility of this effect (for a review, see Wulf and Shea, 2004)[1].

Group differences occurred only in movement form, but not in throwing accuracy (similar to Weeks and Kordus, 1998). This was not surprising, however, given that the feedback was related to the movement form. Also, extrinsic information about movement accuracy was always available. Thus, adjustments could easily be made based on visual outcome information, resulting in similar accuracy scores for both groups.

How can the learning benefits of frequent feedback that promoted an external focus be explained? This pattern is consistent with the concept that more of a good thing (i.e., a frequent reminder to employ a beneficial external focus of attention) is good as is experiencing less of a detrimental influence (i.e., limited use of an impairing thought such as an internal focus of attention). Wulf et al. (2002) speculated that the often found learning benefits of reduced feedback frequencies may not primarily be due to learners' becoming dependent on the extrinsic feedback if it is provided frequently. They surmised that the feedback provided in many previous studies may have induced an internal focus of attention, and that the detrimental effects of frequent feedback were due to constant internal focus reminders, whereas those (negative) effects were attenuated under reduced feedback conditions. Findings by Shea and Wulf (1999) also support the notion that feedback inducing an external relative to an internal focus enhances learning. Interestingly, in their study the feedback presented to different groups was *identical* (i.e., concurrent feedback of the stabilometer platform position) – the only difference was that participants in one condition were led to believe it represented markers on the platform (external), whereas in another condition participants believed it represented their feet (internal). Furthermore, independent of the induced focus, current feedback as opposed to no feedback benefited learning. Shea and Wulf argued that the feedback (i.e., visual feedback on a computer screen) in and of itself induced an external focus. Thus, there is converging evidence that feedback inducing an external focus facilitates the learning process – particularly, if that feedback is given frequently or even concurrently with the movement.

The advantages of adopting an external focus, relative to an internal focus, have been explained with increased automaticity in movement control (constrained action hypothesis; Wulf et al., 2001; McNevin et al., 2003). As a consequence, movements are performed with greater effectiveness and efficiency compared to a situation in which performers consciously try to control their movements (internal focus) – thereby interfering with automatic control processes (see Wulf, 2007, for a review). Support for this notion comes from several lines of evidence. For instance, faster probe reaction times, indicating greater automaticity (e.g., Abernethy, 1988), have been shown to be associated with an external relative to an internal focus (Wulf et al., 2001). Furthermore, postural adjustments in balance tasks generally show higher frequency characteristics when individuals adopt an external focus; this is viewed as an indication for the greater utilization of fast, reflexive, and thus automatic control processes (e.g., Wulf et al., 2001; McNevin et al., 2003). In addition, the adoption of an external focus has been found to result in lower electromyographic (EMG) activity than internal focus or control conditions for the same individuals (e.g., Vance et al., 2004; Marchant et al., 2008, 2009; Lohse et al., 2010; Wulf et al., 2010), as

[1]Some may argue that manipulation checks are important to verify that the feedback induced the attentional focus it was intended to induce. While other studies using manipulation checks have demonstrated that participants generally seem to adopt the instructed focus (e.g., Bell and Hardy, 2009; Marchant et al., 2009; Stoate and Wulf, in press), one might also question the accuracy and reliability of that information (often provided *post hoc*). We would argue that the fact that the predicted attentional focus effects emerged – in the present study as well as in numerous other studies (Wulf, 2007) – is the best evidence that participants adhered to the feedback (or instructions).

well as enhanced endurance (Schücker et al., 2009; Marchant et al., in press) demonstrating that movement efficiency is enhanced as well.

More recently, Wulf and Lewthwaite (2010) expanded this explanation by suggesting that the mere mention of the participant's body parts (e.g., fingers, arms, feet) provokes a focus on the *self*. The self construct has increasingly been recognized as an important factor within social environments, influencing individuals' thoughts, actions, and behavior (see Stapel and Blanton, 2004; Bargh and Morsella, 2008), often implicitly. The fact that motor performance often takes place in the presence of others and can be evaluated by them, may in and of itself lead to a state of self-consciousness and subsequent self-evaluation. This, in turn, can lead to "micro-choking" episodes (Wulf and Lewthwaite, 2010) and a switching of attention to self-regulatory activity. Efforts to manage self-related thoughts and emotions may be so demanding that available attentional capacity is exceeded and performance suffers. It is also conceivable that these processes promote a conscious control of both movement and self-regulatory activities (see Sarter et al., 2006). Considering that feedback, by its nature, implies an evaluation of an individual's performance, it may not be surprising that frequent feedback can have detrimental effects compared to less frequent feedback. These effects are most likely exacerbated when individuals are provided with specific self/body-related or internal-focus feedback. In contrast, the "self-invoking trigger" (Wulf and Lewthwaite, 2010) does not come into play when the feedback promotes an external focus – be it implicitly (e.g., concurrent visual feedback in Wulf et al., 1998; Shea and Wulf, 1999) or explicitly (e.g., external-focus feedback in Shea and Wulf, 1999; Wulf et al., 2002; present study). In fact, frequent external-focus feedback seems to serve as a potent reminder to maintain an external focus – resulting in the observed beneficial effects on performance and learning.

The findings also have implications for applied settings. For example, in interviews of track and field athletes competing at the outdoor national championships, 84.6% reported that their coaches gave instructions related to body and limb movements (Porter et al., 2010). Consequently, the majority of athletes (69.2%) indicated that they focused internally when competing. Similarly, in a recent analysis of feedback statements used by physiotherapists in their treatment of patients with stroke, Durham et al. (2009) found that 95.5% of feedback statements were related to the patient's body movements. While the frequency of feedback was not a concern in those studies, it is clear that the feedback given in practical settings (still) typically induces an internal focus. Thus, there certainly seems to be potential to improve performance in various fields through the education of practitioners.

Clearly, the informational properties of feedback (Schmidt and Lee, 2005) – which are emphasized by the guidance view – cannot sufficiently account for various recent findings. These include findings not only related to attentional focus, but also those showing learning advantages of self-controlled feedback (e.g., Janelle et al., 1997; Chen et al., 2002; Chiviacowsky and Wulf, 2002; Chiviacowsky et al., 2008), feedback regarding "good" versus "poor" performance (Badami et al., in press; Chiviacowsky and Wulf, 2007; Chiviacowsky et al., 2009), and normative feedback indicating above or below average performance (Lewthwaite and Wulf, 2010b; Wulf et al., in press). We suspect that the mechanism outlined above (self-invoking trigger) may play a role in all of those, and presumably similar, feedback manipulations. Clearly, the attentional and motivational function of extrinsic feedback deserves more attention than it has received in the past.

ACKNOWLEDGMENTS

This study received financial support from CNPq (National council of scientific and technological development), Brazil.

REFERENCES

Abernethy, B. (1988). Dual-task methodology and motor skills research: some methodological constraints. *J. Hum. Mov. Stud.* 14, 101–132.

Badami, R. VaezMousavi, M., Wulf, G., and Namazizadeh, M. (in press). Feedback after good trials enhances intrinsic motivation. *Res. Q. Exerc. Sport.*

Bargh, J. A., and Morsella, E. (2008). The unconscious mind. *Perspect. Psychol. Sci.* 3, 73–79.

Bell, J. J., and Hardy, J. (2009). Effects of attentional focus on skilled performance in golf. *J. Appl. Sport Psychol.* 21, 163–177.

Bilodeau, E. A., and Bilodeau, I. M. (1958). Variable frequency of knowledge of results and the learning of a simple skill. *J. Exp. Psychol.* 55, 379–383.

Bilodeau, E. A., Bilodeau, I. M., and Schumsky, D. A. (1959). Some effects of introducing and withdrawing knowledge of results early and late in practice. *J. Exp. Psychol.* 58, 142–144.

Chen, D. D., Hendrick, J. L., and Lidor, R. (2002). Enhancing self-controlled learning environments: the use of self-regulated feedback information. *J. Hum. Mov. Stud.* 43, 1, 69–86.

Chiviacowsky, S., and Wulf, G. (2002). Self-controlled feedback: does it enhance learning because performers get feedback when they need it? *Res. Q. Exerc. Sport* 73, 408–415.

Chiviacowsky, S., and Wulf, G. (2005). Self-controlled feedback is effective if it is based on the learner's performance. *Res. Q. Exerc. Sport* 76, 42–48.

Chiviacowsky, S., and Wulf, G. (2007). Feedback after good trials enhances learning. *Res. Q. Exerc. Sport* 78, 40–47.

Chiviacowsky, S., Wulf, G., Laroque de Medeiros, F., Kaefer, A., and Tani, G. (2008). Learning benefits of self-controlled knowledge of results in 10-year old children. *Res. Q. Exerc. Sport* 79, 405–410.

Chiviacowsky, S., Wulf, G., Wally, R., and Borges, T. (2009). KR after good trials enhances learning in older adults. *Res. Q. Exerc. Sport* 80, 663–668.

Dunham, P., and Mueller, R. (1993). Effect of fading knowledge of results on acquisition, retention, and transfer of a simple motor skill. *Percept. Mot. Skills* 77, 1187–1192.

Durham, K., Van Vliet, P. M., Badger, F., and Sackley, C. (2009). Use of information feedback and attentional focus of feedback in treating the person with a hemiplegic arm. *Physiother. Res. Int.* 14, 77–90.

Fairbrother, J. T., Post, P. G., Houchin, G., and Barros, J. (2009). Self-controlled amount of practice benefits motor learning. *J. Sport Exerc. Psychol.* 31, S62.

Janelle, C. M., Barba, D. A., Frehlich, S. G., Tennant, L. K., and Cauraugh, J. H. (1997). Maximizing performance effectiveness through videotape replay and a self-controlled learning environment. *Res. Q. Exerc. Sport* 68, 269–279.

Lai, Q., and Shea, C. H. (1998). Generalized motor program (GMP) learning: effects of reduced frequency of knowledge of results and practice variability. *J. Mot. Behav.* 30, 51–59.

Lewthwaite, R., and Wulf, G. (2010a). Grand challenge for movement science and sport psychology: embracing the social-cognitive-affective-motor nature of motor behavior. *Front. Mov. Sci. Sport Psychol.* 1:42. doi: 10.3389/fpsyg.2010.00042.

Lewthwaite, R., and Wulf, G. (2010b). Social-comparative feedback affects motor skill learning. *Q. J. Exp. Psychol.* 63, 738–749.

Lohse, K. L., Sherwood, D. E., and Healy, A. F. (2010). How changing the focus of attention affects performance, kinematics, and electromyography in dart throwing. *Hum. Mov. Sci.* doi: 10.1016/j.humov.2010.05.001.

Marchant, D. C. (in press). Attentional focusing instructions, and force production. *Front. Mov. Sci. Sport Psych.*

Marchant, D. C., Greig, M., Bullough J., and Hitchen, D. (in press). Instructions to adopt an external focus enhance muscular endurance. *Res. Q. Exerc. Sport.*

Marchant, D. C., Greig, M., and Scott, C. (2008) *Attentional Focusing Strategies Influence Bicep EMG During Isokinetic Biceps Curls. Athletic Insight*. Available at http://www.athleticinsight.com/Vol10Iss2/MuscularActivity.htm. (Retrieved August 9, 2010).

Marchant, D. C., Greig, M., and Scott, C. (2009). Attentional focusing instructions influence force production and muscular activity during isokinetic elbow flexions. *J. Strength Cond. Res.* 23, 2358–2366.

McNevin, N. H., Shea, C. H., and Wulf, G. (2003). Increasing the distance of an external focus of attention enhances learning. *Psychol. Res.* 67, 22–29.

Nicholson, D. E., and Schmidt, R. A. (1991). "Scheduling information feedback to enhance training effectiveness," in *Proceedings of the Human Factors Society 35th Annual Meeting*. Santa Monica, CA: Human Factors Society.

Porter, J. M., Wu, W. F. W., and Partridge, J. A. (2010). Focus of attention and verbal instructions: strategies of elite track and field coaches and athletes. *Sport Sci. Rev.* 19, 199–211.

Salmoni, A. W., Schmidt, R. A., and Walter, C. B. (1984). Knowledge of results and motor learning: a review and critical appraisal. *Psychol. Bull.* 95, 355–386.

Sarter, M., Gehring, W. J., and Kozak, R. (2006). More attention must be paid: the neurobiology of attentional effort. *Brain Res. Rev.* 51, 145–160.

Schmidt, R. A. (1991). "Frequent augmented feedback can degrade learning: evidence and interpretations," in *Tutorials in Motor Neuroscience*, eds J. Requin and G. E. Stelmach (Dordrecht, The Netherlands: Kluwer Academic Publishers), 59–75.

Schmidt, R. A., and Lee, T. D. (2005). *Motor Control and Learning: A Behavioral Emphasis*, 4th Edn. Champaign, IL: Human Kinetics.

Schücker, L., Hageman, N., Strauss, B., and Völker, K. (2009). The effect of attentional focus on running economy. *J. Sports Sci.* 12, 1242–1248.

Shea, C. H., and Wulf, G. (1999). Enhancing motor learning through external-focus instruction and feedback. *Hum. Mov. Sci.* 18, 553–571.

Sparrow, W. A. (1995). Acquisition and retention effects of reduced relative frequency of knowledge of results. *Aust. J. Psychol.* 47, 97–104.

Sparrow, W. A., and Summers, J. J. (1992). Performance on trials without knowledge of results (KR) in reduced relative frequency presentations of KR. *J. Mot. Behav.* 24, 197–209.

Stapel, D. A., and Blanton, H. (2004). From seeing to being: subliminal social comparisons affect implicit and explicit self-evaluations. *J. Pers. Soc. Psychol.* 87, 468–481.

Stoate, I., and Wulf, G. (in press). Does the attentional focus adopted by swimmers affect their performance? *Int. J. Sports Sci. Coach.*

Swinnen, S. P. (1996). "Information feedback for motor skill learning: a review," in *Advances in Motor Learning and Control*, ed. H. N. Zelaznik (Champaign, IL: Human Kinetics), 37–66.

Thorndike, E. L. (1914). *Educational Psychology*. New York: Columbia University.

Thorndike, E. L. (1927). The law of effect. *Am. J. Psychol.* 39, 212–222.

Vance, J., Wulf, G., Töllner, T., McNevin, N. H., and Mercer, J. (2004). EMG activity as a function of the performer's focus of attention. *J. Mot. Behav.* 36, 450–459.

Weeks, D. L., and Kordus, R. N. (1998). Relative frequency of knowledge of performance and motor skill learning. *Res. Q. Exerc. Sport* 69, 224–230.

Winstein, C. J., and Schmidt, R. A. (1990). Reduced frequency of knowledge of results enhances motor skill learning. *J. Exp. Psychol. Learn. Mem. Cogn.* 16, 677–691.

Wishart, L. R., and Lee, T. D. (1997). Effect of aging and reduced relative frequency of knowledge of results on learning of a motor skill. *Percept. Mot. Skills* 84, 1107–1150.

Wrisberg, C. A., and Wulf, G. (1997). Diminishing the effects of reduced frequency of knowledge of results on generalized motor program learning. *J. Mot. Behav.* 29, 17–26.

Wulf, G. (2007). Attention and motor skill learning. Champaign, IL: Human Kinetics.

Wulf, G. Chiviacowsky, S., and Lewthwaite, R. (in press). Normative feedback effects on the learning of a timing task. *Res. Q. Exerc. Sport*.

Wulf, G., Dufek, J. S., Lozano, L., and Pettigrew, C. (2010). Increased jump height and reduced EMG activity with an external focus of attention. *Hum. Mov. Sci.* 49, 440–448.

Wulf, G., and Lewthwaite, R. (2010). "Effortless motor learning? an external focus of attention enhances movement effectiveness and efficiency," in *Effortless Attention: A New Perspective in Attention and Action*, ed. B. Bruya (Cambridge, MA: MIT Press), 75–101.

Wulf, G., McConnel, N., Gärtner, M., and Schwarz, A. (2002). Enhancing the learning of sport skills through external-focus feedback. *J. Mot. Behav.* 34, 171–182.

Wulf, G., McNevin, N. H., and Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *Q. J. Exp. Psychol.* 54A, 1143–1154.

Wulf, G., and Schmidt, R. A. (1989). The learning of generalized motor programs: reducing the relative frequency of knowledge of results enhances memory. *J. Exp. Psychol. Learn. Mem. Cogn.* 15, 748–757.

Wulf, G., and Shea, C. H. (2004). "Understanding the role of augmented feedback: the good, the bad, and the ugly," in *Skill Acquisition in Sport: Research, Theory and Practice*, eds A. M. Williams and N. J. Hodges (London: Routledge), 121–144.

Wulf, G., Shea, C. H., and Matschiner, S. (1998). Frequent feedback enhances complex motor skill learning. *J. Mot. Behav.* 30, 180–192.

Wulf, G., Shea, C. H., and Park, J.-H. (2001). Attention in motor learning: preferences for and advantages of an external focus. *Res. Q. Exerc. Sport* 72, 335–344.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Received: 12 August 2010; accepted: 19 October 2010; published online: 11 November 2010.

*Citation: Wulf G, Chiviacowsky S, Schiller E and Ávila LTG (2010) Frequent external-focus feedback enhances motor learning. Front. Psychology **1**:190. doi: 10.3389/fpsyg.2010.00190*

This article was submitted to Frontiers in Movement Science and Sport Psychology, a specialty of Frontiers in Psychology.