

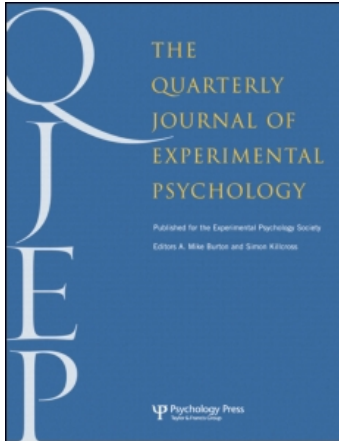
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The automaticity of complex motor skill learning as a function of attentional focus

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The present experiment was designed to test the predictions of the constrained-action hypothesis. This hypothesis proposes that when performers utilize an internal focus of attention (focus on their movements) they may actually constrain or interfere with automatic control processes that would normally regulate the movement, whereas an external focus of attention (focus on the movement effect) allows the motor system to more naturally self-organize. To test this hypothesis, a dynamic balance task (stabilometer) was used with participants instructed to adopt either an internal or external focus of attention. Consistent with earlier experiments, the external focus group produced generally smaller balance errors than did the internal focus group and responded at a higher frequency indicating higher confluence between voluntary and reflexive mechanisms. In addition, probe reaction times (RTs) were taken as a measure of the attention demands required under the two attentional focus conditions. Consistent with the hypothesis, the external focus participants demonstrated lower probe RTs than did the internal focus participants, indicating a higher degree of automaticity and less conscious interference in the control processes associated with the balance task.

In the last few years, there has been converging evidence demonstrating that the focus of attention induced by the instructions or feedback provided to learners can have a significant impact on motor skill learning (McNevin, Shea, & Wulf, 2000; Shea & Wulf, 1999; Wulf, McConnel, Gärtner, & Schwarz, 2000; Wulf, Höß, & Prinz, 1998; Wulf, Lauterbach, & Toole, 1999; Wulf, McNevin, Fuchs, Ritter, & Toole, 2000; Wulf, Shea, & Park, in press; for a review, see Wulf & Prinz, in press). In these studies, the effectiveness of directing the learners' attention to their body movements (internal focus of attention) was compared to that of learners

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directed to focus their attention on the *effects* of their movements on the apparatus or implement—that is, the environment (external focus of attention). Even though the actual differences in the loci to which attention was directed were sometimes very small, an external attentional focus consistently resulted in learning benefits (as measured by performance in retention), relative to an internal attentional focus. Table 1 lists previous studies that compared an external with an internal focus and indicates where significant ($p < .05$) attentional focus differences were found. For example, Wulf et al. (1998, Experiment 1) used a ski-simulator task and found that instructing performers when to exert force on the *wheels* of the platform on which the performer was standing, which were located directly under the performer's feet, was more beneficial than instructing them to focus on when to exert force with their *feet*. Also, in learning to balance on a stabilometer, directing participants' attention to markers attached to the stabilometer platform in front of their feet facilitated learning, compared to directing their attention to the feet themselves (e.g., Shea & Wulf, 1999; Wulf et al., 1998, Experiment 2). More recently, evidence for the learning advantages of inducing an external focus of attention have also been found for sport skills such as golf (Wulf et al., 1999), tennis (Maddox, Wulf, & Wright, 2000), volleyball and soccer (Wulf, McConnel, Gärtner, & Schwarz, 2000).

Even though the learning advantages of an external focus of attention appear to be a relatively robust phenomenon, identifying the exact reasons for these benefits remains a challenge. One possible reason for the advantages of focusing on the effects of one's movements, rather than on the movements themselves, has recently been suggested by McNevin, Shea, & Wulf (2000; see also Wulf et al., in press) proposed a "constrained action hypothesis", according to which trying to consciously control one's movements constrains the motor system by interfering with automatic motor control processes that would "normally" regulate the movement. Focusing on the movement effect, on the other hand, might allow the motor system to more naturally self-organize, unconstrained by the interference caused by conscious control attempts—resulting in more effective performance and learning. In the study by Wulf et al. (in press), for example, an analysis of the time-series movement kinematics of the stabilometer platform, which participants were trying to keep horizontal, seemed to provide support for

TABLE 1
Summary of previous studies comparing groups with an external versus internal focus of attention

	Task	Significant group differences	
		In practice	In retention/transfer
Maddox et al. (2000, Experiment 1)	tennis backhand	yes	yes
Maddox et al. (2000, Experiment 2)	tennis backhand	no	yes
Shea and Wulf (1999)	stabilometer	no	yes
Wulf, McConnel, Gärtner, and Schwarz (2000, Experiment 1)	volleyball serve	yes	yes
Wulf, McConnel, Gärtner, and Schwarz (2000, Experiment 2)	soccer	yes	yes
Wulf, Shea, and Park (in press, Experiment 1)	stabilometer	no	yes
Wulf, Shea, and Park (in press, Experiment 2)	stabilometer	no	yes
Wulf, Höb, and Prinz (1998, Experiment 1)	ski-simulator	yes	yes
Wulf, Höb, and Prinz (1998, Experiment 2)	ski-simulator	no	yes
Wulf, Lauterbach, and Toole (1999)	golf	yes	yes

this assumption. Participants who were instructed to focus on their feet showed not only poorer performance and learning but lower frequency (and larger amplitude) postural adjustments than did participants who focused on markers attached to the platform in front of their feet. Several researchers (see Newell & Slifkin, 1996, for a discussion) have characterized higher frequency responding—such as that observed under external focus conditions (markers)—as indicating an effective increase in and integration of the active degrees of freedom associated with performing a motor task and greater confluence between reflexive and voluntary control mechanisms. Trying to consciously intervene in these control processes—as participants under internal focus condition appear to do—may result in a “freezing” or “constraining” of the degrees of freedom (Vereijken, van Emmerik, Whiting, & Newell, 1992), less fluid interactions between control mechanisms, and less automatic movement execution. As a consequence, performance and learning are degraded.

The major purpose of the present study was to follow up on the issue of whether an external attentional focus promotes more automatic control processes than does an internal focus. To determine the attentional demands under external versus internal focus conditions, we used a secondary probe reaction time (RT) task. This dual-task procedure was used to assess the attention demands associated with internal and external foci of attention. That is, while performing the stabilometer task, participants under different attentional focus conditions were asked to respond as fast as possible with a finger response to randomly presented stimuli. The dual-task method has often been used to assess the amount of attention required to perform a certain (primary) task (e.g., Li & Wright, 2000; McLeod, 1978, 1980; Posner & Keele, 1969; Salmoni, Sullivan, & Starkes, 1976; Temprado, Zanone, Monno, & Laurent, 1999; Wright & Kemp, 1992; Wrisberg & Shea, 1978). Performance on the secondary probe RT task is assumed to be related to the attentional demands of the primary task. That is, poorer secondary task performance is interpreted to indicate that the primary task required more attention (e.g., Abernethy, 1988). The probe technique has been criticized for various reasons (e.g., McLeod, 1978, 1980). However, this criticism mainly refers to situations in which a probe stimulus is presented during various phases of discrete movements in an attempt to determine the relative attention demands associated with these phases (e.g., response selection, execution, movement termination). Therefore, this criticism does not apply to the present case where a continuous long-duration task was used, and probe stimuli were presented several times during each trial to assess the general attentional demands of the balance task as a function of attentional focus. We argued that, if an external focus of attention promotes the utilization of more automatic motor control processes and less conscious control, one might expect performance under these conditions to require less attention and therefore to yield faster probe RTs than performance under internal focus conditions, where relatively more processing activities may be associated with conscious control.

Thus, the inclusion of the secondary probe reaction task allowed us to assess the relative automaticity of processes involved in maintaining balance on a stabilometer as a function of external and internal attentional foci. Two additional purposes of the present study were to replicate the effects on balance performance, as measured by root-mean-square error (RMSE) and mean power frequency (MPF), noted in our earlier papers. If an external relative to an internal focus of attention resulted not only in reduced RMSE and increased frequency adjustments (higher MPF), but also in reduced attention (shorter probe RT), this would provide strong evidence for the constrained action hypothesis proposed by McNevin et al. (2000;

see also Wulf et al., in press). This pattern of results would be consistent with our hypothesis that one of the benefits of an external focus of attention is that it allows the more natural, self-organizing, control processes associated with balancing to regulate behaviour unencumbered by conscious intervention.

Method

Participants

A total of 28 students (23 females and 5 males) from the University of Munich participated in this experiment. None of them had prior experience with the task, and all of them were naive as to the purpose of the experiment. They were paid DM 24 (about 12 Euro).

Apparatus and task

The primary task required participants to balance on a stabilometer. The stabilometer consists of a 65×105 -cm wooden platform, with the maximum possible deviation of the platform to either side being 30 degrees. The task was to remain in balance—that is, to keep the platform in a horizontal position—for as long as possible during each 90-s trial. Two markers (2×2 cm) were placed on the platform, 9 cm from the front edge and 23 cm from the midline of the platform. Participants were instructed to place their feet behind these markers. In addition to these markers, two other oblong markers (6×2 cm) were attached to the platform to the left and right of the sagittal axis of the platform. The movements of the platform were monitored by a potentiometer (Novotechnik P4501, 5 k Ω resistance, and 0.1% linearity) that was linked to the platform. To analyse stabilometer performance, an analogue signal from the potentiometer was recorded (50 Hz, 12-bit resolution) for the whole duration of each trial.

For the secondary task, a hand-held response button was used, which linked to a separate computer that controlled the temporal schedule of tone (auditory stimulus) presentations and recorded the participants' reaction time. The computer that produced the tone was located in front of the participant at a distance of about 150 cm. The participant's secondary task was to extinguish the stimulus as fast as possible by pressing the button that he or she held in his/her right hand.

Procedure

All participants were informed that the task was to keep the platform in the horizontal position for as long as possible during each 90-s trial. In addition, all participants were asked to put their feet on the platform such that each foot was placed behind one of the markers in the middle of the platform, with the tips of the feet touching the markers. Each trial started with the left side of the platform on the ground. Approximately 15 s before the start of a trial, the experimenter asked the participant to step on the platform and to keep the left side down until the experimenter gave the start signal. At the start signal, the participant attempted to move the platform, and data collection began as soon as the platform crossed the horizontal.

Participants were randomly assigned to one of two conditions: the internal and external focus conditions. Under internal focus conditions, participants were instructed to focus their attention on their feet and to try to keep them horizontal; participants in the external focus group were instructed to focus on the markers attached to the platform (as in Wulf et al., 1998). Rather than using markers attached to the platform directly in front of the feet, as in the Wulf et al. study, the markers used here were placed at a distance of about 22 cm from the participant's feet. As McNevin et al. (2000) have shown that the effects of internal (feet) vs. external (markers) attentional foci can be enhanced by increasing the distance of the external focus, more distant markers were used here to maximize any effects of attentional focus. It should

be pointed out, however, that participants were instructed not to look at their feet or the markers, respectively, but rather, to look straight ahead and to concentrate on the movements of the feet or markers, respectively.

During six of the seven 90-s trials in each practice and retention session, auditory stimuli were presented eight times at pseudo-random intervals. The interval between two subsequent stimuli was at least 5 s and no more than 16.75 s. The participant's task was to respond to the stimulus as fast as possible by pressing the button that he or she held in his or her right hand. All participants were instructed that the stabilometer task was the primary task and that the RT task was secondary in priority. Nevertheless, we wanted to be sure that the stabilometer task was not influenced by the concurrent performance of the probe RT task (despite instructions to regard the stabilometer task as the primary task). Therefore, in each practice and retention session, each participant performed one stabilometer trial *without* the RT task. Specifically, the first participant in each group performed the first trial without the RT task, the second participant the second trial, . . . the seventh participant the seventh trial, the eight participant the first trial, . . . and the fourteenth participant the seventh trial. Thus, each participant had six stabilometer trials with the RT task and one trial without the RT task. In addition, participants performed one set of "baseline" reaction time trials without simultaneously performing the stabilometer task at the beginning and end of each practice and retention session. These trials served as a reference from which we compared dual-task reaction time performance.

There were 2 days of practice, each consisting of seven 90-s stabilometer trials. Before each practice trial, participants were given brief reminders to focus on the feet or markers, respectively. A retention test, also consisting of seven 90-s trials, was performed on Day 3. The only difference between practice and retention sessions was that no attentional focus reminders were given in retention.

Dependent variables and data analysis

The potentiometer data were transformed into degrees out of balance. Consistent with previous studies utilizing the stabilometer, participants' proficiency in performing the task was measured by RMSE in degrees, with the 0-degree position (platform in horizontal) as the criterion. In addition, Fast Fourier Transform (FFT) analyses were conducted on the waveforms created by the movement of the platform on retention trials.¹ From this analysis MPF was computed. This analysis is capable of detecting subtle differences in frequency adjustments between groups of participants balancing on the stabilometer under different experimental conditions.

RMSE and probe RT during practice were analysed in 2 (attentional focus) $\times 2$ (days) $\times 6$ (trials) analysis of variance (ANOVA) with repeated measures on days and trials. In addition, to determine whether the secondary task influenced the performance of the primary task during practice, a 2 (attentional focus) $\times 2$ (task type: with vs. without probes) $\times 2$ (day) ANOVA was conducted. The retention RMSE, probe RT, and MPF data were analysed in one-way ANOVAs with trials being used as repetitions. To compare performances on trials with and without the RT task, the average RMSE on the trials with the RT task was compared to that on the trial without the probe task in an additional one-way ANOVA.

¹ We did not include the acquisition FFT data because participants, particularly early in practice, often "slammed" the platform onto the base, sometimes simply hitting the right side, then the left, and so on. The problem concerning this event is two-fold. First, the very rapid movement from one side to the other introduced a relatively high frequency/power component. Second, the reverberation when the participant hit the bottom relatively hard also introduced an artefact into the FFT analysis that was not characteristic of the actual performance. Later in practice and on the retention test these events did not occur—allowing us to compare performance on common ground.

Results

Sample stabilometer and power spectral analysis for a participant in the internal and external focus of attention conditions is provided in Figure 1. Probe RT performances and average stabilometer performances are presented in Figures 2 and 3, respectively.

Practice

RMSE. Both groups demonstrated a consistent improvement across the 2 days of practice, with the external group tending to have lower RMSEs than the internal group towards the end of the first day and throughout the second day (see Figure 3). An Attentional Focus \times Day \times Trial ANOVA with repeated measures on day and trial, however, failed to detect a main effect of attentional focus, $F(1, 26) = 1.43, p > .05$, or any interactions with attentional focus. Only the main effects of day, $F(1, 26) = 144.08, p < .001$, trial, $F(1, 26) = 69.46, p < .001$, and the Day \times Trial interaction, $F(1, 26) = 43.08, p < .001$, indicating relatively greater improvements on Day 1 than on Day 2, were significant.

RMSE—trials without vs. with RT task. RMSE on the trials with and without the secondary RT task were very similar for each group (Table 2). A 2 (attentional focus) \times 2 (task type: with vs. without RT task) \times 2 (day) ANOVA failed to reveal a main effect of task type, $F(1, 26) = 0.001$, or any interaction with task type.

Probe RT. The baseline RTs during practice were generally similar for both groups, as indicated by a 2 (attentional focus) \times 2 (day) \times 2 (trial) ANOVA (see Figure 2).² Neither the attentional focus main effect, $F(1, 26) = 1.98, p > .05$, nor any interaction with attentional focus were significant. There was a slight reduction in RT across days, as confirmed by significant main effects of day, $F(2, 26) = 5.45, p < .05$, and trial, $F(1, 26) = 4.44, p < .05$, as well as a Day \times Trial interaction, $F(2, 26) = 18.47, p < .001$.

TABLE 2
Average RMSEs on trials with and without the RT task

			RMSE	
			With RT task	Without RT task
Practice	Day 1	External	6.0	6.2
		Internal	6.5	6.4
	Day 2	External	4.0	4.1
		Internal	4.7	4.6
Retention	Day 3	External	3.3	3.5
		Internal	4.2	4.1

²Outliers due to technical problems with the response button were removed from the analysis. Raw probe RT data were converted to z scores. Values that equalled or exceeded a z score of ± 2 standard deviations from the mean were eliminated from the data set. The remaining data were averaged to obtain trial means, which were used in all subsequent analyses.

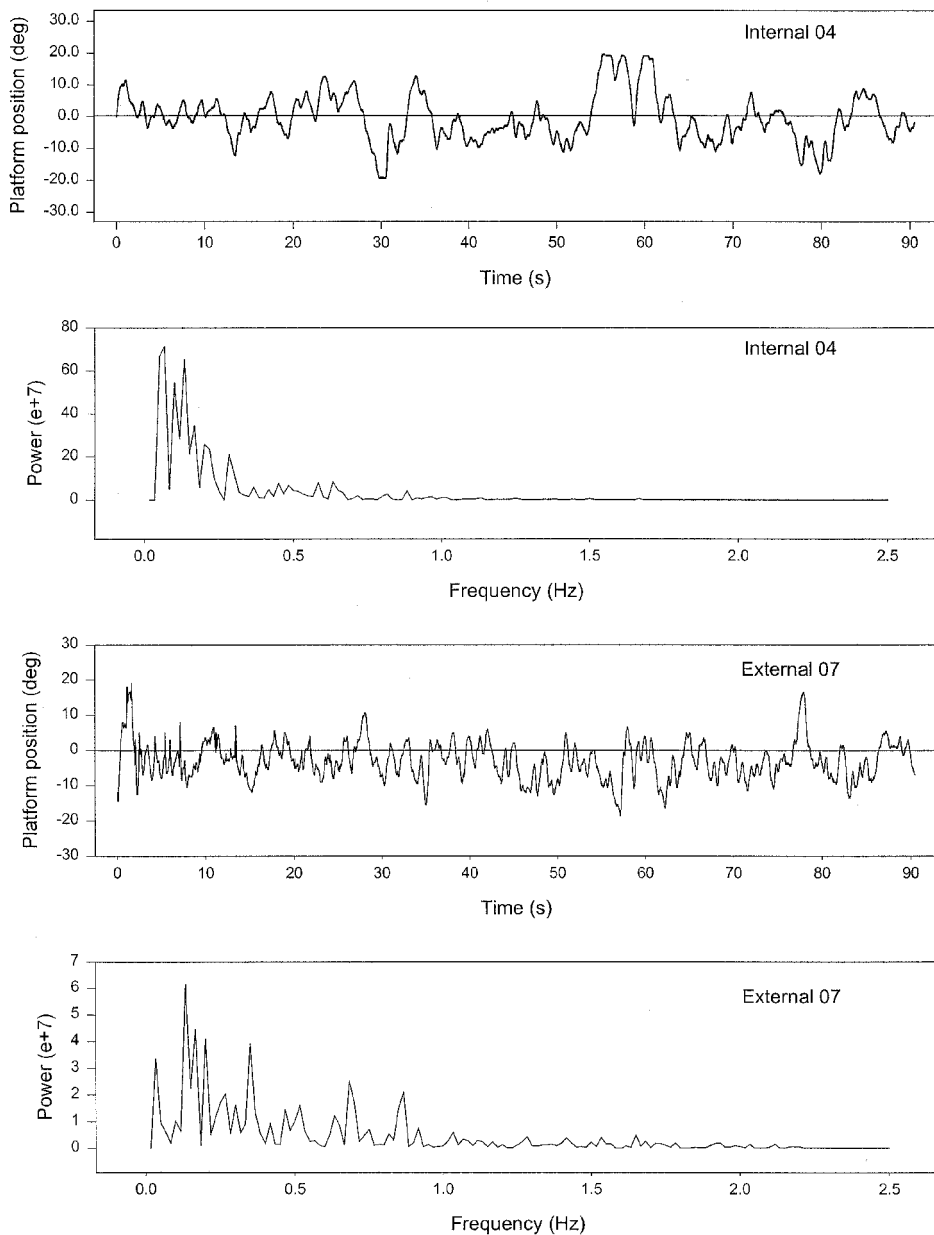


Figure 1. Example of stabilometer performance in retention for a participant in the internal (top two panels) and external (bottom two panels) condition. For each participant the top panel represents the platform displacement, and the bottom panel represents the results of the power spectral analysis.

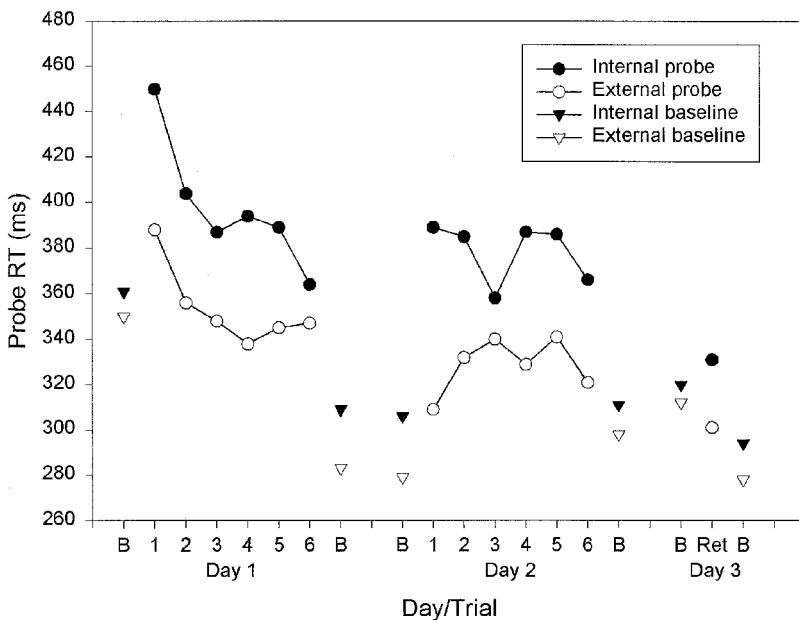


Figure 2. Baseline (B) and probe reaction times for the internal and external focus groups with auditory stimuli during practice (Days 1 and 2) and in retention (Day 3) in Experiment 1.

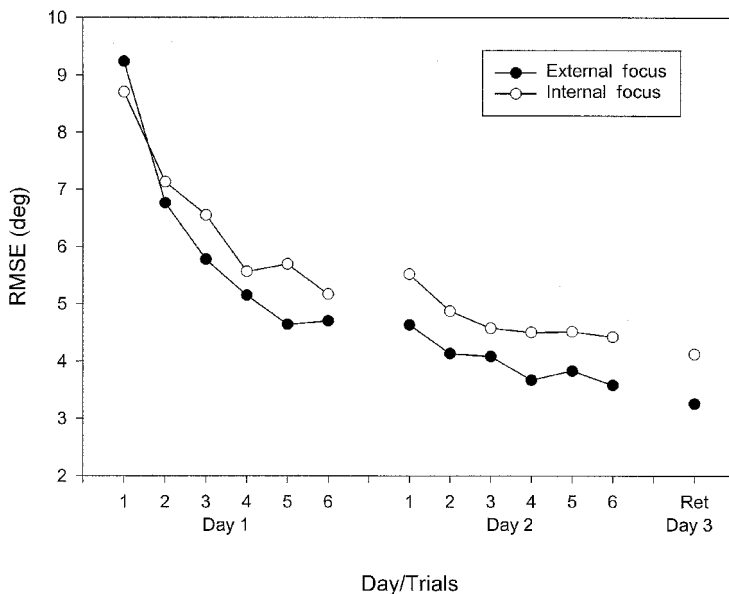


Figure 3. Stabilometer performance (RMSE) of the internal and external focus groups with auditory stimuli during practice (Days 1 and 2) and in retention (Day 3) in Experiment 1.

Probe RT generally decreased over practice, with RT for the external group being generally lower than that for the internal focus group. An Attentional Focus \times Day \times Block ANOVA with repeated measures on day and block indicated main effects for attentional focus, $F(1, 26) = 4.23, p = .05$, day, $F(1, 26) = 17.61, p < .001$, and block, $F(5, 130) = 4.00, p < .01$. The Day \times Block interaction, $F(5, 130) = 6.13, p < .001$, was also significant, indicating greater improvement on Day 1 than on Day 2. The attentional focus effect confirmed our hypothesis that attention demands would be lower for the external group ($M = 342, SE = 6.56$) than for the internal group ($M = 389, SE = 7.17$). Yet, as the baseline RT also tended to be somewhat lower for the external focus than for the internal focus group, we wanted to be sure that this effect was real. We therefore conducted an additional analysis, in which we used the “net” RTs—that is, the increase in each participant’s RTs compared to his or her baseline RTs on each day. These were analysed in a 2 (attentional focus) \times 2 (day) ANOVA with trials used as repetitions. The main effect of attentional focus was again significant, $F(1, 26) = 15.39, p < .001$, providing further support for the conclusion that the attentional demands were lower under external than under internal focus conditions. The external focus group showed, on average, clearly smaller increases in RT than did the internal focus group. In addition, the main effect of day was significant, $F(1, 26) = 4.72, p < .05$.

Retention

RMSE. A group ANOVA on RMSEs during retention testing indicated a difference between groups, $F(1, 166) = 24.23, p < .01$, with the external group ($M = 3.26, SE = 0.091$) recording smaller RMSE values than the internal group ($M = 4.12, SE = 0.129$).

RMSE—trials without vs. with RT task. The supplementary analysis of RMSE on trials with and without the RT task (see Table 2) failed to detect a difference between stabilometer performance with or without RT task, $F(1, 26) = 0.226, p > .05$. Also, there was no interaction of task type and attentional focus, $F(1, 26) = 1.99, p > .05$.

MPF. An analysis of MPFs during retention indicated that the external group ($M = 0.329, SE = 0.011$) demonstrated higher frequency responses than did the internal group ($M = 0.268, SE = 0.011$). This difference between groups was significant, $F(1, 166) = 15.40, p < .01$.

Probe RT. An ANOVA on probe RTs during retention testing also yielded a significant difference between groups, $F(1, 166) = 9.91, p < .01$. The external group ($M = 312, SE = 4.89$) had lower RTs than the internal group ($M = 341, SE = 7.70$). Again, in order to be sure that this effect could not be explained by differences in the baseline RTs, we computed an ANOVA with trials used as repetitions on the net RTs (increase compared to baseline). The effect of attentional focus was again significant, $F(1, 221) = 14.08, p < .001$, with the external focus group demonstrating a smaller increase in RT compared to baseline trials than the internal focus group.

Discussion

The purpose of this study was twofold. First, we wanted to determine the extent of the automaticity of performing the stabilometer task under external and internal attentional focus

conditions. Second, we wished to make sure that we could replicate the RMSE and MPF data from our earlier experiments where balance records indicated enhanced balance performance and increased frequency of responding under external relative to internal attentional focus. The first issue examined here followed up on the constrained action view proposed by McNevin et al. (2000). They suggested that the better balance performance associated with external focus of attention was a result of participants reducing their active intervention into control processes governing balance—allowing the more effective and natural interplay between voluntary and reflexive control processes to emerge. One of the predictions of this hypothesis was that attention demands associated with an external focus of attention would be reduced relative to those associated with an internal focus of attention, where the additional processing results in increased attention demands. The present data confirmed this prediction. Whereas probe RT was reduced over practice for all participants, RT records for the external focus group were generally lower throughout practice and retention, approaching that of the baseline RT during the retention test. This confirmed the assumption of reduced attention and is consistent with the constrained-action hypothesis.

With regard to the replication of our previous results, the RMSE results indicated that balance improved for both groups across practice, with the external focus group tending to show more effective performance than the internal attentional focus group, especially on Day 2. Although the group difference was not significant in practice, the advantage of the external focus group was clearly evident during the retention test. This replicated the results of a number of recent experiments using laboratory (McNevin et al., 2000; Shea & Wulf, 1999; Wulf et al., 1998; Wulf et al., in press), and sports-type tasks (Maddox et al., 2000; Wulf et al., 1999; Wulf, McConnel, Gärtner, & Schwarz, 2000). The benefit of an external focus on learning appears to be a stable finding.

In addition, the frequency characteristics of the balance records that had been noted previously by Wulf et al. (in press) were replicated. That is, more frequent and smaller amplitude adjustments were associated with the external focus relative to the internal focus condition. This effect also has proven to be relatively consistent and reliable. Figure 4 illustrates the data from the present experiment along with those from our other recent experiments that have determined MPF during retention. The relationship illustrated in the figure suggests that the frequency of responding increases as the attentional focus is shifted away from the body. According to the constrained-action hypothesis (McNevin et al., 2000), an internal attentional focus, or a focus directed to something *close* to the body, results in the participants subtly interfering in relatively automatic control processes. As a result of this interference, the degrees of freedom of the motor system are presumably constrained in such a way that the rate and effectiveness of the system to maintain a relatively stable posture is subtly compromised, resulting in lower frequency platform movements. Presumably, there is a delicate balance between conscious processes and automatic processes that play a role in maintaining stable posture, which can be interfered with or overridden when the participant consciously intervenes in the control process. This type of interference seems to occur to a lesser extent when the participants' attention is directed further *away* from their body and to the external effects of their actions (external focus). Figure 4 illustrates the MPF findings from the present experiment and two other recent balance experiments using slightly different attentional focus conditions. What is striking is the stability of the cross-experiment data. Consistent and significant increases in MPF are found as the focus moves farther from the body.

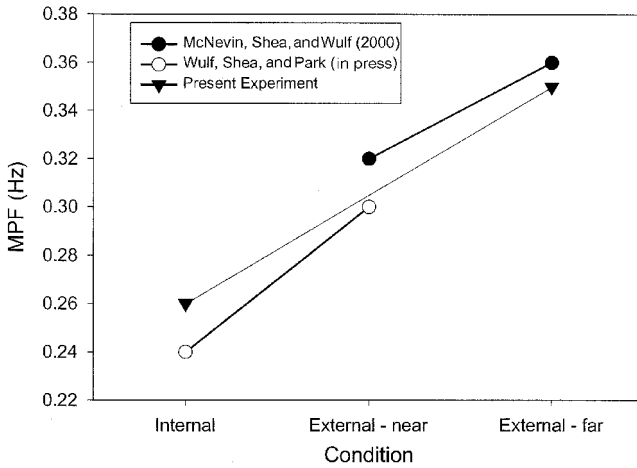


Figure 4. MPF across experiments as a function of internal and external focus of attention conditions.

Although it seems somewhat counterintuitive to find that an increased number of postural adjustments were associated with better balance performance (RMSE), it is important to note that balance on an unstable surface like the stabilometer requires continuous adjustments for the participant to give the appearance of stable balance. In many ways, this is similar to hand tremor in normal persons whereby their outstretched hand appears to be quite stable. In fact, the maintenance of hand position also requires continuous high-frequency, low-amplitude adjustments to maintain this position. However, if the perceptual-motor system is compromised by drugs, ageing, disease, or injury, some of the processes/mechanisms involved in the production and coordination of the hand position may be interfered with or degraded, resulting in a slower frequency pattern of adjustment (and higher amplitude) and a more perceptible hand tremor. Similarly, Gurfinkel, Ivanenko, Levik, and Babakova (1995) tested participants in a balance perturbation experiment. They also noted decreased rate of adjustments (and larger amplitudes) to perturbations when inputs into the vestibular system were systematically decreased by removing external references and further by occluding vision. In this regard, Newell and Slifkin (1996) have argued that increased response frequencies suggest the increased exploitation of the available perceptual-motor degrees of freedom. Our results suggest that an external focus of attention might serve to facilitate the effective utilization of the degrees of freedom, resulting in the observed learning benefits.

In summary, the present experiment provides evidence consistent with the constrained-action hypothesis from three sources. The external focus of attention condition resulted in increased balance performance (RMSE), increased frequency of responding (MPF), and decreased attention demands (probe RT) relative to the internal focus of attention condition. Thus, it appears that the constrained-action hypothesis provides a viable explanation for a phenomenon that has long been searching for a plausible explanation.

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