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Empirical Evidence for the Functionality Hypothesis in Motor Learning: The Effect of an Attentional Focus Is Task Dependent

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Abstract: A large body of research suggests that during learning motor skills, focusing on environmental effects of the movement (external focus) generally leads to better performance than focusing on one's own body (internal focus). The functionality hypothesis states, in contrast, that the superiority of any attentional focus is task dependent. The present study aimed to test the predictions of the latter and searched for underlying mechanisms and task characteristics for one or the other focus being more functional. In Experiment 1, we examined whether the internal focus is superior in a difficult body-oriented balance task. In Experiment 2, we added visual feedback and investigated whether this would enhance the functionality of the external focus. In both experiments, the participants stood one-legged on a balance board and had to shift their centre of pressure (COP) to predefined target points. Per instruction, they were asked to interpret their attentional focus on the COP as either internal (the sole of the foot) or external (the platform). In Experiment 1, the external focus was induced through a mental image. The internal focus group performed significantly better, thereby supporting the functionality hypothesis. In Experiment 2, the COP was dynamically visualized on a screen. The internal focus superiority vanished. We suggest that the internal focus is more functional in motor-learning situations that provide more effect information through body-internal senses than through body-external senses. In these cases, the external focus hampers learning because it is associated with additional cognitive load.

Keywords: external focus; internal focus; balance; mental image; visual feedback

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1. Introduction

A large body of research has shown that a person's focus of attention influences both the learning and the practising of motor skills. The results obtained so far suggest that focusing on environmental effects of the movement (external focus) leads to better performance than focusing on the own body and its movements (internal focus; for a review, see [1]). Wulf argues with a broad body of empirical evidence that the external focus leads to better performance than the internal focus, regardless of the movement task, level of expertise, and population. This assumption is hereafter referred to as the *generality hypothesis*.

Rather than assuming a general superiority of the external over the internal focus, some authors suggest that the superiority of a focus depends on the type of the movement task and the level of expertise [2–4]. Künzell, for example, found that coaches do not generally distinguish between an internal and an external focus. Instead, they direct the learner's attention to key points of the movement. In many movement tasks, the key points are external, e.g., when hitting, throwing, or kicking a ball. Still, movement tasks exist where the key points are internal, particularly when the movement goal concerns the own body and when motor learning is involved. This assumption of a different functional importance of an internal or external focus is hereafter referred to as the *functionality hypothesis*.

In the present study, we used a balance task to experimentally argue in favour of the functionality hypothesis. Besides being part of everyday life, balance tasks are used in sports and rehabilitation training and have already been studied extensively in regard to the attentional focus. In one of the first experiments [5], novices had to stand on a platform of a ski-simulator and move it rhythmically to the right and left as far as possible. The attentional focus was induced by instructions. The internal focus group was instructed to focus on exerting force on their feet, and the external focus group was instructed to focus on exerting force on the wheels of the ski simulator. Both in practice and in retention without instructions the external focus group performed significantly better. Since this first study, participants practised their balance on a stabilometer [6–11], a movable platform [12–15], or a pedalo [16,17]. The superiority of the external focus was repeatedly demonstrated. On first glance, this overwhelming evidence seems to argue against the functionality hypothesis, because internal key points are of critical importance in balancing tasks. However, a more sophisticated view shows that things are not so simple.

In the following, we first limit the objective of the research to situations in which motor learning takes place. Secondly, we elaborate on the theoretical framework of the two concurring hypotheses. In this context, we specify the term of a movement effect and discuss movement goals. This leads to the design and the predictions of our two experiments.

Why did we focus our research on motor learning and exclude practising a highly automated task? The key points of a movement are defined by the movement goal, and this in turn depends, among other things, on the degree of mastery. For an inexperienced hiker, for example, who wants to balance on a tree trunk over a stream, the goal is not to fall down, and the proprioceptive feedback from his feet and his vestibular organs tells him whether he is well in balance or about to lose it. In contrast, for an artistic gymnast who takes a run-up for a somersault on the balance beam, the goal is to optimize the power of the jump, wherein the balance-keeping during the steps of the run-up is subordinate to this goal and highly automatized. According to Künzell [3], in a task of the former type, it may be functional to concentrate on sensory signals from the own body (internal focus), whereas, in the latter task, just this would destroy the learned automaticity of the run-up. The functionality and the generality hypothesis make opposite predictions only in the first case, i.e., the learning phase, where new associations are to be formed between movement control and sensory effects. For highly automated movement skills, both correspond in predicting an external superiority. Therefore, we are only interested in tasks difficult enough so that learning can take place, i.e., the performance should be able to improve during the training, and the participants should be novices. The apparent general superiority of the external focus in the above-cited balance studies might partly be due to the choice of task and/or population.

On theoretical grounds, both the generality and the functionality hypothesis refer to the ideomotor principle, which was first formulated by James [18] and may trace back even further. The ideomotor principle describes how humans translate movement goals into movements. In short, movements are carried out through neuro-muscular motor programs (proximal events), which are not consciously accessible, e.g., they cannot directly be used for guiding a goal-oriented movement. Consciously accessible are only the perceived changes that accompany a movement, which are the effects (distal events). Anticipating these effects guides the movements that achieve them. On the basis of this rationale, Prinz [19,20] formulated his common-coding theory of perception and action according to which actions and their perceived effects are coded and stored in a common format. Action–effect associations are not innate but have to be learned by experience. Once learned, the ideas, i.e., the anticipatory images, of the effects trigger actions that are expected to yield these anticipated effects, considering the current environmental circumstances. Based on this approach, several theoretical models have been formulated that specify in more detail how perception and action planning may interact (e.g., the theory of effect coding TEC, [21]) and how motor learning may take place (e.g., the two-stage-model, [22]; the anticipative learning model, [23]; and the anticipatory behavioural control (ABC) model [24,25]). In

German sport science, the ABC model has been expanded by Hossner [26] and Künzell ([27]; see also [28]) to the concept of effect-controlled motor behaviour, which accounts for more complex and situationally more variable motor tasks than usually investigated in experimental psychology (e.g., skiing and sailing). Scherer [29,30] translated this concept into didactical recommendations in which he emphasized the creation of situations and effects over the teaching of movement sequences.

Since neither the generality nor the functionality hypothesis is specifically supported or contradicted by any of these models, it is not necessary to describe or contrast them in detail here. Proponents of both hypotheses refer theoretically to the ideomotor principle and models based on it. So how do they arrive at their contradictory statements? Central to the ideomotor approach and its successor model is the concept of an effect of a movement. We argue that proponents of the generality hypothesis and the functionality hypothesis use the concept of effect in different ways.

In providing a theoretical explanation for the claimed general superiority of the external focus, Wulf [1] refers to the common-coding hypothesis, according to which distal events constitute the common coding format for perception and action. Then, she writes (p. 90): "Thus, the finding that movements were more effective when they were planned in terms of their intended effects (i.e., with an external focus), rather than in terms of the specific movement pattern (i.e., with an internal focus), is in line with the common-coding theory assumptions." Herein, she seems to equate an effect with an event external to the body, possibly misled by the term "distal." (We will explain below why we speak of misled here.) Her constraint-action hypothesis, with which she and her co-workers [10,11] explain the benefits of the external focus and the harms of the internal focus more specifically, bolsters this impression: "According to this view, an internal focus induces a conscious type of control, causing individuals to constrain their motor system by interfering with automatic control processes. In contrast, an external focus promotes a more automatic mode of control by utilizing unconscious, fast, and reflexive control processes" ([1] p. 91).

In contrast, Hossner [26], Künzell [27], and Scherer [29,30] consider effects of movements on all sensory modalities. Accordingly, they propose that it is most functional to focus on the effect that carries the most information related to the learner's needs. Sensory physiology has long distinguished between far and near senses. Movements usually have effects on both. For example, if you hit a tennis ball, both the visual sensation of racket and ball trajectories and the proprioceptive sensation in the hand and arm are effects. In referring to Hoffmann's ABC model, Scherer points out that "for this anticipation mechanism it makes no difference whether effects refer to changes in the environment or to body-related effects, e.g., increased tension in a certain muscle. In both cases, the effects are resultant effects of motor efferences" ([30] p. 3, translation by the authors).

In the present study, we favoured the functionality hypothesis. Theoretically, we based our view on the ideomotor principle, the TEC, and the concept of effect-controlled motor behaviour, as superficially viewed—both the opposing positions do. However, we argue that Wulf and other proponents of the generality hypothesis have misinterpreted these theories in terms of the concept of effect. In a recent summary and advancement of the TEC, Hommel [31] mentions two types of effects: "The ideomotor principle [. . .] claims that carrying out movements is accompanied by a learning process that integrates the motor patterns driving the movement with the sensory information that the movement generates, such as the proprioceptive experience of moving and the visual changes of hand position, or the kinesthetic and auditory effects of touching a piano key. Note that part of the integrated re-afferent information refers to the movement itself, i.e., the bodily experience, while another part refers to the way the movement changes the environment" ([31] p. 2140). On first glance, the two types of re-afferent information might correspond to the dichotomy of distal and proximal codes introduced by Prinz [32], who referred to Heider [33] in stating that the common code of action and perception can only be the language of distal events, because proximal events are the neuronal efferences and afferences, which are not consciously accessible. However, this implies that all perceptions refer to distal events, regardless of the sensory modality through which they are transmitted (visual, auditory, proprioceptive, kinaesthetic, etc.). Consequently, the perceptible movement of the body is a distal event itself. If Wulf equated an internal focus with a proximal event in Prinz' terminology, she would have instructed her participants to focus on neuronal, i.e., unconscious events. This is not possible. If not, she should have defined her concept of effect differently. Therefore, we think that her argument contains a logical flaw.

In the remainder of the article, movement effects on the own body, usually transmitted through the near, mostly proprioceptive and vestibular senses, are termed *internal sensory effects*. Movement effects on the environment, usually transmitted through the far senses, mostly visual, are termed *external sensory effects*.

The different concept of an effect of the generality and the functionality proponents is also obvious in how they formulate their focus instructions. Whereas Wulf and co-workers usually instruct the external focus with "focus on what you see" and the internal with "focus on what you do" (e.g., "the swing of the club" versus "the swing of your arms" [34]), the internal focus must correctly be instructed with "focus on what you feel" (e.g., "the pressure of the ski boot on the shinbone" [29]). Since it is clear that a movement cannot be focussed per se, what does a participant do if so instructed? If the internal focus instruction is more ambiguous than the external one, more variance in the data is to be expected, which statistically leads to a smaller learning effect in the internal focus group. The apparent general superiority of the external focus in the balance studies quoted in the beginning might partly be due to this artefact.

In the present study, we wanted to empirically test the predictions of the functionality hypothesis. In logical terms, it is easy to falsify the generality hypothesis: find one example in which it is wrong. Empirically, however, which task is a suitable candidate? As Künzell [3] pointed out, the concept of a functional focus is not orthogonal to the concept of an external focus. Scherer ([30] p. 3) convincingly argued why in many circumstances the external focus is also the functional one: body-internal perceptions are usually less differentiated than perceptions of the environment so that the latter are usually more effective in guiding movements. This explains the superiority of the external focus in all movement skills that have a perceptible effect on the environment. For example, in the balance studies mentioned at the beginning, the environmental effects are the movement of the stabilometer, the movable platform, or the pedalo. The state of these devices is more informative for achieving the goal than the state of the body.

Only if an environmental feedback is absent or weak, the learner must rely on his somatosensory perception. This is the case if, in terms of Göhner [35], the goal of the movement is process-related, and if the movendum (the term was coined by Göhner, it is a Latin gerundive and means "the thing to be moved") is the own body and not an environmental object. We call this type of task body-oriented (strictly speaking, however, environment- and body-oriented movement tasks are not dichotomous concepts, but endpoints of a continuum. Skiing, windsurfing, or riding, for example, can be regarded as lying on the continuum. On the basis of the sensory modality, their effects are perceived with the skis, the board, or the horse ,which are characterized as "fused with the body" by Tholey [36]).

According to the above considerations, as a candidate for falsifying the generality hypothesis we chose a task (1) that was difficult enough to induce some learning, (2) where the movendum was the own body, and (3) that had a process-related goal that could be better assessed through proprioceptive than through visual information. Experiment 1 was conceptualized accordingly. Novices had to stand one-legged on a balance board and had to shift their centre of pressure (COP) to a pre-defined target point in front of or behind the natural point of gravity for a certain amount of time without falling down. The target was visualized as a green dot on a screen. The COP was introduced differently for the internal and external focus groups. The internal focus group was instructed to focus on the perceived pressure on the sole of the foot. The external focus group was instructed to focus on the exerted deformation on the platform. Both interpretations correspond to the COP, but the internal interpretation includes an actual perception, while the external interpretation includes a mental image, as the deformation of the platform could not be perceived. In a body-oriented task like this, an external focus could only be achieved through a mental image of an external event. Wulf and colleagues specifically emphasized that an external focus can be applied to tasks that have no obvious environmental effect. In these cases, they suggest to "use metaphors, which might have a similar function as an attentional focus directed to the movement effect, in that they might distract the performer's attention from his or her body movements and provide a mental image of the movement goal" ([37] p. 237; [38,39]). We hypothesized that, in Experiment 1, the external focus would be less functional than the internal focus because it imposed an extra workload through building up a mental image of an external event. With Experiment 2, we tried to gain more insight in the concept of functionality and therefore added an environmental effect through visual feedback.

2. Experiment 1

Experiment 1 examined a body-oriented balance task in practice and retention. According to the functionality hypothesis, an attentional focus should be more functional than the other if the sensory effects to which it is directed are more informative in terms of task performance. A body-oriented balance task is the extreme case in which the external focus cannot be directed to any perceptual sensory effect and is therefore not associated with any information. Thus, the following experimental hypotheses were formulated:

1. During practice, the internal focus leads to a better performance than the external focus.
2. In retention, the internal focus leads to a better performance than the external focus.

2.1. Method

2.1.1. Participants

Twenty-two healthy individuals (ages 18–31 years; 10 men, 12 women) volunteered to participate. This sample size was derived from experiments that have already empirically shown focus effects (e.g., [5]). The participants were recruited from the Technische Universität Berlin. Exclusion criteria included the self-reported presence of balance or vestibular disorders, movement disorders, neurological disorders, injuries in the last six months that may affect balance, and impaired and not corrected-to-normal vision. The participants were blind to the purpose of the study. All participants signed an informed letter of consent prior to data collection. The protocol was approved by the research ethics committee of the Department of Psychology and Ergonomics at the Technische Universität Berlin.

2.1.2. Apparatus

Balance-performance data were collected using the Wii balance board (WBB), a reliable and valid tool for assessing standing balance [40]. The WBB has four force sensors at each corner and calculates the resulting force on the platform, which corresponds to the centre of pressure (COP). The COP corresponded to the point on the sole of the foot where the most pressure was perceived, because the participants only stood with one leg on the WBB. The COP was measured every 20 ms, so that approximately 500 COPs were recorded in a 10 s trial. For all COPs, the Euclidean distance to the target point was calculated and stored. The mean was then calculated for each trial.

2.1.3. Procedure

The participants had to shift their balance to predefined target points while standing one-legged on the WBB and keeping their balance for 10 s. The position of the target points was based on the COP that is generated when standing upright (this was not measured by WBB but determined based on the participants' foot size). The front target point was located 20% of the participant's foot size in front of this COP and the back target point 20% behind this COP. A screen provided visual information and feedback (see Figure 1). The visual information consisted of a virtual platform and a foot template representing the

WBB and the footprint of the participant (see Figure 2). The prerequisite for accomplishing the task was not to fall down. Otherwise, the trial was saved as non-valid and had to be repeated.

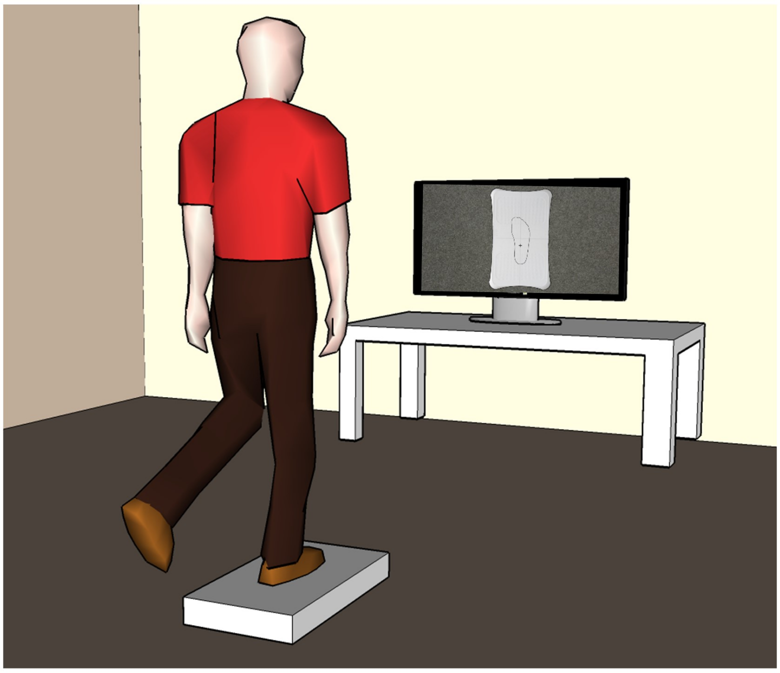

Figure 1. Illustration of the experimental setup.

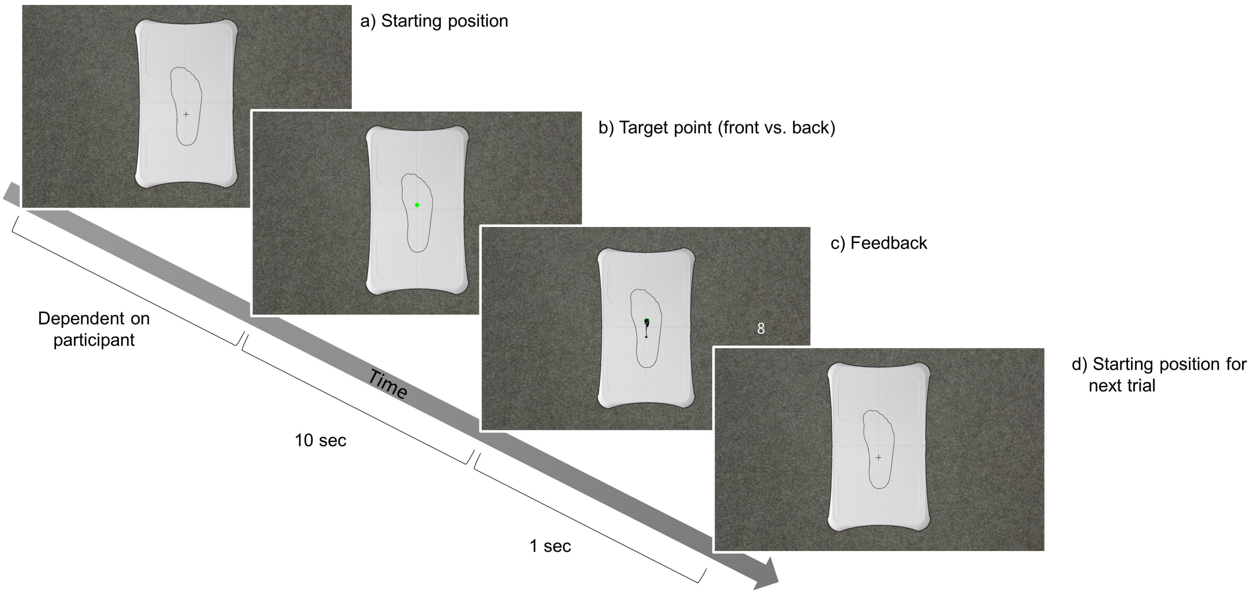

Figure 2. Schematic illustration of the displays and the timing of events during practice.

A trial was structured as follows. While the participants were standing on one leg, a cross on the screen signalled them to take up the starting position (see Figure 2a), so as to distribute their weight as evenly as possible. When they reached this starting position, a green target point appeared either to the front or back on the foot template (see Figure 2b). The task was to balance their weight towards the target point and keep it there for 10 s. After the 10 s, a terminal visual feedback appeared as a digit providing the average distance in mm from the target point and as a path showing all COPs recorded over the trial (see Figure 2c). After the feedback, the next trial started (see Figure 2d).

There were three sessions over three consecutive days. The first two sessions served as practice sessions and the last one as a retention session. The participants received no terminal feedback, focus instructions, or reminders in the retention session. Each session consisted of 10 blocks with four trials each. Two front and two back targets were displayed per block in random order. In order to prevent fatigue, breaks of 40 s were taken between blocks, and the leg was changed at each block. Before the first session, the participants tried out the task in a block of four trials. This practice block served to familiarise the participants with the task. It was not taken as a baseline because the participants were already applying the attentional focus. The task cannot be performed independently of an attentional focus.

Since the object of investigation was the influence of the attentional focus on learning a new task, the attentional focus was not varied within subjects but between subjects. Participants were randomly assigned to the external or internal focus group. The respective attentional foci were induced via explicit instructions. Participants in the internal focus group were instructed that they would see a target point on the sole of their foot. They were asked to shift their balance to this target point until they felt the maximum pressure at this point on the sole of the foot. Participants in the external focus group were instructed that they would see a target point on the platform. They were asked to shift their balance to this target point until they exerted maximum deformation on the platform at this point. The external focus instruction corresponded to Wulf's guidelines to evoke a mental image of the intended environmental effect (here the deformation of the platform) when none is perceptible [37–39]. The focus groups were balanced by sex and balance expertise.

For a manipulation check of the focus instruction, an interview was administered after the last session. The participants of both groups were asked to rate the extent to which they actually focused on the deformation of the platform as well as on the pressure at the foot during the three days on a 10-point scale ranging from 1 (never) to 10 (in every trial). Afterwards, participants were informed about the two focus instructions and were asked the following question: "What do you think from your experience with the task, which one is easier or more difficult and why?" The open answers were assigned to categories, the frequency of which was analysed. After completion of the experiment, the participants were fully debriefed.

2.1.4. Design and Data Analysis

All analyses were carried out using R (version 4.0.3; [41]). The calculation of the performance data for each participant was made in two consecutive steps: (1) Calculating mean values for each of the 120 trials and (2) calculating median values for each of the six experimental conditions, resulting from the two factors target (front vs. back, within) and session (1 vs. 2 vs. 3, within). Both steps are explained in more detail in the following.

A mean value of the Euclidian distance between COP and the target point was calculated for each trial, i.e., we computed 120 mean values for each participant. The first two seconds of a trial were not included in the calculation of the mean value, because, in that time, the participants moved from the starting point to the target point and the recorded distances did not reflect the ability to keep the COP as stable and as close as possible to the target point.

Each participant completed 20 trials for every combination of the conditions session (session 1, session 2, and session 3) and target point (front and back). The performance in every experimental condition was assessed by the individual median distance of COP from the target point across the 20 trials of each condition, resulting in six median values for each participant. (We preferred the median to the mean because the median, unlike the mean, is robust against outliers. There could easily be an outlier if the participant lost his balance for a few seconds.) These served as random variables in our statistical model—see Appendix A.

To test our two hypotheses (superior performance of the internal over the external focus group in task practice and retention), we summed the variable values corresponding to the respective hypothesis for each person, and we compared the expected values of the "summed performance" between the two groups with directional t-tests. For example, to test for group differences during practice, each person's performance was summed across the 2 (sessions) $\times$ 2 (targets) = 4 practice conditions. Formal details are provided in Appendix A. This approach may sound complicated, but it offers two statistical advantages over testing main effects or simple main effects in the 3 $\times$ 2 $\times$ 2 factorial design with two within-subject factors (session, target) and one between-subject factor (group). First, a directional t-test usually entails larger statistical power than a corresponding undirected F-test. Secondly, by summing random variables within each person we avoided dealing with their variances and covariances, in particular with the well-known problem of sphericity in repeated measures ANOVA. Instead, in each hypothesis test, only the variance of the respective sum variable was statistically relevant. The assumption of variance homogeneity in the t-test could be ignored due to equal sample sizes in the two groups [42].

However, prior to hypothesis testing, we conducted two manipulation checks. In the first, we tested whether the task was difficult enough to induce motor learning by comparing the performance between session 1 and session 2 across groups. Unlike the above hypothesis test, where performance was summed across sessions to compare between groups, now performance had to be summed across groups to compare between sessions (see Table A1). For this purpose, a simple linear model (LM; [43] ch. 6, ch. 8) was set up whose intercept corresponded to the increase in performance from session 1 to session 2 summed across groups. Details are given in Appendix A. Statistically, the intercept was assessed with a directional t-test on the LM intercept.

The second manipulation check concerned compliance with the focus instruction. In the interview after each session, the participants indicated on a 10-point scale how often they focused externally and internally. Difference scores were obtained by subtracting the external focus value from the internal focus value. The focus manipulation would be successful if participants of the external focus group had higher difference scores compared to the participants of the internal focus group in every session. Thus, for each session, a one-tailed two-samples t-test was carried out with Bonferroni correction for the three tests. The data for both experiments can be found in a data repository under the link https://doi.org/10.14279/depositonce-10617.

2.2. Results

2.2.1. Manipulation Check

Two manipulation checks were conducted. First, it was tested whether the task was difficult enough to show a learning effect. The performance difference between session 1 and session 2 was tested within the LM described above by a one-tailed t-test. This difference was significantly greater than zero, $t(20) = 3.31, p = 0.002$.

Secondly, the participants indicated for each day how often they focused externally and internally on a 10-point scale (see Figure 3). Positive difference scores "external – internal" indicate a stronger bias towards an external than an internal focus, and negative difference scores indicate a stronger bias towards an internal than an external focus. The Bonferroni-corrected one-tailed t-tests revealed significant differences in the expected direction between the external and internal focus group for all three days (session 1: $t(20) = 3.74, p = 0.002$; session 2: $t(20) = 6.52, p < 0.001$; session 3: $t(20) = 7.12, p < 0.001$).

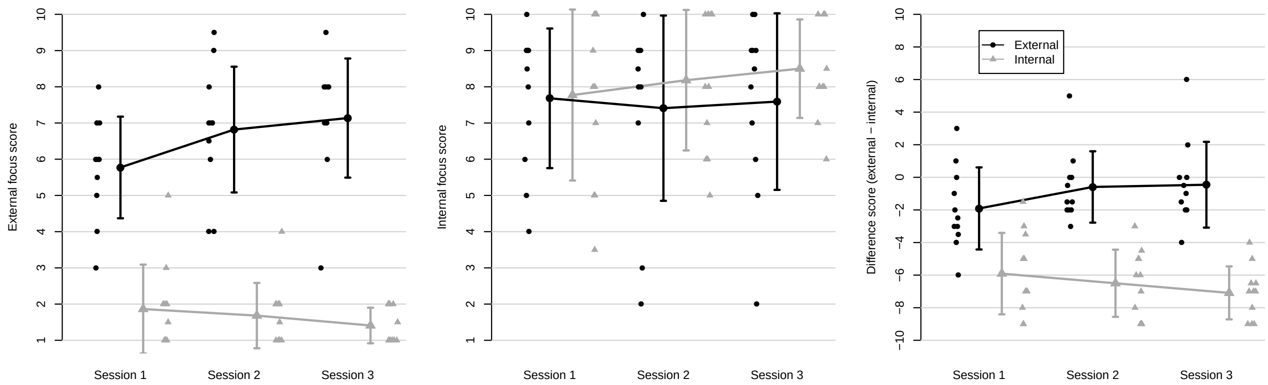

Figure 3. Manipulation check: External and internal focus score (high numbers indicate high degree of focus) and the difference score (external–internal) as a function of attentional focus group (internal vs. external). Points represent individual values; the connected points represent means; and error bars represent standard deviations.

2.2.2. Hypotheses Test on Performance

Figure 4 shows the balance performance for practice and retention. The external focus group performed significantly worse than the internal focus group during practice, $t(20) = 2.3, p = 0.02, \hat{d_p} = 0.49$ (for the definition of the effect size d_p, see Appendix A. Please note that Cohen's d conventions do not apply here). In retention, the external focus group also performed worse than the internal focus group, but the difference just missed the significance level, $t(20) = 1.7, p = 0.052, \hat{d_p} = 0.36$.

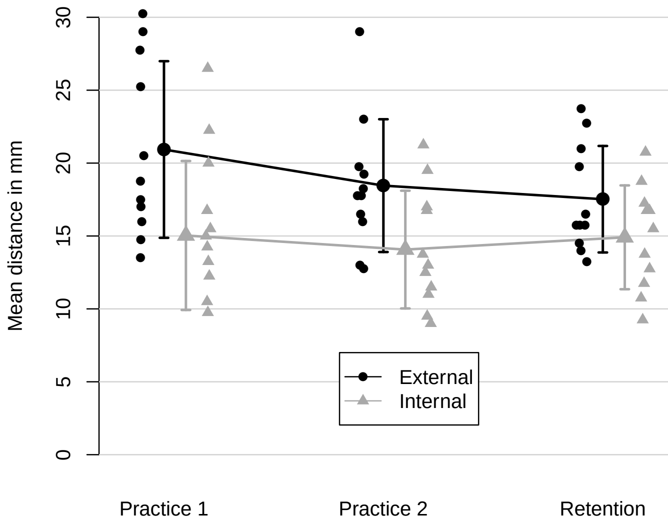

Figure 4. Performance: Mean distance in mm as a function of attentional focus (internal vs. external) and the three sessions. The connected points represent means, and error bars represent standard deviations.

In order to ensure that the results are not an artefact of a risky behaviour of the internal focus group, i.e., that participants provoked a fall to achieve better performance, in an additional analysis, the number of invalid trials was included as a covariate in the statistical model and thus statistically controlled—see Figure 5. At a constant number of invalid trials, the difference between the focus groups remained significant during practice, $t(19) = 2.76, p = 0.006, \hat{d_p} = 0.62$. During retention, the performance of the internal focus group was significantly better than that of the external focus group when the number of invalid trials was kept statistically constant, $t(19) = 2.04, p = 0.03, \hat{d_p} = 45$, due to the increased power of the test.

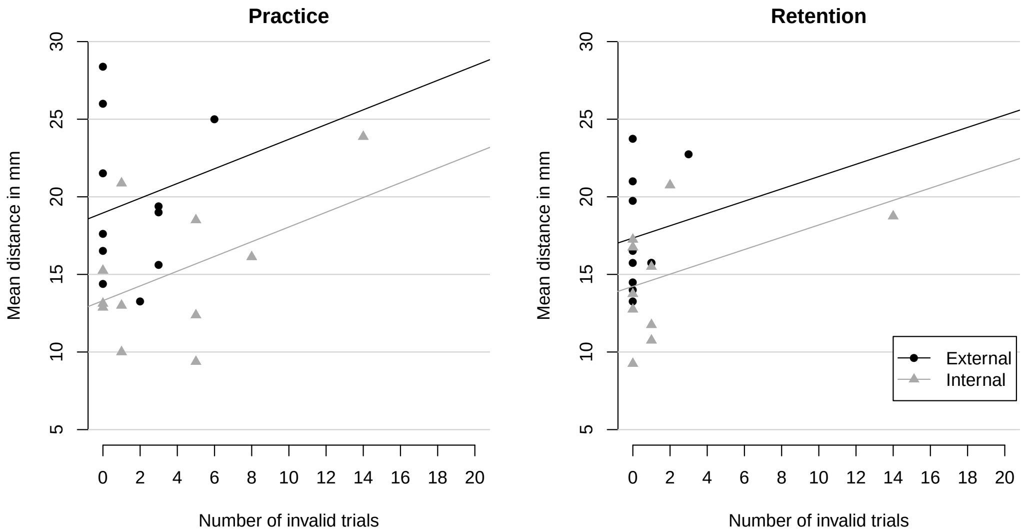

Figure 5. Number of invalid trials as covariate: Mean distance in mm as a function of attentional focus (internal vs. external) and number of invalid trials for practice and retention. Points represent individual values, and lines represent the regression lines.

2.2.3. Interview Data

Most of the participants (12; 8 for the internal and 4 for the external focus group) preferred the internal focus; eight participants (2 internal and 6 external) preferred the external focus; and two participants (1 internal and 1 external) answered that it depends (e.g., on experience). The most frequent explanation for the preferred internal focus (9; 5 internal and 4 external) was that it is cognitively less demanding than the external focus for this balance task.

2.3. Discussion

The present experiment examined the effect of the attentional focus on learning a body-oriented balance task. The findings offer support for the superiority of the internal focus. The internal focus group demonstrated a significantly better performance during practice. During retention, the internal focus group showed a significantly better performance when the number of invalid trials was statistically controlled. Figure 5 indicates that a high number of invalid trials was not associated with better performance. In Figure 5, please notice that including the number of invalid trials increased the effect size mainly because it controlled for the two outliers in practice and retention. If these were removed from the analyses and the two *t*-tests from Figure 4 were carried out again, both tests would also be significant ($t(19) = 2.9$, $p = 0.005$ for practice and $t(19) = 1.92$, $p = 0.04$ for retention), with similar effect sizes ($\hat{d_p} = 0.63$ for practice and $\hat{d_p} = 0.42$ for retention). Therefore, it can be excluded that participants provoked a fall to achieve better performance.

The results of the performance data contradict the generality hypothesis and confirm the functionality hypothesis. The results of the manipulation check and the interview provide a post hoc explanation for the superiority of the internal focus. For the external focus group, the difference scores were around zero (see Figure 3), which means that the external focus group has focused both the platform and the sole of the foot in equal proportions. It seems as if participants of the external focus group tried both to use the tactile perception as feedback and to derive a mental image of the deforming platform from this feedback. Participants of the internal focus group had to focus only on the tactile perception. The additional cognitive load for the external focus group could be the cause of their poorer performance.

The absence of a performance-related environmental effect of the movement seems to lead to a better functionality and thus superiority of the internal focus. This suggests that this superiority would disappear if a performance-related environmental effect is added to the same movement task. We investigated this hypothesis in Experiment 2.

3. Experiment 2

Experiment 2 differed from Experiment 1 only in that participants received additional visual feedback during practice. This feedback should be interpreted either externally (exerted pressure) or internally (felt pressure). We expected that the visual feedback would make the balance task more environment-oriented. According to the assumptions of the functionality hypothesis, the external focus would now be superior. The external interpretation offers the possibility to use visual feedback as the main sensory effect for motor learning, which is an environmental effect. The internal interpretation presents both the visual feedback and the felt pressure as sensory effects. As outlined in the introduction, we assumed that the (environmental) visual feedback is more informative than the (body-internal) felt pressure due to the better resolution of the external senses. In addition, it was investigated whether the superiority persists even if the feedback is removed during retention. The following two experimental hypotheses were tested:

1. During practice, the external focus leads to a better performance than the internal focus.
2. In retention, the external focus leads to a better performance than the internal focus.

3.1. Method

3.1.1. Participants

Twenty-two healthy individuals (ages 21–34 years; 11 men, 11 women) participated. They were recruited from the Technische Universität Berlin. Exclusion criteria were identical to those in Experiment 1. The participants were blind to the purpose of the study. All participants completed an informed consent prior to the experiment.

3.1.2. Apparatus, Procedure, Design, and Analysis

The apparatus and the procedure were similar to those used in Experiment 1, with a few exceptions. The COP was visualized via a grey point during the execution of the balance task. The COP was only visualized during practice in session 1 and session 2 but not during retention in session 3. The participants received additional instructions about the visualized COP. The internal focus group received the following instructions: “During each trial, you will be shown a grey point where you feel the pressure point at its maximum. Try to shift your balance so that the pressure point is as close as possible to the target point.” The external focus group received the following instructions: “During each trial, you will be shown a grey point where you deform the platform to the maximum. Try to shift your balance so that the deformation point is as close as possible to the target point”. Design and analysis were identical to Experiment 1.

3.2. Results

3.2.1. Manipulation Check

It was tested whether the task was difficult enough to show a learning effect. Within the LM, the difference in performance between session 1 and session 2 averaged over all participants was significant, $t(20) = 6.108, p < 0.001$.

As in Experiment 1, the participants indicated for each day how often they focused externally and internally (see Figure 6). For each session, the difference score was tested using a one-tailed independent samples *t*-test with Bonferroni correction over the three sessions. The *t*-tests showed significant differences between the external and internal focus group for days 2 and 3 but not for day 1 (session 1: $t(20) = 1.92, p = 0.10$; session 2: $t(20) = 4.62, p < 0.001$; session 3: $t(20) = 7.71, p < 0.001$). The difference between the focus groups increased over the three sessions, which becomes apparent when looking at the test statistics and Figure 6.

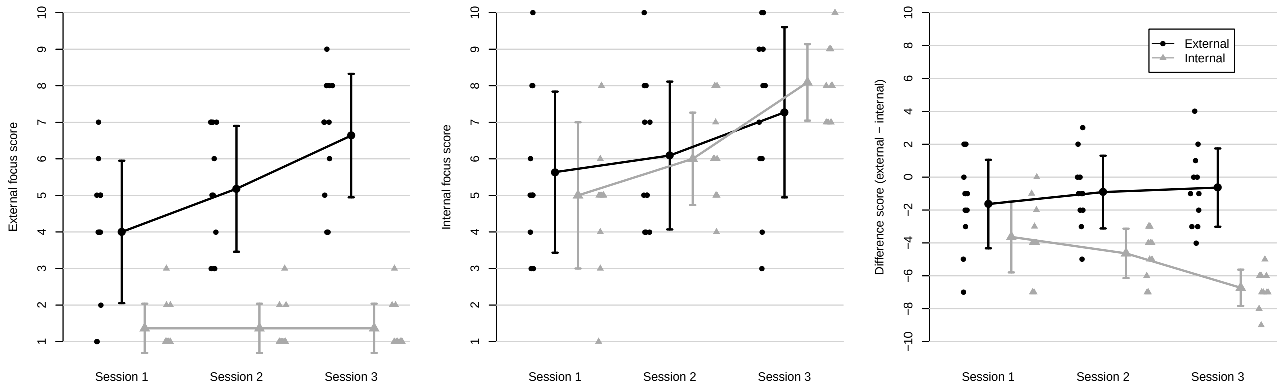

Figure 6. Manipulation check: External and internal focus score (high numbers indicate high degree of focus) and the difference score (external–internal) as a function of attentional focus group (internal vs. external). Points represent individual values; the connected points represent means; and error bars represent standard deviations.

3.2.2. Hypotheses Tests on Performance

Figure 7 shows the balance performance for practice and retention. There was no significant difference between the focus groups either during practice, $t(20) = -0.13, p = 0.45$, or during retention, $t(20) = 0.36, p = 0.64$. Since no significant difference was found in the manipulation control for the first session, this session was excluded as an explorative analysis of balance performance during practice. Still, no significant group differences were found for balance performance in session 2 either, $t(20) = -0.79, p = 0.22$. (However, our sample size would most probably only reveal large effects. A post-hoc power analysis let us infer that only effects larger than $d_p = 0.55$ would be detected with $1 - \beta = 0.80$.)

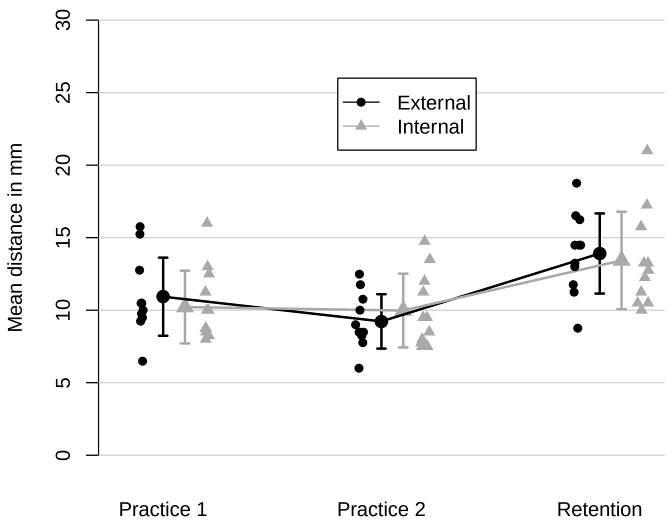

Figure 7. Performance: Mean distance in mm as a function of attentional focus (internal vs. external) and the three sessions. The connected points represent means, and error bars represent standard deviations.

3.2.3. Interview data

Most of the participants (15; 9 internal and 6 external) preferred the internal interpretation of the visual feedback; four participants (1 internal and 3 external) preferred the external interpretation; one participant (external) answered that it depends on experience; and two participants answered that there is no difference. The most frequent explanation for the preferred internal interpretation (13; 8 internal and 5 external) was the same as in Experiment 1, namely, that it is easier to perceive and therefore cognitively less demanding than the external interpretation.

4. Discussion

The purpose of Experiment 2 was to investigate the effect of the attentional focus on performance during the learning of a balance task with visual feedback. The balance task was the same as in Experiment 1, with the only difference that an additional grey point indicated the actual COP during practice. We predicted that adding visual feedback to a body-oriented movement task would reverse it into an environment-oriented movement task. Since visual-perception signals' effects are more differentiated than proprioceptive perception [30], we expected the external focus would be more functional in this case and that the external focus group would perform better than the internal focus group. Contrary to our predictions, there were no significant differences in balance performance across focus groups, neither during practice nor during retention.

Interestingly, the participants generally performed better in Experiment 2 than in Experiment 1. Therefore, it might be argued that the visual feedback made the movement task too easy so that no attentional focus effect could show up. This can be empirically rejected, because the participants showed significant performance improvements from session 1 to session 2. Given that the present task was quite difficult, what is the explanation for the lack of a focus effect?

Possibly, the visual feedback did not result in the entire movement task becoming more environment-oriented, but rather in the emergence of a second (virtual) connected movement task with its own movendum and movement goal. Using the balance shift, a grey point now had to be brought into correspondence with a green point. The real movement task remained body-oriented. The virtual movement task was environment-oriented, because here the movendum (grey point) was not the own body, and the movement goal (correspondence with green point) could be assessed using external sensory effects. In the real movement task, the internal focus possibly remained superior. The interview data provide some evidence for this: the participants preferred the internal interpretation and reported the same explanations as in Experiment 1. For the virtual movement task, unfortunately, no questions were asked on how strongly the participants focused on the grey point. We can only make conjectures about the interaction between the focus in regard to the real movement task and the focus in regard to the virtual movement task. There are several possibilities. First, the external focus group actually might have made greater use of the virtual feedback, but this advantage might have been eliminated by the cognitive load of the mental image from the real movement task. Secondly, both focus groups might have focused strongly on the virtual feedback, so that possible group differences in relation to the real movement task might have become negligible. An indication for the second explanation gives the manipulation check. The absolute values of how much focus was put on the pressure at the feet and the pressure onto the platform were lower in comparison to Experiment 1 during practice. Only when the feedback in retention was no longer displayed, values became similar (see Figures 3 and 6).

Shea and Wulf [8] investigated the contribution of visual feedback and attentional focus on learning and used an environment-oriented movement task, namely, maintaining balance on a stabilometer. Two focus groups performed the task without feedback and focused either internally or externally. The other two focus groups received the same focus instructions but were also given feedback about their deviations from the horizontal on a computer screen and were informed that the feedback represented either their feet or the markers on the platform. During retention, the main effect of the focus was significant, but not the interaction focus x feedback. Regardless of whether the focus groups received feedback during practice, the external focus group showed better performance in retention. Shea and Wulf's study differs from the present study in two respects. First, in their approach, the movement task was environment-oriented both in reality (movendum = platform) and on the screen (movendum = visual feedback). The environment-oriented movement task on the screen may have attracted less attention because it more closely mirrored the environment-oriented movement task in reality. Second, Shea and Wulf report that there was no performance decrement when feedback was withdrawn. The degrading effects of feedback are partly explained by the fact that feedback attracts attention and may overshadow the remaining task-intrinsic information. In contrast to Shea and Wulf's study, participants in the present study performed worse when feedback was withdrawn (see Figure 7), indicating a greater focus on feedback.

More attention on additional virtual feedback may result in focus effects not occurring. This could explain the results of De Bruin et al. [44]. In this study, older people trained their balance on a stable and an unstable platform for five weeks. They were given visual feedback in the form of a moving point and were explicitly instructed to pay attention to this feedback. The external focus group was instructed that the feedback represented an air bubble in a level, which was placed on the platform. The internal focus group was instructed that the feedback represented their body's centre of gravity. Both focus groups showed learning effects but did not differ significantly from each other. The authors explained the result by the older age of the participants. However, given the result of the present study, it is also conceivable that possible focus-group differences may have been lost due to the strong cognitive load in processing the additional virtual feedback.

In another study, Maxwell and Masters [45] had students train their balance on a wobble board. In Experiment 1, subjects received additional visual feedback that they were instructed to interpret either externally or internally. There were no significant focus-group differences, and the authors argued: "Concurrent feedback received during the Learning Phase may have led all participants to adopt an external focus regardless of the instructions they received" ([45], p. 80). They conducted another experiment without feedback (Experiment 2) but found no focus-group differences here either, so the focus on additional feedback cannot be the only explanation for the lack of group differences here.

5. General Discussion

5.1. Summary of Results

The present study adds two important findings to the current state of knowledge. First, the results from Experiment 1 have shown that the internal focus can be superior. This contradicts the generality hypothesis put forward by Wulf [1]. The superiority of the internal focus in a body-oriented movement task was predicted by the functionality hypothesis, because in such tasks both the movement goal and the movendum can be assessed more accurately through internal sensory effects. In order to induce the external focus, imagined external sensory effects are required. Experiment 1 suggests that the external focus induced by mental images leads to cognitive load and thus to a performance decrement. The cognitive load results from constantly updating the mental image depending on the movement. Secondly, in Experiment 2, we added visual feedback to the practice of a body-oriented movement task. Such kinds of tasks are not unusual in the context of rehabilitation [46,47]. Here, it probably does not make any remarkable difference whether you interpret the visual feedback externally or internally.

5.2. Falsification of the Generality Hypothesis and Outlook

The results of the present study indicate that the superiority of the external focus cannot be generalized to all movement tasks. Wulf and colleagues have theoretically substantiated the superiority of the external focus with the common-coding hypothesis and later with the constrained-action hypothesis [5,7].

As outlined in the introduction, neither the common-coding hypothesis nor the constrained-action hypothesis provide a satisfactory theoretical explanation for the external focus being generally superior to the internal focus in learning a new movement task. We argue against the generality assumption and propose the functionality hypothesis to explain the focus effects. It states that the superiority of any attentional focus depends on the task. More exactly, it states that the superiority of any focus depends on the sensory effects that give information about the movement goal and the movendum.

Future research could further differentiate what functionality of sensory effects may include. It may not only depend on sensory information but could also be related to the necessary variability of sensory effects during movement execution. In his classical work, Bernstein had found that when experienced blacksmiths hammered a chisel several times, the movement of the hammer head was relatively constant and resulted in a precise hit on the chisel. The movement of the arm joints, on the other hand, varied between repetitions [48]. More recent work based on EMG measurements has demonstrated that variance-per-dimension is consistently smaller in the task-relevant subspace than in the task-irrelevant subspace [49]. Several authors have already pointed out that this relationship can explain the superiority of the external focus in many cases [50,51]. Russell noted that "the reduced performance during internal focus may be a function of reducing variability of the wrong movement characteristics, rather than internal focus per se" ([50] p. 47).

5.3. Mental Images and the Attentional Focus

In Experiment 1, we used a mental image to induce an external focus. For a focus on a mental image to correspond to an external focus, it must meet the same definition criteria. The following three criteria have been established in the literature to define an external focus:

1. Identical movement goals: If a movement task contains several movement goals, the two attentional foci should refer to the same movement goal and differ only in relation to this movement goal [52].
2. Environmental effect: The external focus refers to environmental effects caused by the movement and not to changes in the environment that take place before the movement [37].
3. Performance-related: The benefit of the external focus is not caused by distracting the learner from one's own movements but by focusing on performance-related environmental effects [9].

Mental images meet these definition criteria when they refer to the same movement goal, represent an (imaginary) environmental effect that is caused by the movement, and are performance-related. In our study, the three definition criteria were applied: (1) Both attentional foci referred to the same movement goal, namely, the balance shift. (2) The external focus referred to an imaginary environmental effect caused by body movement, namely, the deformation of the platform. (3) Both attentional foci referred to the perceived or imagined COP that defined performance.

Although there are attentional focus experiments regarding the use of mental images in the literature, these criteria were mostly not met. For example, in the experiment of da Silvaa et al. [53], children learned a pirouette. The movement task was to rotate as far as possible, and the performance was defined by the number of degrees rotated. The internal focus group was instructed "to focus on the initial position of their head relative to the wall in front of them, and on keeping it in that position for as long as possible". The external focus group was instructed "to focus on a spotting point on the wall in front of them, and on fixing their gaze on it for as long as possible". The external focus group demonstrated significantly better performance relative to the internal focus group during practice, retention, and transfer. However, the mental image of the point on the wall is no environmental effect, because it does not change with rotation. (For example, the following mental image would be an environmental effect: an imaginary ray attached to the head and projected onto the wall. This mental image is equivalent to the horizontal position of the head; it is caused by the head movement, and it indicates the performance of keeping the head on the initial position as long as possible.)

In another example, Koufou et al. [54] let children learn a forward roll. They received either several internal or several external focus instructions. An internal focus instruction was, e.g., "7. During the roll, keep your body tucked with knees bent". The corresponding external focus instruction was: "7. During the roll, keep your body tucked like a ball with knees bent". Here, the only difference between the external and internal focus instructions was the expression "like a ball". The children in the external focus group learned the forward role significantly better than the children in the internal focus group, but the definition criteria for an external focus were again not met: the mental image did not correspond to any environmental effect. Instead, the movement was only described more vividly.

In the experiments by da Silvaa et al. [53] and Koufou et al. [54], participants in the external focus groups performed better, although they also used mental images. As already explained, however, these mental images did not refer to environmental effects. If a mental image does not change as a function of movement, it does not need to be constantly updated and integrated into the body perception. Therefore, it requires only few mental resources. This means that mental images can be very useful, but in that case they do not correspond to the external focus.

5.4. Limitations and Outlook

In the present research, we successfully falsified the generality hypothesis and supported the functionality hypothesis with an experiment in which participants were learning a body-oriented balance task. This showed that the external focus is not always the functional one. Our results suggest that in the specific task, this was due to the external focus being associated with more cognitive load due to keeping up a mental image. However, our experiments also have limitations. First, the sample size was relatively small. It was sufficient to show an effect in Experiment 1. However, it is possible that smaller effects in Experiment 2 remained uncovered. Secondly, we cannot be certain whether participants actually focused on what was instructed. Within the manipulation control, we did ask the participants about their actual attentional focus. However, as with any form of self-report, this kind of manipulation control has its problems. For one thing, it implies that participants are capable of making this judgement. Since the attentional focus is a dynamic process, it is by no means easy to quantify the intensity for the whole session. Possible memory effects cannot be ruled out either, as the interview was conducted at the end of the experiment on the last day. In addition, self-reporting implies that participants give honest answers. Questions about the actual attentional focus can lead to socially desirable answers because they indirectly address whether the participants followed the instructions as desired. For these reasons, manipulation control by self-report must be taken with caution, but it is so far the only method we know of to gain insight into what participants actually focus on during movement execution. Another limitation relates to Experiment 2, where the participants were asked to what extent they applied the internal and external interpretation. However, it was not asked how strongly the participants focused on the virtual feedback. This information would have been useful in interpreting the results. Overall, it is open how far these results can be generalized. More research is needed in order to obtain a characterization of a functional focus that is both abstract and precise. Related to this basic research question is the question of useful properties of virtual visual feedback in motor learning and rehabilitation.

5.5. Conclusion and Practical Recommendation

In the present study, we found empirical evidence against the generality hypothesis and for the functionality hypothesis, which states that the superiority of any attentional focus depends on the movement task. Movement tasks can be classified, among other things, according to the extent to which they have visually perceptible effects on the environment. If such effects are small or absent, the literature often recommends that learners mentally imagine such environmental effects and focus on the mental image. However, this may impose additional cognitive load and hinder learning. When it comes to learning perception–action links between bodily sensations and movements (as in balance tasks), we recommend focusing internally.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data for both experiments are publicly available under the link https://doi.org/10.14279/depositonce-10617.

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Abbreviations

The following abbreviations are used in this manuscript:

ABC model	Anticipatory behavioral control model
COP	Centre of pressure
LM	Linear model
TEC	Theory of effect coding
WBB	Wii balance board

Appendix A

In the following, we describe the statistical model that was used as a basis for hypothesis testing in Experiments 1 and 2. In the first section, we define the random variables in the $2 \times 3 \times 2$ mixed design and their hypothesis-oriented sums on which the directional two-sample-t-tests were run in order to assess the research hypotheses in the two experiments. In the second section, we introduce an effect-coded reparametrization of this model in order to test the overall learning effect with a directional t-test on the regression intercept. This served as a manipulation check in the two experiments.

Appendix A.1. Statistical (Linear) Model and Hypotheses-Oriented Sums of Random Variables for Testing the Research Hypotheses

Let N be the sample size in the experiment and $N/2$ the sample size in each focus group. As usual in linear models (e.g., [43]), we assume N populations Ω_1 to Ω_N, where each person forms an element of a separate population. We also assume N six-dimensional random vectors $\mathbf{Y}_i$, where the index i denotes the person ($i = 1, ..., N$). In the components of the random vectors, the first index k denotes the target point in the experimental task ($k = 1$ for the front and $k = 2$ for the back target, see main text), and the second index l denotes the experimental session ($l = 1, 2, 3$ for the three sessions; note that $l = 1, 2$ were practice sessions and $l = 3$ was the retention session). The random vector for person i reads thus:

$$\mathbf{Y}_i = (Y_{11,i}, Y_{21,i}, Y_{12,i}, Y_{22,i}, Y_{13,i}, Y_{23,i}) \quad \text{(A1)}$$

It assigns a six-tuple of real numbers to each element from Ω_i:

$$\mathbf{Y}_i : \Omega_i \to \mathbb{R}^6 \tag{A2}$$

From the components of the random vector, summed random variables were built so that the hypotheses of interest could be tested by comparing their means with two-sample-t-tests across the two focus groups. Table A1 shows the random variables in the $2 \times 3 \times 2$ mixed design of Experiments 1 and 2.

Table A1. Random variables in the $2 \times 3 \times 2$ mixed design of Experiments 1 and 2. The rows of the table correspond to the between-subjects factor "focus group" and the columns to the within-subjects factors "session" and "target." The superscripts $(1), (2)$ indicate whether person i is in focus group 1 (internal, for $i = 1, ..., N/2$) or 2 (external, for $i = N/2 + 1, ..., N$).

	Session 1 (Practice)		**Session 2 (Practice)**		**Session 3 (Retention)**	
	Front	**Back**	**Front**	**Back**	**Front**	**Back**
Internal	$Y_{11}^{(1)}$	$Y_{21}^{(1)}$	$Y_{12}^{(1)}$	$Y_{22}^{(1)}$	$Y_{13}^{(1)}$	$Y_{23}^{(1)}$
External	$Y_{11}^{(2)}$	$Y_{21}^{(2)}$	$Y_{12}^{(2)}$	$Y_{22}^{(2)}$	$Y_{13}^{(2)}$	$Y_{23}^{(2)}$

According to our two research hypotheses "the internal focus leads to a better performance than the external focus in (i) practice and (ii) retention," we define for every $i = 1, \ldots N$ the following two random variables as sums of the components of the six-dimensional random vector. They denote performance in the two practice sessions and performance in the retention session. They are assumed to be normally distributed in every population $\Omega_1, \ldots, \Omega_N$ with an equal mean across the populations of the same focus group and an equal variance across all populations. Formally written:

(i) Performance in the practice sessions:

$$S_{12,i} : \Omega_i \to \mathbb{R} \tag{A3}$$

$$\text{with} \quad S_{12,i} = Y_{11,i}^{(j)} + Y_{21,i}^{(j)} + Y_{12,i}^{(j)} + Y_{22,i}^{(j)}. \tag{A4}$$

$$S_{12,i} \sim N(\mu_{S12}^{(j)}, \sigma_{S12}^2), \tag{A5}$$

where $j = 1$ for the internal and $j = 2$ for the external focus group.

(ii) Performance in the retention session:

$$S_{3,i} : \Omega_i \to \mathbb{R}$$

$$\text{with} \quad S_{3,i} = Y_{13,i}^{(j)} + Y_{23,i}^{(j)}.$$

$$S_{3,i} \sim N(\mu_{S3}^{(j)}, \sigma_{S3}^2),$$

where $j = 1$ for the internal and $j = 2$ for the external focus group.

The two research hypotheses correspond thus to directional comparisons of the expected values of the random variables S_{12} (practice) and S_3 (retention) between the two groups. The two pairs of hypotheses

$$(i) \quad H_0 : \mu_{S12}^{(2)} \leq \mu_{S12}^{(1)} \tag{A6}$$

$$H_1 : \mu_{S12}^{(2)} > \mu_{S12}^{(1)} \tag{A7}$$

$$(ii) \quad H_0 : \mu_{S3}^{(2)} \leq \mu_{S3}^{(1)} \tag{A8}$$

$$H_1 : \mu_{S3}^{(2)} > \mu_{S3}^{(1)} \tag{A9}$$

were assessed with a two-sample-t-test each.

Appendix A.2. Effect-Coded Linear Model for Assessing an Overall Learning Effect as Manipulation Check

In the manipulation check, we expected that learning occurred, i.e., that the performance increased from session 1 to session 2 averaged across the two focus groups.

Therefore, we built a linear combination from the components of the random vector $\mathbf{Y}_i$ that denotes the increase in performance from session 1 to session 2 for $i = 1, \ldots, N$ (see Table A1):

$$D_{12,i} : \Omega_i \to \mathbb{R} \tag{A10}$$

$$\text{with} \quad D_{12,i} = Y^{(j)}_{12,i} + Y^{(j)}_{22,i} - Y^{(j)}_{11,i} - Y^{(j)}_{21,i}. \tag{A11}$$

$$D_{12,i} \sim N(\mu^{(j)}_{D12}, \sigma^2_{D12}), \tag{A12}$$

where $j = 1$ for the internal and $j = 2$ for the external focus group. The hypothesis is that the mean performance increase is greater than zero, averaged across the two groups:

$$H_0 : \frac{\mu^{(1)}_{D12} + \mu^{(2)}_{D12}}{2} \leq 0 \tag{A13}$$

$$H_1 : \frac{\mu^{(1)}_{D12} + \mu^{(2)}_{D12}}{2} > 0 \tag{A14}$$

In order to test this with a directional t-test, it is most easy if we reparametrize the hypotheses so that we get a linear regression equation (see e.g., [43] ch. 8). We define the following new parameters:

The grand mean

$$\mu = \frac{\mu^{(1)}_{D12} + \mu^{(2)}_{D12}}{2} \tag{A15}$$

It denotes the arithmetic mean of the expected values of the performance difference ("learning") across the two groups.

The effect of group j ($j = 1, 2$)

$$\alpha_j = \mu^{(j)}_{D12} - \mu \tag{A16}$$

It denotes the deviation of the expected value of group j from the grand mean.

Since $\alpha_2 = -\alpha_1$ (zero constraint), the expected value of the random variable $D_{12,i}$ can be expressed by the following simple linear-regression equation:

$$E(D_{12,i}) = \mu + \alpha_1 \cdot R_i \tag{A17}$$

$$\text{with } R_i = \begin{cases} 1 & \text{for } j = 1 \text{ (internal)} \\ -1 & \text{for } j = 2 \text{ (external)} \end{cases} \tag{A18}$$

Using Equation (A15), the hypotheses pair in Equations (A13) and (A14) is equivalent to the hypotheses pair

$$H_0 : \mu \leq 0 \tag{A19}$$

$$H_1 : \mu > 0, \tag{A20}$$

which is assessed by a one-tailed t-test on the regression intercept.

Appendix A.3. Effect Size

All of the statistical hypotheses that we tested within the LM can be expressed in the following general form:

$$H_0 : \psi \leq \psi_0$$
$$H_1 : \psi > \psi_0$$

The term ψ is called the parametric function and is defined as the linear combination of the linear-model parameters [43]. The term ψ_0 is the value that the parametric function takes under the H_0. Applied to our example from the last section, they are equivalent to:

$$\psi = \mu$$
$$\psi_0 = 0$$

Analogous to Cohen's d, an effect size can now be formulated in terms of the parametric function:

$$d_p := \frac{\psi - \psi_0}{\sigma}$$

This effect size can be estimated using:

$$\widehat{d_p} = \frac{\widehat{\psi} - \psi_0}{\widehat{\sigma}}$$

For our example, this is equal to:

$$\widehat{d_p} = \frac{\hat{\mu} - 0}{\widehat{\sigma}}$$

The effect size d_p should always be interpreted according to the linear combination of the model parameters.

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