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# External focus of attention improves performance in a speeded aiming task

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Athletic skills are often executed better when learners focus attention *externally* (e.g., on the trajectory of the ball after a tennis serve), rather than *internally* (e.g., on the position of their arm) (e.g., Wulf, 2007a). The current study explored the effects of attention focus on learning of speeded responses, and examined whether these benefits hold for retention and transfer. Participants performed a computerized speeded aiming task while focusing on the direction of the cursor (external focus) versus the direction in which their hand moved the mouse (internal focus). One week later, half of the participants performed the same task again (retention), and half performed the task under conditions in which the mouse movements were changed (transfer). Relative to internal focus, external focus led to faster acquisition and better maintenance of speeded responses over the retention interval.



Learning new motor skills often involves guidance from a coach or instructor that emphasizes certain aspects of performance. For example, instructions such as, "keep your feet planted," or "keep your elbow straight," direct a learner's attention to particular features of the task. With athletic skills, learners are often encouraged to attend to aspects of their body position (Wulf & Prinz, 2001). However, recent research suggests this may *not* be the optimal way to promote learning of new motor skills.

This topic has been addressed through studies in which participants adopt either an *internal focus* of attention (i.e., focusing on body positions or movements) or an *external focus* of attention (i.e., focusing on effects of these positions or movements) while acquiring a new skill. Retention of these skills is often superior when acquired with an external focus rather than an internal focus (Porter, Nolan, Ostrowski, & Wulf, 2010; Shea & Wulf, 1999; Wulf, 2007a). For example, Wulf, Höß, and Prinz (1998) found that simulated ski training was retained better if participants focused on the simulator's wheels (external focus), rather than on their own feet (internal focus), during learning. Similar results have been demonstrated for a number of more complex athletic skills such as golf (e.g., Bell & Hardy, 2009; Wulf, Lauterbach, & Toole, 1999; Wulf & Su, 2007), basketball free-throw shooting (e.g., Zachry, Wulf, Mercer, & Bezodis, 2005), volleyball serves (e.g., Wulf, McConnel, Gärtner, & Schwarz, 2002), dart throwing (e.g., Lohse, Sherwood, & Healy, 2010; Marchant, Clough, & Crawshaw, 2007), and vertical jumping (e.g., Wulf & Dufek, 2009; Wulf, Dufek, Lozano, & Pettigrew, 2010).

It is unclear whether these benefits are limited to tasks involving a relatively large range of motion, or whether they occur for simpler motor tasks as well. Although benefits of external focus have been well documented for *retention* of a previously-learned skill, relatively few studies have explored whether these benefits also occur for *transfer* of skills to novel but related tasks (but see Lohse, 2012; Totsika & Wulf, 2003). The current study explored the effects of attention focus on retention and transfer using a computerized speeded aiming task that offers precise controls and a variety of performance measures. This task, created by Pauli (e.g., see Pauli, Braun, Wiech, Birbaumer, & Bourne, 2005), has been used in past research (e.g., Wohldmann, Healy, & Bourne, 2008) and requires participants to move a mouse cursor to one of eight digits arranged around a center starting position (see Fig. 1). Once the cursor is positioned over the center X, one of the eight digits is presented above it, and participants must move the cursor to that digit as quickly as possible. Standard dependent measures are *initiation time*—time required to initiate the required movement, and *movement time*—time required to reach the target after movement has been initiated.

An added perceptual-motor learning component is introduced into this task by reversing the compatibility of mouse-cursor movements. For example, leftward movement of the mouse might produce rightward movement of the cursor on the screen (i.e., horizontal reversal), or upward movement of the mouse might

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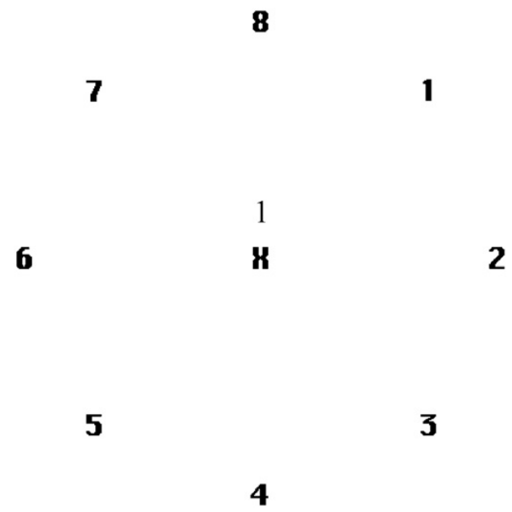


**Fig. 1.** Speeded aiming task used in the current study. In this example, the target digit is 1.

produce downward movement of the cursor (i.e., vertical reversal). Movements could also be reversed on both dimensions. Although performing the task under these reversal conditions is difficult at first, participants learn and retain this skill after sufficient practice (e.g., Healy, Wohldmann, Sutton, & Bourne, 2006). Previous studies have also demonstrated that training on the horizontal reversal facilitates later performance on both reversals (i.e., positive part–whole transfer), but training on both reversals can impede later performance on the horizontal reversal (i.e., negative whole–part transfer) (e.g., Healy, Wohldmann, & Bourne, 2011).

In the current study, participants learned this task under conditions of internal versus external focus of attention. In accord with previous research (e.g., Wulf, 2007a), we defined internal focus as attention to the part of one's body relevant to performing the task (i.e., mentally focusing on the direction in which one's hand moved the mouse), and external focus as attention to the effect of movements produced by the body (i.e., mentally focusing on the direction in which the cursor moved on the screen). Participants performed 400 trials of the task under these conditions. One week later, participants performed 400 additional trials under conditions in which the mouse reversal was the same (i.e., horizontal–horizontal or both–both) or different from before (i.e., horizontal–both or both–horizontal).

Based on the documented benefits of external focus in athletic skills (e.g., Lohse, Wulf, & Lewthwaite, 2012), one might predict that performance on the current task would benefit more from attending to the cursor than to the hand. These benefits are sometimes stronger during later tests than during initial training (e.g., Lohse, 2012; Wulf, 2007a), suggesting that they may take time and/or a sufficient amount of practice to develop. It is feasible that any effects of attention focus might therefore be stronger during the one-week delayed test than during training. Whereas past research has obtained benefits of external focus in relatively brief test sessions (e.g., Totsika & Wulf, 2003), it is unknown whether these benefits persist over a lengthy test session that involves extensive practice with the task. To more fully explore the time course of these effects, the current study provided participants with 400 trials of the task during training (in which attention focus was manipulated), and again during later testing (in which attention focus was not manipulated). Based on previous research, one might predict that the benefits of external focus would emerge over time and be most pronounced during the initial stage of the test phase. Whether or not these effects persist throughout the later stages of testing provides important information about the durability of these effects.

## 1. Method

### *1.1. Participants*

Forty-eight undergraduate students participated for partial course credit.

### *1.2. Task and design*

Participants were tested individually on Mac G4 computers. The task required them to move a mouse cursor to one of eight numerically labeled digits arranged equidistant in circular fashion around a central reference point (Fig. 1). Once the cursor was positioned over the center X, a digit was displayed above it, and the participant had to move the cursor to the corresponding digit on the display.

Movement of the cursor from the X to the target digit constituted one trial. In order to end the trial, the cursor was required to contact the target digit (but did not have to maintain stationary position over the digit). The trial did not end until the target digit was contacted, so accuracy was always 100%. Initiation time and movement time were recorded for each trial. Participants were not given any specific instructions about when to initiate movement, so the index of movement time is primarily a measure of execution but presumably includes some planning as well.

Two samples of eight target digits each (16 trials total) were displayed within each sub-block of trials, five of which constituted one block (80 trials total). Five blocks were completed, a total of 400 trials during the training session (Session 1). One week later, participants returned for a test session (Session 2) and completed another 400 trials arranged in the same fashion. During both sessions, presentation of specific digits was always randomized within a sub-block.

During both sessions, the relationship between mouse and cursor movements was made incompatible in one of two ways. The mouse and cursor directions were reversed only for right-left movements, but not for up-down movements (*horizontal* condition); or the mouse and cursor directions were reversed for both right-left and up-down movements (*both* condition). Participants were randomly assigned to perform either the same reversal during training and testing (e.g., horizontal–horizontal, both–both), or different reversals during training and testing (e.g., horizontal–both, both–horizontal). Measures of retention were therefore obtained for both reversal conditions, along with measures of part–whole transfer (horizontal–both) and whole–part transfer (both–horizontal).

During Session 1, half of the participants were asked to perform the task while "attending to the direction in which your hand moves the mouse" (internal focus), and half were asked to perform the task while "attending to the direction in which the cursor moves on the screen" (external focus). Half of the participants who were given internal focus instructions performed the task during Session 1 with the horizontal reversal, and half with both reversals. Likewise, half of the participants who were given external focus instructions performed the task during Session 1 with the horizontal reversal, and half with both reversals. Half of the participants within each of these four conditions then completed the task during Session 2 with the same reversal as before, and half with the other reversal. Six participants were randomly assigned to each of the eight resulting conditions. Two participants failed to return for Session 2, yielding five participants in the internal, horizontal, same and external, horizontal, switch conditions and six in the remaining conditions.

### 1.3. Procedure

Participants were seated in front of the computer and first given a computer-animated demonstration of the task. The program displayed the task along with the instructions "First place the cursor on the X in the center of the screen," while the program automatically moved the cursor to the X. Participants were then instructed, "Next, wait for the target digit to appear above the X. Then move the cursor to the correct target digit." Simultaneously with these instructions, a target digit appeared above the X, and the cursor moved to that digit. Finally, participants were given the instructions "Last, move the cursor back to the X in the center of the screen," while the cursor automatically moved to the X. Participants were not informed ahead of time that the direction of the mouse and cursor movements would be reversed.

Immediately following the demonstration, all participants completed five practice trials with the experimenter present. At the end of the fifth practice trial, all participants were read the following instructions: "Now that you have seen the task, let me tell you about the key part of this experiment. We are interested in how well you can learn this task based on where you focus your attention. When people learn tasks like this one, there are two ways of focusing attention. The first way is to focus on the direction in which the cursor moves on the screen, and the second way is to focus on the direction in which your hand moves the mouse. Research that has been done in this area has found that people learn the task in very different ways depending on whether they focus on the cursor movements or the hand movements. So, while you are performing this task, it is very important that you focus on the direction of the [cursor or hand] movements, and try not to focus on the direction of the [hand or cursor] movements. When you see a number above the X, I want you to think to yourself 'Which direction does the [cursor or hand] have to move to reach that number?' Try to maintain that focus throughout the experiment." Participants verified they understood the instructions, and completed the remainder of the experiment individually.

Between each block of trials, participants were probed as to whether they had maintained the appropriate focus of attention. The display was removed from the screen and the following instructions appeared: "You just completed 80 trials in which you were required to move the cursor from the center X to one of the numbers on the screen. Out of these 80 trials, in how many do you think you were successful at maintaining the appropriate focus of attention?" Participants entered a number between 0 and 80. A rest period then occurred to minimize fatigue, during which participants were shown the instructions "Take a short break! When you are ready to continue, click on the button below." Upon clicking this button, the next block of 80 trials began, followed by the question regarding attention focus, and then the rest period. This procedure occurred for five blocks. At the end of the fifth block, participants were asked to estimate on how many of the entire 400 trials they had maintained the appropriate focus of attention.[1]

Session 2 began with participants being informed they would be performing a similar task to a week ago. No instructions for attention focus were given, nor were participants informed that the mouse-cursor reversals might be different from what they had previously encountered. Participants performed the task under the same mouse-cursor reversal as before or under a different mouse-cursor reversal. As in Session 1, participants completed 400 trials that were organized into the same format of five 80-trial blocks. As before, mandatory rest periods were inserted between each block, but Session 2 rest periods contained no reminders about focus of attention.

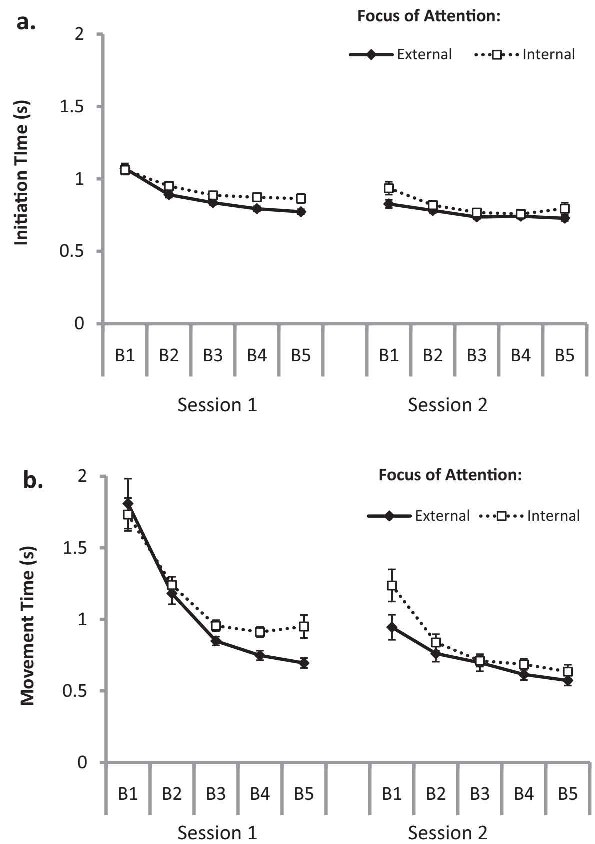


**Fig. 2.** Effects of attention focus on performance across all blocks and sessions for initiation time (a) and movement time (b). Error-bars show within-subject standard errors (Cousineau, 2005).

## 2. Results

Performance was analyzed using a mixed factorial $2 \times 5 \times 2 \times 2 \times 2$ Analysis of Variance (ANOVA) that included within-subject variables of session (Session 1 versus Session 2) and block (Blocks 1–5) and between-subjects variables of attention focus (internal versus external), Session 1 reversal condition (horizontal versus both), and correspondence between Session 1 and Session 2 reversal conditions (same versus switch).

### 2.1. Effects of training

Fig. 2 shows performance across all 5 blocks in both sessions as a function of attention focus during learning. Performance improved across blocks for initiation time [$F(4, 152) = 60.69$, $p < .001$, $\eta_p^2 = .61$] and movement time [$F(4, 152) = 96.24$, $p < .001$, $\eta_p^2 = .72$], and performance was faster in Session 2 compared to Session 1 for initiation time [$F(1, 38) = 29.30$, $p < .001$, $\eta_p^2 = .43$] and movement time [$F(1, 38) = 53.88$, $p < .001$, $\eta_p^2 = .59$]. A significant Block × Session interaction reflected a greater speed-up in performance across blocks during Session 1 compared to Session 2 for initiation time [$F(4, 152) = 8.51$, $p < .001$, $\eta_p^2 = .18$] and movement time [$F(4, 152) = 13.63$, $p < .001$, $\eta_p^2 = .26$].

[1] Participants reported maintaining the appropriate focus of attention on the majority of the 80 trials following Block 1 (69% of trials for both internal and external focus groups), Block 2 (80% of trials for both groups), Block 3 (75% of trials for the internal focus group, and 85% for the external focus group), and Block 4 (73% of trials for the internal focus group, and 84% for the external focus group). When asked the same question about the entire 400 trials at the end of Session 1, participants in both the internal and external groups reported maintaining the appropriate focus on the majority of trials (76% and 78% of trials, respectively).

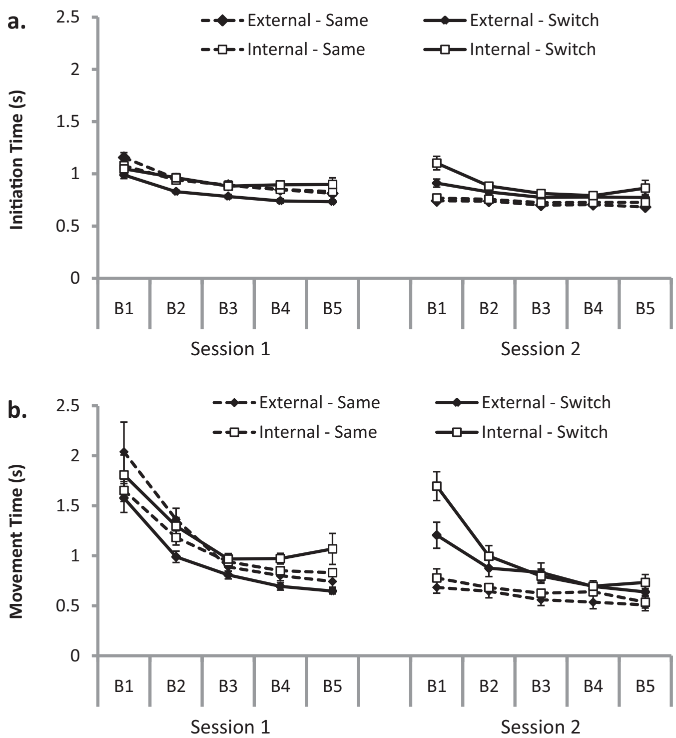


**Fig. 3.** Performance across all blocks and sessions as a function of attention focus and correspondence between Session 1 and Session 2 reversals. Participants adopted either an internal or external focus of attention, and either kept the same reversal from Session 1 to Session 2 (same) or switched reversals (switch). Performance is displayed for initiation time (a) and movement time (b). Error-bars show within-subject standard errors (Cousineau, 2005).

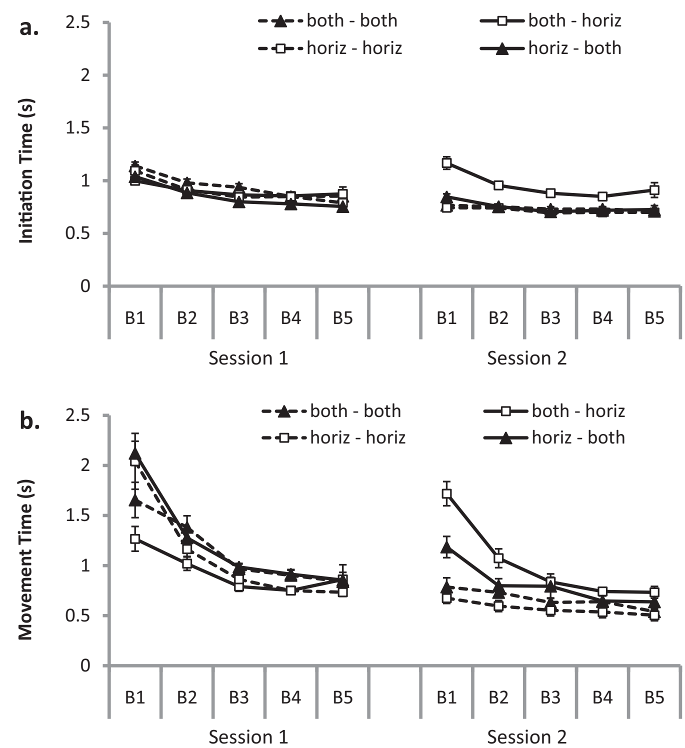


**Fig. 4.** Performance across all blocks and sessions as a function of Session 1 and Session 2 reversal conditions. Participants either encountered both reversals in Sessions 1 and 2 (both–both), both reversals in Session 1 and the horizontal reversal in Session 2 (both–horizontal), the horizontal reversal in Sessions 1 and 2 (horizontal–horizontal), or the horizontal reversal in Session 1 and both reversals in Session 2 (horizontal–both). Performance is displayed for initiation time (a) and movement time (b). Error-bars show within-subject standard errors (Cousineau, 2005).

### 2.2. *Effects of attention focus*

Participants who adopted an external focus, relative to an internal focus, showed greater improvement across blocks in Session 1 and exhibited faster performance during the early stages of Session 2. This three-way interaction (Block × Session × Attention Focus) was significant for initiation time [$F(4,\ 152) = 4.36$, $p = .002$, $\eta_p^2 = .10$] and movement time [$F(4,\ 152) = 3.71$, $p = .007$, $\eta_p^2 = .09$]. Planned comparisons using a 2 × 2 × 2 (attention focus × reversal × correspondence between Session 1 and Session 2 reversals) ANOVA restricted to Block 5 of Session 1 revealed a significant benefit of external focus on movement time [$F(1, 38) = 5.09$, $p = .030$, $\eta_p^2 = .12$], and the same analysis restricted to Block 1 of Session 2 revealed a significant benefit of external focus on movement time [$F(1, 38) = 4.71$, $p = .036$, $\eta_p^2 = .11$].

Fig. 3 shows performance across all 5 blocks in both sessions as a function of attention focus during learning, and correspondence between Session 1 and Session 2 reversals (same versus switch). A three-way interaction was observed between block, attention focus, and correspondence between Session 1 and Session 2 reversals for movement time [$F(4, 152) = 2.66$, $p = .035$, $\eta_p^2 = .07$], indicating an advantage of external focus in the early blocks for participants who switched reversals but not for participants who kept the same reversal from Session 1 to Session 2.

### 2.3. *Retention and transfer*

Fig. 4 presents performance across all five blocks in both sessions as a function of the reversals encountered during Session 1 and Session 2. Session 2 performance was better for participants who encountered the same reversal condition as in Session 1, compared to those who switched reversals from Session 1 to Session 2. Overall performance during Session 1, however, did not differ between those participants who would later encounter the same reversal (i.e., retention) or switch to a different reversal (i.e., transfer). This two-way interaction between session and correspondence between Session 1 and Session 2 reversals was significant for initiation time [$F(1, 38) = 17.85$, $p < .001$, $\eta_p^2 = .32$] and movement time [$F(1, 38) = 13.76$, $p < .002$, $\eta_p^2 = .27$]. A significant three-way interaction between block, session, and correspondence between Session 1 and Session 2 reversal conditions for initiation time [$F(4, 152) = 9.21$, $p < .001$, $\eta_p^2 = .20$] and movement time [$F(4, 152) = 7.96$, $p < .002$, $\eta_p^2 = .17$] indicated that the performance advantage for retention over transfer was not present in Session 1, but was present in Session 2 and was particularly strong during the early stages of Session 2 (see right-hand side of Fig. 4).

Fig. 4 also shows a significant Session × Session 1 Reversal Condition interaction for movement time [$F(1, 38) = 9.01$, $p = .005$, $\eta_p^2 = .19$]. Participants who trained with the horizontal reversal were slower in Session 1, but faster in Session 2, compared to those who trained with both reversals. A significant three-way interaction between block, session, and Session 1 reversal condition for initiation time [$F(4, 152) = 3.50$, $p = .009$, $\eta_p^2 = .08$] and movement time [$F(4,\ 152) = 10.99$, $p < .001$, $\eta_p^2 = .22$] indicated that participants who trained with the horizontal reversal showed no advantage over those who trained with both reversals during Session 1, but showed an advantage during Session 2 that was most pronounced during the early stages of Session 2.

Performing the task with the horizontal reversal during Session 1 led to faster overall performance in Session 2 than in Session 1 regardless of whether participants encountered the same horizontal reversal again during Session 2 or switched to both reversals.

However, performing the task with both reversals during Session 1 led to faster performance during Session 2 only when Session 2 contained both reversals again. For those who started out with both reversals in Session 1 and then switched to the horizontal reversal in Session 2, performance actually suffered (i.e., compare Session 1 and Session 2 performance for the solid line with open square in Fig. 4). This three-way interaction between session, Session 1 reversal, and correspondence between Session 1 and Session 2 reversals was significant for initiation time [$F(1, 38) = 5.05$, $p = .030$, $\eta_p^2 = .12$] and movement time [$F(1, 38) = 5.84$, $p = .021$, $\eta_p^2 = .13$]. These results provide evidence of positive part–whole transfer (i.e., horizontal–both), but negative whole–part transfer (i.e., both–horizontal), as found in earlier studies (Healy et al., 2011, 2006). Finally, a four-way interaction between block, session, Session 1 reversal condition, and correspondence between Session 1 and Session 2 reversals for initiation time [$F(4, 152) = 4.05$, $p = .004$, $\eta_p^2 = .10$] indicated that the advantage for part–whole transfer, relative to whole–part transfer, appeared in Session 2 but not in Session 1, and was particularly strong during the early stages of Session 2.

## 3. Discussion

Performance on a computerized speeded aiming task was affected by whether one focused attention externally (i.e., on the cursor) versus internally (i.e., on one's hand) during learning. Although an external focus did not benefit performance over the entirety of training and testing, participants who focused externally, rather than internally, performed the task faster by the end of training and maintained this advantage one week later during the early stages of testing.

Whereas other studies have reported benefits of external focus on retention of relatively complex motor skills (e.g., for a review, see Lohse et al., 2012; Mechsner, Kerzel, Knoblich, & Prinz, 2001; Wulf, 2007a, 2007b; Wulf & Prinz, 2001), the current study, using a simpler computerized task, observed benefits of external focus that were most pronounced later in Session 1 and during the early stages of Session 2. With continued practice at the task in Session 2, the external focus advantage was eliminated, possibly due to ceiling effects or to the fact that focus of attention was not manipulated during Session 2. These results add important new data on the durability of the effects of attention focus, suggesting that the deficit that results from initially focusing internally might be overcome following continued practice.

Consistent with previous studies using this task (e.g., Healy et al., 2011, 2006), the current results demonstrated that part–whole transfer (i.e., horizontal–both) was superior to whole–part transfer (i.e., both–horizontal). This finding is consistent with the global inhibition hypothesis proposed by these investigators, according to which individuals inhibit all normal movements when they encounter a defective mouse and then add disinhibitions along dimensions with no reversals. No evidence was obtained to suggest that positive or negative transfer were differentially affected by the focus of attention during learning, however.

There is currently no exclusively accepted theory for why it is beneficial to focus attention externally (see Lohse et al., 2012; Wulf, 2007b, for a theoretical discussion). Some key findings from the current study may help to guide theoretical progress. It is possible, for example, that external focus is beneficial because it emphasizes the visual *result* or *goal* of the task more than internal focus (e.g., Hommel, 2007). If external focus emphasizes the relationship between movements and the visual results of those movements, then the benefits of external focus might be expected to be stronger when the skill is assessed under conditions that involve a mapping between movements and results that is similar to, rather than different from, the previously-learned mapping. The current study did not observe greater effects of attention focus on retention than on transfer, suggesting that any visual effects that may be emphasized by external focus do not appear to be specific to test conditions that involve the same mapping between movements and visual results that was acquired during training.

It is also possible that performing a task under internal focus instructions requires greater processing resources than performing the same task under external focus instructions (e.g., Poolton, Maxwell, Masters, & Van der Kamp, 2007). In the current study, the performance of external focus participants at the beginning of Session 1 was similar to that of internal focus participants, suggesting that there appeared to be no differences in the initial difficulty of the task as a function of attention focus. It is also not clear how the processing resources initially required by a task might affect performance at a later time. Participants who learned the task with the more difficult, resource-demanding (i.e., horizontal) reversal in Session 1 performed better in Session 2 than those who learned the task with the easier (i.e., both) reversal, suggesting that what is easier to perform initially might not result in better learning.

Finally, the constrained action hypothesis proposes that an external focus of attention allows a motor skill to be acquired through implicit mechanisms that operate independently of conscious awareness (e.g., Wulf, 2007a, 2007b). Awareness of one's own movements (i.e., internal focus) can disrupt these mechanisms and result in poorer learning. The acquisition of a novel skill via these mechanisms would presumably take time to develop, because implicit control of the movement relies on robust skill representations that are acquired through experience. Consistent with this reasoning, we found that the external focus advantage emerged over training. Follow-up work is encouraged that might reveal more about the nature of these mechanism(s) and how they operate. These explanations need not be mutually exclusive, and it is possible that still other factors may account for the effects of attention focus in this and other tasks.

### 3.1. Practical applications

Focusing attention externally, rather than internally, benefits performance on a computerized task involving a relatively small range of motion. This finding suggests that external focus may benefit learning of basic skills such as visual tracking and eye–hand coordination, which are important elements of athletic and military training. External focus also appears to benefit learning when the task involves incompatibility between a movement and the effect produced by it, raising the possibility that external focus could enhance performance on real-world tasks that involve such incompatibility, such as operating an automobile or aircraft, or performing robotic-assisted microsurgery. Although these results offer some promise, future research is needed to explore the full applicability of the external focus benefit.

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