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Multiple measures of visual attention predict novice motor skill performance when attention is focused externally

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ABSTRACT

Multiple lines of evidence indicate that the control of attention and motor skill performance are related. Athletes of various skill levels differ in terms of their control over the focus of attention and directing athletes to adopt an internal or external focus of attention modulates performance. However, it is unclear (a) whether the relationship between skill level and attentional control arises from preexisting individual differences in attention or from practice of the motor skill and (b) whether the effect of adopting an internal or external focus of attention on motor performance is influenced by individual differences in attention. To address these issues, individuals were measured on three distinct attention functions – orienting, alerting, and executive – prior to engaging in a novel golf-putting task performed with either external or internal focus instructions. The results indicated that, on average, attentional functioning and putting performance were related but that the strong relationships with orienting and executive attention were only present in the group given external focus instructions. These findings suggest that individual differences in attentional abilities are predictive of novel skill performance under an external focus of attention and they shed light on the mechanisms underlying the effects of focus instructions during motor performance.

1. Introduction

Watch virtually any broadcast of a major sporting event and one will likely hear an announcer talk about the uncanny ability of the winning athletes to "focus" their attention. While such descriptions

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are intuitive, they do imply that high performance athletes have more efficient voluntary control over their focus of attention and that individual differences in this ability to control attention are an important determinant of success in motor performance. One line of empirical evidence that is consistent with this notion comes from studies that have compared athletes from different sports and of different skill levels to non-athletes in terms of their performance on simple laboratory tasks. These studies consistently find benefits for athletes over non-athletes in tasks measuring visual attention orienting, selective attention, divided attention, and in tasks that generally measure processing speed (for reviews see Memmert, 2009; Voss, Kramer, Basak, Prakash, & Roberts, 2010), thus supporting the idea that a strong link exists between motor performance, attention, and higher-level cognitive functioning.

While the demonstration of a link between attention and motor skill performance provides a key insight into the interaction between cognitive and motor processes, further critical insights can be gained by investigating the relationship between the multiple functions of attention and athletic motor skill performance. According to one classic theoretical framework, spatial orienting, alerting, and executive control have been implicated as distinct attentional operations (Posner & Petersen, 1990; Fan, McCandliss, Sommer, Raz, & Posner, 2002). One of the most widely studied components of attention in athletes has been the voluntary orienting of visual attention (Memmert, 2009), which is typically measured using laboratory tasks by comparing response times to visual targets that appear at validly cued locations to response times to targets at invalidly cued locations (i.e., the spatial cueing task; Posner, 1980). These studies have consistently found that athletes from a variety of different sports, ranging from professional boxers to volleyball players, exhibit more efficient attentional orienting (i.e., smaller differences between valid and invalid trials) compared to non-athletes (Castiello & Umilta, 1992; Nougier, Azemar, Stein, & Ripoll, 1992; Nougier, Ripoll, & Stein, 1989). Moreover, comparisons within the same sport also indicate that high-skill athletes have more efficient orienting compared to low-skill athletes (Enns & Richards, 1997). These empirical findings support the notion that high-skill athletes have more efficient orienting abilities than low-skill athletes or non-athletes.

Although orienting in athletes has been the most studied component of attention, there is good reason to believe that other attentional operations may also play a role in mediating skill performance. Consider visual alerting, which is characterized as either the decrease in reaction time when a target is preceded by a warning signal (phasic alerting; e.g., Fan et al., 2002) or the overall reduction in reaction time while engaging in a task for an extended duration (tonic alerting or vigilance; see Posner, 2008 for a discussion). Evidence suggests that the brain systems involved in tonic alerting are linked with those involved in mediating arousal (see Aston-Jones, Chiang, & Alexinsky, 1991) and that the relationship between physiological arousal and skill performance follows the classic inverted U-shaped function (Janelle, 2002; Yerkes & Dodson, 1908), which suggests that alerting should play a key role in athletic skill performance. However, it remains unclear whether this arousal-performance relationship extends to phasic visual alerting, and evidence for the specific inverted U relationship is mixed (Arent & Landers, 2003; Paller & Shapiro, 1983; VaezMousavi, Barry, & Clarke, 2009), potentially because the two forms of alerting may be confounded in some studies. While both forms of alerting may be important for motor skill performance, phasic alerting is of particular interest because it would appear to be the system most related to the rapid onset of stimuli in many athletic motor skills. Despite this potential link, to our knowledge, there have not been studies specifically investigating phasic visual alerting in athletes (see also Memmert, 2009) and, as a consequence, theories of cognitive and attentional functioning in motor performance have largely ignored this aspect of attention.

When one considers the executive control of attention, there is also suggestive evidence of a link with motor skill performance. Executive attention mechanisms are involved in a variety of functions, including conflict resolution in the presence of distracting competing responses (e.g., Eriksen & Eriksen, 1974), maintenance and manipulation of information in working memory (WM) (e.g., Kane & Engle, 2002), and managing performance in one or more tasks (e.g., Rogers & Monsell, 1995). The existing evidence suggests that executive attention may play a role in athletic skill performance by mediating distraction or by managing performance in more than one task (e.g., divided attention, see Memmert, 2009). Consistent with this hypothesis, performance in a flanker task (e.g., Eriksen & Eriksen, 1974) is greater in athletes compared to non-athletes (see Voss et al., 2010). Additionally, managing performance on multiple tasks can have differential effects on expert and novice skill

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performance (Beilock, Bertenthal, McCoy, & Carr, 2004). Recent work also suggests that WM load can hinder motor skill execution under dual task conditions (Poolton, Maxwell, Masters, & Raab, 2006), which also implies an increased load on executive attention. Taken together, evidence suggests that executive attention functions should play an important role in motor skill performance under a variety of circumstances.

While much of the research described in the preceding paragraphs indicates that athletes may have generally improved attention abilities in laboratory tasks, other sets of studies suggest that the deployment of attention during motor performance is important as well. For example, Wulf and colleagues have shown that focusing attention on internal, body-related aspects of a motor task hinder performance, whereas performance is enhanced when attention is focused on the external effects of the task (see Wulf, 2007). Under the constrained action hypothesis, internal focus is thought to disrupt the automatic motor control processes needed for optimal motor execution at all stages of expertise (Wulf & Prinz, 2001; Wulf, 2007). Support for this hypothesis has come from previous studies showing that attentional capacity is reduced during internal focus (Wulf, McNevin, & Shea, 2001), that low amplitude and high frequency movement adjustments associated with automatic control are seen during external focus conditions (McNevin, Shea, & Wulf, 2003; Wulf et al., 2001), and that electromyography (EMG) activity is reduced under external focus instructions (Vance, Wulf, Tollner, McNevin, & Mercer, 2004; Wulf, Dufek, Lozano, & Pettigrew, 2010).

While there is empirical evidence for the constrained action hypothesis, several studies have also shown that novices perform best when attending to skill-related components while experts perform best when attending to unrelated external stimuli (Beilock & Carr, 2001; Beilock, Carr, MacMahon, & Starkes, 2002; Beilock et al., 2004). To account for these results, Beilock and Carr (2001), have proposed an explicit monitoring hypothesis that, in contrast to the constrained action hypothesis, proposes that the differential effect for novices and experts results from the need to attend to and process the individual skill components early in learning, but not once the skill is proceduralized. An additional challenge to the constrained action hypothesis comes from the work of Poolton et al. (2006), who provide evidence that internal focus detriments (e.g., Wulf & Prinz, 2001) may be explained by the increased working memory load induced by the maintenance of extra skill-related information. Although this theoretical debate about the mechanisms driving focus effects in motor performance remains unresolved, it is clear that the focus of attention during skill execution can directly affect the performance of that skill and that the direction of this effect may depend on both individual differences in attentional function and skill level.

Despite the apparent consistency in the literature indicating that performance of motor skills and voluntary focusing of visual attention are tightly coupled, there are several key issues about the relationship between motor skill performance and attention that remain unresolved. The first unresolved issue that we address here is the question of whether the previously established relationships between motor skill performance and attention functioning, such as voluntary orienting (Enns & Richards, 1997; Memmert, 2009; Voss et al., 2010), emerge after practice of the skill or whether preexisting individual differences in attention capabilities facilitate skill acquisition and performance. All previous studies showing a link between motor skill performance and higher cognitive functions have only looked at abilities of individuals *after* establishing expertise in a particular athletic motor skill. The first aim of the present study is to determine how attentional abilities that are in place *before* practice of a novel motor skill affect performance. The second unresolved issue addressed here is the lack of understanding about how the focus of attention during motor skill performance affects the relationship between visual attention abilities and motor skill execution. To our knowledge, no studies have looked at how individual differences in attention relate to effects of instructional focus manipulations in motor skill tasks. The constrained action hypothesis (Wulf, 2007) predicts that an external focus should result in a stronger interaction between attention abilities and motor performance, whereas the WM hypothesis (Poolton et al., 2006) predicts no effect of WM-equated focus instructions. On the other hand, the explicit monitoring hypothesis (Beilock & Carr, 2001) predicts a relationship between attention and motor performance for novices under a general skill focus, but does not make clear predictions regarding the difference between internal skill focus and external skill focus.

To investigate these unresolved issues, a group of participants performed a golf-putting task (Beilock et al., 2004) with which they had no prior experience. Each participant was given instructions

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that directed attention either to internal or external aspects of skill performance (Wulf & Prinz, 2001) and were matched to control for WM load (Poolton et al., 2006). Prior to performing the golf task, a variant of the Attention Network Task (ANT; Fan et al., 2002) was used to measure voluntary attentional orienting abilities as well as the efficiency of the alerting and executive control networks. This design allowed us to directly compare the degree to which pre-existing individual differences in each of the components of attention predict subsequent putting performance. Furthermore, this design allowed us to investigate whether pre-existing individual differences in attention components were differentially related to motor performance under internal and external focus conditions. Based on the literature, we predicted that more efficient orienting, alerting, and executive attention abilities would be related to better motor skill performance. Additionally, the design also afforded the opportunity to discriminate between the constrained action hypothesis that predicts stronger relationships between attention and performance under external focus, and the WM hypothesis that predicts no difference between attention and performance under external and internal focus conditions.

2. Methods

2.1. Participants

Twenty-five UCSB undergraduates (14 female) between the ages of 17 and 22 (average age = 19) participated for course credit. All participants were screened so that none had any prior golf experience and all had normal or corrected-to-normal vision. The efficiency scores for the three attention networks were calculated and subjects with scores that deviated more than 2.5 standard deviations from the mean were excluded, resulting in the exclusion of four additional subjects.

2.2. Attention task

The ANT task (Fan et al., 2002) was modified to specifically measure the voluntary component of the orienting network in addition to the alerting and executive control networks. Participants sat 110 cm from a 19-inch CRT monitor in a dimly lit room. They were instructed to keep their eyes fixated at a central crosshair throughout the duration of the task. Two rectangles ($\sim$3° wide by 1° high) were onscreen 2° above and below fixation throughout the entire task. After a variable delay of 400–1600 ms, a number cue (0, 3, or 9; $\sim$1° visual angle) was presented at fixation for 100 ms. The numbers 3 and 9 were spatial number cues that indicated the likely target location. Each number represented either the upper or lower location, and this spatial cue was valid 80% of the time. The mapping of the number to the likely location was given to the participant at the outset and was counterbalanced across subjects. On a small number of trials a neutral cue (0) or no cue was presented. Following a stimulus onset asynchrony (SOA) of either 100 or 600 ms, a string of five arrows appeared in either the upper or lower rectangle. The task was to indicate the direction of the middle arrow while ignoring the flanker arrows that could be either congruent (>>>>>) or incongruent (>><>>). Participants were instructed to respond as quickly and as accurately as possible by pressing one of two corresponding keys on the keyboard. The target display remained on the screen until response, or for a maximum of 1700 ms. Fig. 1A shows the sequence of the attention task.

Within subjects factors for the attention task were cue type (valid, invalid, neutral, and no cue), SOA (100 and 600 ms) and target type (congruent and incongruent). In order to index the three attention networks, response time (RT) subtractions were calculated (Fan et al., 2002). These subtractions have been shown to be reliable measures in single subjects and statistically independent of each other (Fan et al., 2002). To index the orienting network, the RT to validly cued trials was subtracted from the RT to invalidly cued trials. Smaller differences reflect more efficient orienting. For the alerting network, the RT to trials preceded by a spatially uninformative cue (the number 0) was subtracted from RT to trials preceded by no cue at all. Here, larger values indicate a greater ability to adopt the alerting cue. The executive network was indexed by subtracting the RT to congruent flanker trials from the RT to incongruent flanker trials. More efficient conflict resolution would be reflected in smaller RT differences in the executive network calculation. For the purpose of computing the attention network scores

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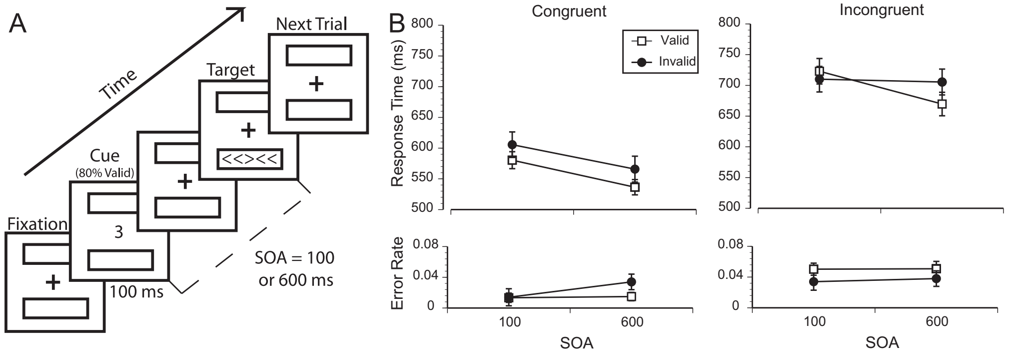

Fig. 1. (A) The attention task sequence is shown. (B) The upper figures show the response times in milliseconds in the attention task. The lower figures show the attention task error rates. Error bars represent standard error of the mean.

we collapsed across SOA, but a separate analysis using only short or long SOAs did not affect the pattern of results with putting performance.

2.3. Putting task

Putts were executed on a carpeted floor with a standard putter and ball in a task similar to that used by Beilock et al. (2004). Participants were instructed to get the ball to stop on a 3 × 2 cm piece of tape placed on the carpet at one of two target locations separated by an angle of approximately 45° from the putting location and at distances of 137 cm (4.5 feet) and 150 cm (5 feet). The two different target locations were used to prevent subject performance from relying on a single distance and trajectory, thereby ensuring sufficient variability in putting performance for individual difference analyses. All participants followed the same random order of target locations in each block.

While a wide variety of methods that measure motor performance, such as kinematics, can provide insights into specific motor production components (e.g., Zentgraf & Munzert, 2009), the overall performance outcome in a novel motor skill is of interest here. Therefore, motor performance was operationally defined as putting accuracy, which was measured as the distance from the edge of the ball to the center of the target location for each putt. Participants completed an average of 30 putts on the first day immediately after completing the attention task, and then returned approximately one week later for an additional 70 to 100 putts. Putting accuracy was computed for each block of ten putts. The first two blocks were considered practice and were not included in the analysis. Each participant completed an average of 10.5 blocks of putting, with accuracy computed across both target distances. Putting performance was defined as the average accuracy over the entire set of blocks, excluding practice blocks.

At the beginning of each putting session, simple putting instructions were read aloud by the experimenter. Participants were randomly assigned to one of two instruction conditions, one emphasizing internal skill components ($n = 13$) and the other emphasizing external skill components ($n = 12$). The content of the instructions were modified from Beilock et al. (2004) to be as similar as possible across groups in terms of content and information load (see Poolton et al., 2006) while subtly focusing attention on either the body (internal) or the golf club (external). The instructions are presented in Table 1. Participants were asked to use these instructions during performance, but no further coaching or feedback was given throughout the putting sessions.

2.4. Hypothesis tests

All results are reported using two-tailed hypothesis tests at an alpha significance threshold of $p = .05$. Due to the possibility of alpha inflation as a result of multiple comparisons, the False Discovery Rate (FDR) method was used that corrects for multiple comparisons by controlling the expected

Table 1
Instructions given to the internal and external focus groups during putting.

Internal focus instructions	External focus instructions
Position your feet so that the ball sits between them and in front of you	Position the ball between your feet and in front of you
Swing arms straight back, no further back than they extend forward on follow-through	Swing the head of the club straight back, no further back than it goes forward on follow-through
It is better for the arms to have a shorter follow-through than a longer one	It is better for the club to have a shorter follow-through than a longer one
Accelerate arm swing through the contact in a straight motion	Accelerate the club head straight through the ball
Finish with arms pointing straight in the direction of the target	Finish with "face" of the club head pointing straight in the direction of the target

Table 2
Mean, standard error, and median values for the reaction time subtractions of each attention network score are shown in milliseconds.

Attention network	*Mean*	*SEM*	*Median*
Orienting	19.39	4.26	19.82
Alerting	8.21	3.81	7.95
Executive	133.43	12.77	123.15

proportion of Type I errors, or false discoveries (Benjamini & Hochberg, 1995). In addition to typical p values, q values are also reported that reflect the FDR at a significance threshold of $q = .05$. These FDR corrections are reported for all comparisons of interactions between attention measures and putting performance.

3. Results

3.1. Attention task performance

An ANOVA using RT on correct trials as the dependent measure revealed a significant main effect of cue type, $F(3, 72) = 11.75$, $p < .01$, $\eta^2 = .33$, reflecting generally slower RT on invalid trials and generally faster RT on valid and center cue trials, thus replicating the validity effect. A main effect of SOA revealed faster RT at long SOAs relative to short SOAs, $F(1, 24) = 46.06$, $p < .01$, $\eta^2 = .66$, while RT was also faster on congruent distractor trials versus incongruent trials, $F(1, 24) = 113.71$, $p < .01$, $\eta^2 = .826$. The cue effect was more pronounced on congruent than incongruent trials, $F(3, 72) = 5.81$, $p < .03$, $\eta^2 = .17$, whereas the congruency effect was more pronounced at longer SOAs, $F(1, 24) = 7.07$, $p < .02$, $\eta^2 = .23$. Consistent with previous studies that have investigated the time-course of voluntary attention (e.g., Muller & Rabbitt, 1989), the cue effects were larger at long SOAs than short SOAs, $F(3, 72) = 3.41$, $p < .03$, $\eta^2 = .14$. This cue by SOA interaction was more pronounced on incongruent than congruent trials, $F(3, 72) = 2.94$, $p < .04$, $\eta^2 = .11$. Mean RT for valid and invalid cues are shown in Fig. 1B.

Mean error rates also are shown in Fig. 1B. Overall the error rate was low ($M = 0.03$, $SEM = 0.01$). There was a significant effect of congruency, reflecting an increase in errors when the flanking arrows were incongruent with the target, $F(1, 24) = 26.52$, $p < .01$, $\eta^2 = .53$. Additionally, there were more errors on short SOA trials, $F(1, 24) = 4.36$, $p < .05$, $\eta^2 = .15$. No other effects were significant (all $F < 2.4$, $p > .08$, $\eta^2 < .10$).

The attention network efficiency scores were calculated for each subject by collapsing across SOA. The resulting mean, median, and standard error for each subtraction are presented in Table 2.

3.2. Focus effects on putting performance

Analysis of putting performance between the two focus instruction groups revealed that putting for internal focus ($M = 26.69$, $SEM = 0.98$) and external focus ($M = 26.21$, $SEM = 2.05$) did not differ

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significantly ($t(23) = .21$, $p > .80$, $d = .09$). In other words, the focus instruction manipulation did not affect overall putting performance.

Even though there was no effect of focus instructions on overall putting accuracy, it is possible that random inherent differences in individual attention abilities assigned to the two groups may have served to obscure this effect. Individuals randomly assigned to the external focus group did have significantly less efficient executive scores ($M = 160.10$, $SEM = 18.12$) than those in the internal group ($M = 108.80$, $SEM = 14.10$), $t(23) = 2.21$, $p < .04$, as well as larger alerting scores ($M = 16.40$, $SEM = 4.32$) than those with an internal focus ($M = 6.50$, $SEM = 5.28$), $t(23) = 2.29$, $p < .04$, while there was no difference between orienting scores for external ($M = 15.07$, $SEM = 6.00$) and internal groups ($M = 23.37$, $SEM = 5.81$), $t(23) = 0.99$, $p > .33$. To test whether these differences in attention abilities might be obscuring an overall instruction effect, we conducted a post hoc analysis that selected individuals with attention scores within one standard deviation from the mean for that measure. For the executive scores, the removal of these 8 subjects resulted in the equalization of the focus groups in executive efficiency scores ($p > .29$), and also resulted in the external group having significantly higher putting accuracy ($M = 22.43$, $SEM = 1.68$) compared to the internal focus group ($M = 26.48$, $SEM = 0.77$), $t(15) = 2.27$, $p < .04$. However, the removal of 8 and 9 subjects for the orienting and alerting scores, respectively, did equalize the attention measures (both $p > .39$) but did not reveal any differences in putting accuracy (both $p > .88$). While post hoc analyses of this sort must be interpreted with caution, equalizing the individual attention measures for executive scores, but not orienting or alerting, resulted in the typical motor performance benefit for external focus over internal focus.

3.3. Relationships between attention measures and putting performance

The question of whether pre-existing individual differences in the three separate attentional functions[1] are related to novel motor skill performance was addressed in two steps. First, we considered the relationships between attention measures and putting performance by collapsing across instruction condition in order to get a sense of the general relationships. In the second step, these relationships were unpacked by considering each of the instruction focus conditions separately. For each of these steps, two complementary analyses were performed: a correlational analysis and a rank order analysis.

For investigating the general relationships between attention measures and putting performance, a correlational analysis was performed first to gauge the strength of these possible relationships. Based on prior evidence indicating a strong relationship between orienting and athletes (e.g., Enns & Richards, 1997; Nougier et al., 1989), a correlation between prior orienting ability and putting performance was predicted *a priori*. In line with this prediction, a significant positive correlation was found between orienting scores and putting performance ($r(23) = 0.43$, $p < .04$, $q < .10$) such that more efficient orienting was associated with more accurate putting. While we predicted a negative relationship between alerting speed and distance from the putting target, this correlation was not significant ($r(23) = -.24$, $p > .24$, $q > .24$). Additionally, the predicted positive relationship between more efficient conflict resolution and putting accuracy resulted only in a trend for a correlation between executive attention and putting performance ($r(23) = 0.37$, $p > .07$, $q > .10$). Fig. 2 shows the results of the correlations.

The second analysis was designed to assess the extent to which each attention measure was able to rank-order pairs of individuals in terms of their performance on the putting task. For this analysis, two subjects were randomly selected from the sample and their attention network scores and putting performance were compared. If subject A's attention score was better than subject B's (e.g., more efficient orienting) and subject A's putting performance was also better, this was considered a correct rank ordering. The rank order comparisons were done for each subject pairing using a jackknife method that left out one participant for each full cycle of comparisons so that standard error could be computed. The results of this analysis, shown in Fig. 3, revealed that the orienting ($M = 0.65$, $SEM = 0.012$), alerting ($M = 0.61$, $SEM = 0.02$) and executive ($M = 0.59$, $SEM = 0.02$) rank order accuracies were all significantly above random permutation tests ($M = 0.50$, $SEM = 0.02$), all $t > 5.0$, $p < .01$,

[1] In line with Fan et al. (2002), a correlation analysis showed that there was no clear relationship between any of the attention measures (all $p > .10$).

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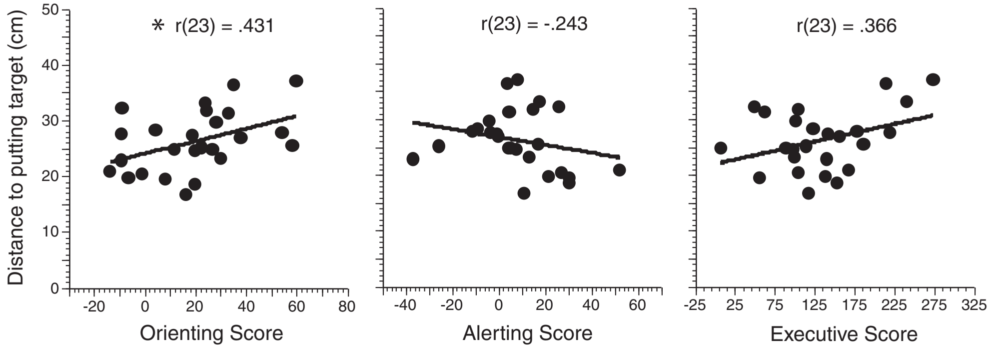

Fig. 2. Correlations between mean distance (in cm) from the putting target and attention task reaction time scores (in ms) are displayed. Asterisks indicate significance at $p < .05$.

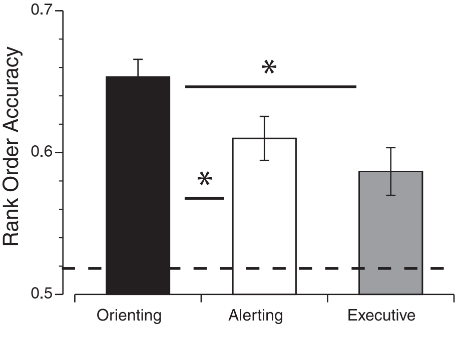

Fig. 3. Shown is the proportion correct for attention scores in rank ordering putting task accuracy. Error bars represent standard error of the mean. The dotted line represents one standard error above random permutation, and asterisks indicate significance at $p < .01$.

$q < .01$. Direct comparisons using independent samples *t*-tests revealed that rank order accuracy for orienting was significantly greater than alerting ($t(48) = 3.11$, $p < .01$, $q < .01$, $d = .62$) and executive attention ($t(48) = 4.57$, $p < .01$, $q < .01$, $d = .90$), but the alerting and executive accuracies did not differ from each other ($t(48) = 1.45$, $p > .15$, $q > .15$, $d = .29$). Thus, all three attention measures accurately rank ordered individuals on their novel putting performance above chance, with alerting and executive network scores being equally accurate and orienting scores being the most accurate.

In order to address the question of how focus instructions interact with the relationships between attention and motor performance, the second step of the analyses considered these relationships separately for external and internal focus groups. This was done using both correlation and rank order analyses. For the external focus instruction group, there was a significant correlation between orienting and putting ($r(10) = .68$, $p < .02$, $q < .04$), executive attention and putting ($r(10) = .65$, $p < .03$, $q < .04$), but not between alerting and putting ($r(10) = -.48$, $p > .11$, $q > .11$). Interestingly, no correlations were significant in the internal focus group (all $r(11) < .06$, $p > .80$, $q > .95$), suggesting that pre-existing differences in attention were only related to performance when an external focus was adopted. The scatter plots of each attention measure and putting performance for the two focus groups are shown in Fig. 4.

The rank order analysis results are shown in Fig. 5. For the external focus group, rank order accuracies using orienting ($M = 0.73$, SEM = 0.03), alerting ($M = 0.67$, SEM = 0.02), and executive attention ($M = 0.67$, SEM = 0.03) were all significantly above random chance permutations, all $t(22) > 4.5$, $p < .01$, $q < .01$. Additionally, orienting was significantly better at rank ordering subjects on their putting

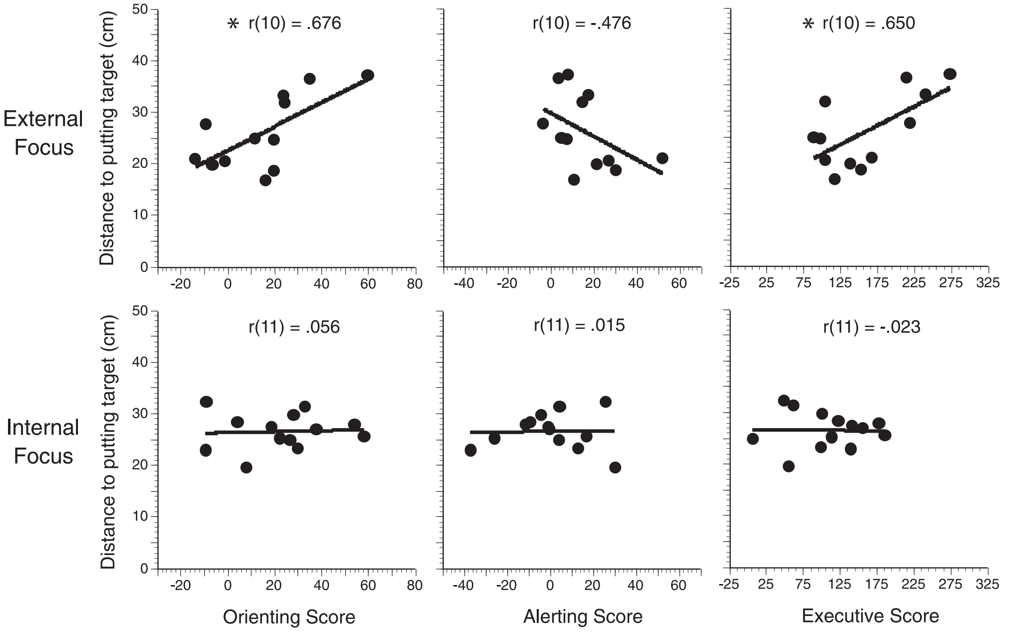

Fig. 4. Correlations between mean distance (in cm) from the putting target and attention task reaction time scores (in ms) are displayed for the external and internal focus groups. Asterisks indicate significance at $p < .05$.

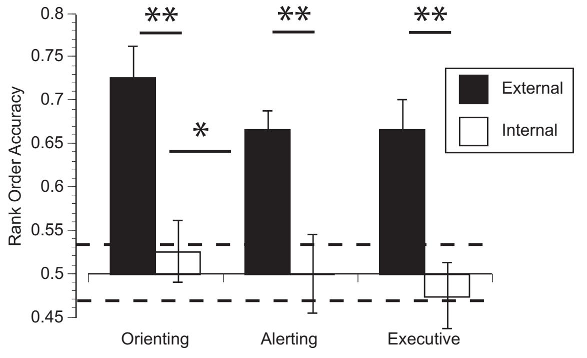

Fig. 5. Shown is the proportion correct for attention scores in rank ordering putting task accuracy in both the external and internal focus instruction groups. Error bars represent standard error of the mean. The dotted lines represent one standard error above and below random permutation. Single asterisks indicate significance at $p < .05$, double asterisks indicate significance at $p < .01$.

performance than alerting ($t(22) = 2.19$, $p < .04$, $q = .10$, $d = .61$), but not better than executive scores ($t(22) = 1.77$, $p = .09$, $q = .14$, $d = .51$). The alerting and executive rank order accuracies did not differ from each other ($t(22) < 0.01$, $p > .99$, $q > .99$, $d < .01$). Similar to the correlation results, rank order accuracies for the internal focus group did not differ from chance for any of the attention measures (all $t(24) < 0.90$, $p > .35$, $q > .35$, $d < .25$) and all were significantly lower than the accuracies for the external focus group (all $t(23) > 4.5$, $p < .01$, $q < .01$). Thus, all three attention measures could successfully order individuals in terms of their putting performance under external focus conditions, but not under internal focus conditions.

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4. Discussion

The first aim of this study was to determine whether the previous demonstrations of a relationship between visual attention and motor skill performance (e.g., Enns & Richards, 1997; Memmert, 2009; Voss et al., 2010) could be due to preexisting individual differences in attention rather than from the repeated performance of a skill. Second, the study aimed to determine if any relationships between attention abilities and motor skill performance were affected by manipulating the focus of attention during skill performance. These questions were investigated by measuring attentional functions using the ANT prior to performance of a golf-putting task with which the participants had no experience and in which half adopted an internal focus and half an external focus. Our results revealed relationships between different components of attention and motor skill performance overall, but critically they also revealed that these relationships were only present when an external focus of attention was adopted during motor skill performance. These findings have important implications for understanding the relationship between attention, motor performance, and the nature of focus instructions.

4.1. Individual differences in attention

Of the three attention functions of interest in the present study, the voluntary orienting of attention and the executive attention networks have clearly established relationships to athletic motor performance in the literature (e.g., Castiello & Umilta, 1992; Enns & Richards, 1997; Memmert, 2009; Voss et al., 2010). A key question, though, has been whether the difference in attention ability between skilled and unskilled athletes found in the literature arises out of practice in athletic skills or if the differences were in place before practice in the sport began. We found that when an external focus was adopted during motor skill performance, individual differences in both voluntary visual orienting and executive attention functioning were not only correlated significantly with motor performance, but these individual differences also could be used to accurately predict performance outcomes. This result suggests that previous findings of orienting and executive attention differences between skilled and unskilled athletes may be at least partially due to pre-existing individual differences. In contrast, visual phasic alerting has not been well studied in athletes. While the alerting measure did not correlate significantly with putting performance, the rank order accuracies revealed that alerting ability could be used to rank order putting performance above chance levels for the entire group as well as the external focus group alone, suggesting a role for alerting in motor skill performance. One possible explanation for the lack of significant correlations between phasic alerting and putting performance is that the context in which the motor skill task was performed may not have relied as heavily on alerting functions. Indeed, it is possible that under the appropriate conditions, such as tasks involving speeded performance or conditions of high stress, the predictive efficacy of the alerting measure would improve.

There are two key caveats regarding the finding that pre-existing individual differences in attention affect novel motor performance under external attentional focus conditions. The first caveat is that it is unclear whether individual differences in attentional functioning are due to some inherent trait in the individuals or whether these differences arise from prior training in other tasks. For example, attention could be modified through training in other athletic skills (Castiello & Umilta, 1992; Voss et al., 2010) or in other activities such as playing action video games, with the latter having been shown to modify various attention functions (Green & Bavelier, 2003). Thus, a third variable may be able to explain the correlations between putting performance and attention ability. However, even if a third variable is responsible, the present findings suggest that training methods that improve basic attention abilities may serve to improve novel motor performance as well. The second caveat is that the attention abilities measured here do not fully account for all of the variance in putting performance. This finding indicates that additional factors, yet to be determined, must play a role. Future studies are needed to explore the role that other cognitive functions (e.g., working memory) and other factors (e.g., personality traits) have in both short-term acquisition and long-term learning of motor skills. These caveats notwithstanding, it is clear from the present results that individual differences in well-studied visual attention capacities, whatever the cause, can benefit and predict the level of performance of a new motor skill.

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4.2. Skill focus: theoretical implications

A critical finding of this study was that the focus of attention adopted during motor skill performance was critical for revealing the relationship between individual differences in attention abilities and motor performance. It was found that the group given instructions emphasizing external skill components showed significant correlations and rank order accuracies between attention measures and putting performance while the group given internal focus instructions showed no clear relationships. The explicit monitoring hypothesis (Beilock & Carr, 2001) predicts better novice performance when attention is focused on the skill itself, but does not differentiate between internal skill-related and external skill-related focus. Therefore, it is difficult to clearly bring the present findings to bear on this hypothesis. On the other hand, the working memory (WM) load hypothesis (Poolton et al., 2006) predicts no differences between internal and external focus conditions when the WM load in the conditions is equated. In the present design, differences in working memory load between the focus conditions were carefully controlled for by matching the instructions given to each group, yet there was a clear effect of attentional focus on the relationship between individual differences in attention and putting performance.

Whereas the finding that the relationship between individual differences in attention ability and motor performance exists only under external and not internal focus provides a challenge for both explicit monitoring and working memory hypotheses, it can be readily explained by the constrained action hypothesis (Wulf & Prinz, 2001; Wulf, 2007). According to this hypothesis, both motor and perceptual processes are automatically coded in the brain in terms of the external environment (see Wulf & Prinz, 2001), so instructions that emphasize an external focus encourage this automatic motor planning whereas internal focus instructions override or interfere with these processes. This leads to the prediction that motor skills that rely on the functioning of attention will show stronger relationships with these attention functions when an external focus is adopted compared to an internal focus. However, there are multiple possible mechanisms that could lead to this enhanced relationship under an external focus and an absent one under an internal focus. While these possible mechanisms are not necessarily mutually exclusive, they do generate specific testable predictions.

One potential explanation for the influence of focus instructions on the attention-performance relationship hinges on differences in individual preferences for a focus of attention in the absence of instruction. Some studies have shown that motor skill performance is indistinguishable between groups who are given internal focus instructions and those in a control group without instruction (see Wulf & Su, 2007). Other studies have shown individual differences in the preference for internal and external skill focus and that this preference can play a role in performance outcomes when a non-preferred focus is adopted (Ehrlenspiel, Lieske, & Rübner, 2004; Weiss, 2011; Weiss, Reber, & Owen, 2008). Therefore, it may be that those individuals who have more control over volitional attention are better able to override a preferred internal focus and maintain an external focus. In other words, individuals with more efficient control over volitional attention abilities may be better able to adopt and maintain an external focus, thereby minimizing the likelihood that attention will interfere with the natural production of the motor skill under an internal focus. This explanation could be tested in future studies by measuring both individual attention abilities and focus preference. Additionally, this could be addressed by replicating the present study while forcing subjects to switch from a preferred focus or by manipulating the focus of attention within individual subjects.

A second possible explanation for the observed interaction with the focus of attention based on the constrained action hypothesis is that the automatic control processes supporting motor skill performance involve the three attention systems of orienting, alerting, and executive attention, and that these processes are disrupted when an internal focus is adopted. This disruption would effectively render individual differences in the functioning of attention systems useless during skill execution. It has been suggested that this disruption may be caused by subjects attempting to increase the amount of conscious control over automated or proceduralized motor processes (Masters & Maxwell, 2008; McNevin et al., 2003; Wulf, 2007), or alternatively by increasing the decision noise in the motor system (Zachry, Wulf, Mercer, & Bezodis, 2005). A strong interpretation of this account predicts that subjects who are particularly good at voluntarily focusing their attention (i.e., efficient orienters) would exert even greater interference of motor processes if assigned to the internal focus condition, resulting

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in poorer motor skill performance. However, such a negative relationship between attention and internal putting accuracy was not apparent in the present data.

A third possibility is that an internal focus prevents individuals from using relevant visual cues in the environment, whereas an external focus encourages the attentional processing of visual information that may be beneficial to task performance. The search for and use of relevant visual information in the environment is important for athletic performance (see Memmert, 2009) and the use of external skill-related information for motor execution is thought to be driving external focus benefits under the constrained action hypothesis (Wulf, 2007). This leads to the prediction that when an external focus is adopted during skill performance, visual attentional processing should be enhanced. This prediction could be tested by employing integrated behavioral methods to measure attention, the performance of motor tasks under degraded visual conditions, or by the use of neuroimaging methods such as electroencephalography (EEG) to probe the extent of visual processing during skill-focused conditions.

Each possible explanation of the focus effects outlined above is consistent with the constrained action hypothesis and these explanations are not mutually exclusive from each other. However, the unresolved cause of the interaction of attentional focus on the involvement of attention abilities in motor performance underlines the importance of investigating the specific mechanisms by which attentional focus affects motor execution. Although studies have found behavioral, kinematic, and neural benefits of external focus, future studies need to systematically test for interactions between multiple types of measures, including cognitive measures, in order to construct a detailed account of the mechanisms underlying the effect of focus manipulations. While the underlying mechanisms remain unresolved, the present data show that individual differences in attention and focus instruction manipulations interact to affect the performance of novel motor skills in a manner consistent with the constrained action hypothesis.

4.3. Skill focus: caveats

Although the influence of focus instruction on the attention-motor skill relationship is consistent with the constrained action hypothesis, the lack of an overall difference in putting performance between internal and external focus groups cannot be as easily explained. In fact, these results are inconsistent with previous studies showing strong benefits for external focus (e.g., Wulf & Prinz, 2001; Wulf, 2007), yet they are consistent with a study by Poolton et al. (2006) in which no performance effects were seen when internal and external instructions were matched in WM load, as they were in the present study. However, assuming an equal WM load here, the fact that attention abilities were related to putting only in the external group suggests that WM is not the sole determinant of differences in attentional focus.

One explanation for the lack of performance difference between the focus groups that may reconcile the constrained action hypothesis interpretation is that the effect of focus instructions on putting accuracy may have been obscured by random inherent differences in individual abilities assigned to the two groups. Indeed, the two groups differed in their alerting and executive scores that were measured at the outset. A follow-up analysis focusing on the individuals within one standard deviation for each attention network score served to equalize the two groups in terms of attention scores, and in the case of executive attention this equalization also resulted in the typical benefit in putting accuracy for the external focus group. However, this was not true for orienting or alerting measures, and these comparisons are limited by the relatively small sample size (7–9) in each condition. Future studies that control for the individual variability in attention efficiencies in each focus group are necessary for solving this potential dilemma. Additionally, although the instructions were worded and delivered in a manner very similar to those given in Experiment 2 of Poolton et al. (2006), in which manipulation checks revealed successful maintenance of attentional focus, the maintenance of proper attentional focus was not directly probed in the present work and so the WM explanation of these differential relationships cannot be completely ruled out. Nonetheless, the fact that attention abilities were related to putting performance only under external focus indicates that instructional focus manipulations did in fact cause differences in the engagement of attention during skill execution, despite the lack of an observed difference in overall putting accuracy.

5. Conclusion

In summary, the present study used simple laboratory tests of visual attention to predict the level of success in subsequent motor skill performance, but only when instructions emphasizing external focus were adopted during skill execution. These findings indicate that pre-existing attention abilities can influence the performance of a novel motor skill, at least under certain conditions. Furthermore, the finding that the relationship between attention abilities and motor performance was only apparent under instructions that focused attention to external skill components is consistent with the constrained action hypothesis of external focus benefits and provides a further understanding of the possible mechanisms underlying the effects of focus manipulations. These results highlight the importance of considering both pre-existing individual differences of cognitive functioning as well as the focus of attention during execution in studies of motor skill performance.

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References

Arent, S. M., & Landers, D. M. (2003). Arousal, anxiety, and performance: A re-examination of the inverted-U hypothesis. *Research Quarterly for Exercise and Sport, 74*, 436–444.

Aston-Jones, G., Chiang, C., & Alexinsky, T. (1991). Discharge of noradrenergic locus coeruleus neurons in behaving rats and monkeys suggests a role in vigilance. *Progress in Brain Research, 88*, 501–520.

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

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

Beilock, S. L., Bertenthal, B. I., McCoy, A. M., & Carr, T. H. (2004). Haste does not always make waste: Expertise, direction of attention, and speed versus accuracy in performing sensorimotor skills. *Psychonomic Bulletin & Review, 11*, 373–379.

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Society, Series B, 57*, 289–300.

Castiello, U., & Umilta, C. (1992). Splitting focal attention. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 837–848.

Ehrlenspiel, F., Lieske, J., & Rübner, A. (2004). Interaction between preference and instructions for a focus of attention in billiards. *Perceptual and Motor Skills, 99*, 127–130.

Enns, J. T., & Richards, J. C. (1997). Visual attentional orienting in developing hockey players. *Journal of Experimental Child Psychology, 64*, 255–275.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a non-search task. *Perception & Psychophysics, 16*, 143–149.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*, 340–347.

Green, C., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature, 423*, 534–537.

Janelle, C. M. (2002). Anxiety, arousal and visual attention: A mechanistic account of performance variability. *Journal of Sports Sciences, 20*, 237–251.

Kane, M., & Engle, R. (2002). The role of prefrontal cortex in working-memory capacity, executive attention, and general fluid intelligence: An individual-differences perspective. *Psychonomic Bulletin & Review, 9*, 637–671.

Masters, R., & Maxwell, J. (2008). The theory of reinvestment. *International Review of Sport and Exercise Psychology, 1*, 160–183.

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

Memmert, D. (2009). Pay attention! A review of visual attentional expertise in sport. *International Review of Sport and Exercise Psychology, 2*, 119–138.

Muller, H. J., & Rabbitt, P. M. A. (1989). Spatial cueing and the relation between the accuracy of "where" and "what" decisions in visual search. *Quarterly Journal of Experimental Psychology, 41*, 747–773.

Nougier, B., Ripoll, H., & Stein, J. F. (1989). Orienting of attention with highly skilled athletes. *Journal of Sport Psychology, 20*, 205–223.

Nougier, V., Azemar, G., Stein, J. F., & Ripoll, H. (1992). Covert orienting to central visual cues and sport practice relations in the development of visual attention. *Journal of the Experimental Child Psychology, 54*, 315–333.

Paller, K., & Shapiro, D. (1983). Systolic blood pressure and a simple reaction time task. *Psychophysiology, 20*, 585–592.

Poolton, J. M., Maxwell, J. P., Masters, R. S. W., & Raab, M. (2006). Benefits of an external focus of attention: Common coding or conscious processing? *Journal of Sports Sciences, 24*, 89–99.

Posner, M. I. (1980). Orienting of attention. *Quarterly Journal of Experimental Psychology, 32*, 3–25.

Posner, M. I., & Petersen, S. E. (1990). The attention system of the human brain. *Annual Reviews of Neuroscience, 13*, 25–42.
Posner, M. I. (2008). Measuring alertness. *Annals of the New York Academy of Sciences, 1129*, 193–199.
Rogers, R. D., & Monsell, S. (1995). Costs of a predictable switch between simple cognitive tasks. *Journal of Experimental Psychology: General, 124*, 207–231.
VaezMousavi, S. M., Barry, R. J., & Clarke, A. R. (2009). Individual differences in task-related activation and performance. *Physiology and Behavior, 98*, 326–330.
Vance, J., Wulf, G., Tollner, T., McNevin, N. H., & Mercer, J. (2004). EMG activity as a function of the performer's focus of attention. *Journal of Motor Behavior, 36*, 450–459.
Voss, M. W., Kramer, A. F., Basak, C., Prakash, R. S., & Roberts, B. (2010). Are expert athletes 'expert' in the cognitive laboratory? A meta-analytic review of cognition and sport expertise. *Applied Cognitive Psychology, 24*, 812–826.
Weiss, S., Reber, A., & Owen, D. (2008). The locus of focus: The effect of switching from a preferred to a non-preferred focus of attention. *Journal of Sports Sciences, 1049*, 1057.
Weiss, S. (2011). The effects of reinvestment in conscious processing on switching focus of attention. *Research Quarterly for Exercise and Sport, 82*, 28–36.
Wulf, G., Dufek, J. S., Lozano, L., & Pettigrew, C. (2010). Increased jump height and reduced EMG activity with an external focus. *Human Movement Science, 29*, 440–448.
Wulf, G., McNevin, N. H., & Shea, C. H. (2001). The automaticity of complex motor skill learning as a function of attentional focus. *The Quarterly Journal of Experimental Psychology, 54A*, 1143–1154.
Wulf, G., & Prinz, W. (2001). Directing attention to movement effects enhances learning: A review. *Psychonomic Bulletin & Review, 8*, 648–660.
Wulf, F., & Su, J. (2007). An external focus of attention enhances golf shot accuracy in beginners and experts. *Research Quarterly for Exercise and Sport, 78*, 384–389.
Wulf, G. (2007). Attentional focus and motor learning: A review of 10 years of research. *E-Journal Bewegung und Training, 1*, 4–14.
Yerkes, R. M., & Dodson, J. D. (1908). The relation of strength of stimulus to rapidity of habit-formation. *Journal of Comparative Neurology and Psychology, 18*, 459–482.
Zachry, T., Wulf, G., Mercer, J., & Bezodis, N. (2005). Increased movement accuracy and reduced EMG activity as the result of adopting an external focus of attention. *Brain Research Bulletin, 67*, 304–309.
Zentgraf, K., & Munzert, J. (2009). Effects of attentional-focus instruction on movement kinematics. *Psychology of Sport and Exercise, 10*, 520–525.

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