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Examination of Visual Information as a Mediator of External Focus Benefits

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Attunement to visual information has been suggested to mediate the performance advantage associated with adopting an external focus of attention (e.g., Al-Abood, Bennett, Moreno Hernandez, Ashford, & Davids, 2002; Magill, 1998). We tested this hypothesis by examining the extent to which online visual information underpins the external focus advantage. The study examined skilled golfers on a putting task under one of three attentional focus conditions: control (no instructions), irrelevant (tone counting), and external (movement effect focus), with either full or occluded vision. In addition to task performance, the effect of attentional focus and vision on between-trial movement variability was examined. We found a significant advantage for an external focus of attention in the absence of vision. The results of the movement variability analysis further indicated that external focus was not mediated by the online use of vision. We discuss these findings in the context of traditional cognitive perspectives to external focus effects.

Keywords: attention, common coding, vision, constraints-led perspective, movement variability, golf

Research has consistently shown that an individual's focus of attention can have a significant influence on task performance (e.g., Beilock, Carr, MacMahon, & Starkes, 2002; Gray, 2004; Jackson, Ashford, & Norsworthy, 2006; Land & Tenenbaum, 2012; Wulf, 2007a). Specifically, an external focus of attention has been found to facilitate both learning and outcome performance (see Wulf, 2007a, for a review). These benefits have been shown to generalize across a variety of complex motor skills, such as golf putting and chipping (Wulf, Lauterbach, & Toole, 1999), batting in baseball (Castaneda & Gray, 2007; Gray, 2004), basketball free throws (Zachry, Wulf, Mercer, & Bezodis, 2005), tennis serves (Wulf, McNevin, Fuchs, Ritter, & Toole, 2000), and performance on ski simulators (Wulf, Höß, & Prinz, 1998). Furthermore, an external focus directed specifically to the effects of one's movement on the environment (e.g., trajectory of a hit ball) has been demonstrated to be more beneficial than focus on movement technique (i.e., internal focus) or on non-skill-related stimuli (Castaneda & Gray, 2007; Wulf & McNevin, 2003). Unfortunately, however, the mechanism through which external focus benefits performance remains unclear (Poolton, Maxwell, Masters, & Raab, 2006). Largely, the findings pertaining to an external focus of attention have been made relative to an internal focus of attention. However, research findings imply that the benefit is not merely a result of preventing an internal focus of attention (Castaneda & Gray, 2007; Wulf & McNevin, 2003); thus, it is worthwhile to consider the underlying mechanisms independent of an internal focus reference.

Traditionally, researchers have suggested that external focus facilitates performance through priming of actions whose anticipated effects overlaps with the goal of the action (Hommel, 2007; Wulf, 2007b; Wulf & Prinz, 2001). Based on the principles of ideomotor theory (James, 1890; Lotze, 1852), Prinz's (1990) theory of common coding suggests that actions are encoded with respect to the perceivable effects they produce in the environment (Prinz, 1990, 1997). That is to say, actions are represented in terms of their reafferent effects (Hommel, 2007). Moreover, the anticipation of an action's perceivable effects is stated to automatically cue the associated sensorimotor representation, which acts to prime the desired motor execution (Kunde, Koch, & Hoffmann, 2004). Support for this assumption has come from experimental studies examining learning contingencies between actions and their effects (e.g., Elsner & Hommel, 2001; Hommel & Elsner, 2000; Kunde, 2001, Kunde et al., 2004). These studies have demonstrated that the preparation and selection of actions are mediated by the anticipation of the action's effect, such that the action effect becomes an effective retrieval cue or prime of the motor pattern (Hommel & Elsner, 2009). In regards to

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an external focus of attention, the anticipated perceivable effects of an action brought about by focusing attention externally are thought to play an important role in the planning and production of action through priming the sensorimotor representations whose distal effects are most associated with the action goal (Ford, Hodges, & Williams, 2007).

More recently, however, a different conceptualization of the mechanisms underlying external focus of attention has been offered based on a constraints-led perspective to motor control (see Davids, 2007; Davids, Button, & Bennett, 2008). This approach suggests that an external focus promotes the self-organization of dynamic properties of the system, namely, by facilitating attunement to information that specifies the affordances of the environment. More specifically, Davids (2007) suggested that an external focus on movement effects could aid a performer's exploration of specifying information by framing (i.e., directing the search for) the relevant affordances for task execution. In functional terms, the claim is that an external focus of attention "directs" the pick-up of relevant environmental information that, in turn, fosters perception–action coupling and constrains self-organization of task performance (Davids et al., 2008).

Consistent with the constraints-led perspective, vision and visual information has been viewed as a potential mediator of external focus benefits (e.g., Al-Abood, Bennett, Moreno Hernandez, Ashford, & Davids, 2002; Hodges & Ford, 2007; Magill, 1998). Although each of the five sensory modalities can play a role in the attunement to environmental constraints, vision is typically the most useful source of information in goal-directed movements (Carlton, 1981, 1992; Heath, 2005). In this regard, Magill (1998) suggested that an external focus might act to direct visual focus to "information-rich areas" that contain important environmental regulatory features (i.e., features in the environmental context that "regulate" how the body and limbs must move to successfully achieve the goal). Moreover, Russell (2007) suggested that attention to an external cue may emphasize changes in optic flow. Consistent with these assertions, a study by Al-Abood et al. (2002) examined the visual behaviors of participants while watching a video of a skilled model performing a basketball free-shooting task. Before watching the video, participants were given verbal instructions to focus either on movement form or movement effects. Results indicated that the "movement effects" group significantly outperformed the "movement form" group on a follow-up performance test. In addition, examination of visual gaze behaviors indicated that the "movement effect" group spent more time viewing information outside the body than the "movement form" group, which suggests that the difference between the groups may be related to the use of external sources of visual information.

The common-coding and constraints-led approaches provide different accounts for the underlying mechanism behind the beneficial role of external focus. For instance, if the benefit associated with an external focus is mediated by the attunement to environmental information by means of visual information, then one might expect that a disruption to visual information during movement, without removing an external focus of attention per se,[1] would effectively disrupt perception–action coupling and eliminate the observed benefit to performance. In contrast, if an external focus cues action–effect representations, or some other cognitively mediated mechanism, then the availability of visual information would not be expected to affect the relative performance benefits typically observed when adopting an external focus.

Examination of underlying movement trajectory variability may also provide an indicator of the degree to which vision mediates external focus (Khan et al., 2006). Research on goal-directed movements has indicated large reductions in trial-to-trial spatial variability toward the end of a movement when visual feedback is available (Elliott et al., 2010; Khan et al., 2006). In this regard, reductions in movement variability can represent the continued attunement of the motor system to continuous visual information. Support for this contention has come from research examining the distribution of temporal and spatial variability across repeated trials (see Bootsma & van Wieringen, 1990; Khan et al., 2003). For example, Bootsma and van Wieringen (1990) found that expert table tennis players exhibited high levels of trial-to-trial temporal variability at the initiation of a forehand drive, with reducing variability as paddle–ball contact approached. The authors stated that this reduction reflects the compensatory nature of perception–action coupling within the performer.

If one considers that external focus facilitates the attunement to environmental constraints via visual information, then an external focus should result in a greater reduction in trial-to-trial spatial variability as movement is continuously fine-tuned toward contact compared with conditions that do not support online processing of visual information (e.g., no vision or irrelevant focus, presumably). Under conditions when visual information is not available during movement execution, the benefit of external focus would be effectively eliminated, and thus the level of between-trial variability would be similar to that of conditions that do not facilitate the use of visual information.

Given these conceptual differences pertaining to the mediating effects of vision, the purpose of the current study was to examine the extent to which limiting the availability of visual information during movement execution negates the advantages of an external focus. If external focus acts to cue underlying action–effect representations, we hypothesized that external focus would maintain a relative performance advantage regardless of the availability of visual information during performance. In contrast, if external focus facilitates attunement to visual information, we hypothesized that external focus would only benefit performance when visual information is made available during performance. To test these predictions, we examined performance on a golf-putting task while participants were instructed either to focus their attention on the effects of movement (i.e., external focus), to perform an irrelevant (i.e., tone counting) task, or were given no focus instructions (i.e., control). Participants engaged in each condition with both full and occluded vision. The irrelevant focus condition allowed us to show that focusing attention externally on the action effects of one's movements is more beneficial than focusing on an external distraction, which has largely been assumed to be effective because it inhibits the ability to focus on movement technique (Beilock et al., 2002). In addition, a secondary aim of the current study was to explore the relationship between kinematic variability and visual information under conditions altering in attentional focus. More specifically, if external focus is mediated by visual information, we predicted a reduction in spatial movement variability as time to contact decreases relative to the other conditions only when visual information is available.

Method

Participants

Thirty male participants ($n = 10$ each in control, external, and irrelevant focus conditions) were recruited to participate in the study. Participants consisted of experienced golfers with a United States Golf Association (USGA) handicap of ≤ 12 ($M_{\text{handicap}} = 6.51$, $SD = 3.4$). A handicap of 12 or below was selected to represent experienced golfers as only 35% of the male golfing population meets this standard (Men's USGA Handicap Index Statistics, 2011). Golfers for this study were recruited from a local golf course and ranged in age from 29 to 69 ($M = 47.93$, $SD = 14.37$) with an average of 30.21 ($SD = 13.75$) years of golf experience. No significant differences in age, skill level, or number of years playing golf existed for participants across treatment conditions, (all $p > .05$). Informed consent was provided before participation and the ethical procedures recommended by the university's institutional review board were strictly followed.

Apparatus

To record putting performance, a JVC Everio (GZ-MG630AU) video camera was mounted directly above the putting surface to capture a top-down view of each putt. The lens of the camera was mounted above and parallel to a simulated golf hole—a thin white disc equal in size to a regulation golf hole (10.8 cm in diameter) placed on the putting surface. The putting surface consisted of an outdoor practice golf green with a bent grass (*Agrostis*) surface. Participants performed the golf-putting task using a Titleist Scotty Cameron golf putter and Titleist Pro V1 golf balls.

Movement variability was assessed using Science and Motion (SAM) Puttlab technology (Science & Motion, Munich, Germany). SAM Puttlab is a motion tracking system in which three ultrasound transmitters are attached to the shaft of the golf club (positioned at a distance of 25 cm from the lower edge of the putter head) and tracked in 3-dimensional space. The overall sampling frequency of the unit was 210 Hz and with an error rate of < 0.1 mm and 0.1 degree at a distance of 1.5 m from the receiver unit (Marquardt, 2007).

Task and Procedure

The putting task required participants to putt a golf ball to a target (i.e., simulated golf hole) 10 feet (3.05 m) away. The objective was to putt the ball as accurately as possible to the hole. Once the participants were given the task, they were allowed to make five practice putts to familiarize themselves with the speed and slope of the green. Next, participants were randomly assigned to one of three attentional focus conditions: control, external focus, and irrelevant focus (see below). Participants in each condition took 40 ($k = 20$ full vision, and $k = 20$ occluded vision) test putts.

Attentional Focus Conditions

To manipulate and direct attentional foci, explicit verbal instructions were given to the participants before the experimental conditions (see below). The verbal instructions drew largely from the research of Bell and Hardy (2009) and Wulf et al. (2000). The use of verbal instructions to induce a particular focus of attention is considered an acceptable method of studying attentional focus (Castaneda & Gray, 2007).

Control Condition. Participants in the control condition were not given any attentional focus instructions. They were instructed to putt as normal.

External Focus Condition. Participants in the external focus condition were explicitly instructed to focus on the external effects of the putting stroke while attempting to make as many golf putts as possible. Specifically, they were instructed to focus on the "direction and speed of the ball rolling to the golf hole" during the movement execution. After completion of each putt, participants were then asked to estimate the final outcome of the putt relative to the hole. The instruction to report the envisioned outcome location was intended to help participants adhere to the external focus of attention.

Irrelevant Focus Condition. Participants in the irrelevant focus condition were instructed to perform a secondary tone-counting task while attempting to make as many putts as possible. After participants took their stance over the golf ball, audible tones were produced by a computer at irregular intervals ranging from 900 to 1500 ms. After completion of the putt, participants were then instructed to indicate the number of tones presented during performance.

Visual Occlusion and Knowledge of Results

Participants were tested under full and occluded vision. Regardless of visual condition, all participants wore visual occlusion spectacles (PLATO Model: P-1, Translucent Technologies, Toronto, Ontario, Canada,). Before task execution, all participants regardless of visual condition, were allowed to set up to the ball with full vision (i.e., with the spectacles set to translucent). In the full vision condition, participants had full vision throughout the execution of the putt. However, approximately 1.5 s after clubhead–ball contact,[2] the spectacles were manually set to opaque until the outcome of the putt could be recorded. This allowed us to limit knowledge of results, and thus variability in the outcome and movement kinematics associated with feedback-based corrections from one trial to the next, while still providing full vision throughout movement execution. In the occluded condition, the spectacles became opaque once the participants verbally indicated that they had set up to the golf ball, and remained opaque during movement execution and recording of the outcome.

Postexperimental Manipulation Check

After completion of each visual condition, participants were administered a questionnaire designed to gauge the extent to which they adopted the attentional focus strategies (adapted from Bell & Hardy, 2009). Participants were asked to respond to the following question: Please, indicate which statement best reflects what you were thinking about during performance? Response categories consisted of the following options: (a) *movement/technique*, (b) *outcome/ball going to hole*, (c) *audible tones*, (d) *other*. In addition, the responses from each trial—indicating either the outcome of each putt (external focus condition) or the total number of tones heard (irrelevant focus condition)—were used to examine adherence to the attentional focus manipulation.

Dependent Measures and Statistical Analyses

Outcome performance and movement variability were used to measure putting performance. Outcome performance was defined as the number of successful putts indicated by the number of putts that stopped on or rolled over the simulated hole. The number of successful putts was examined via a repeated-measures analysis of covariance (RM ANCOVA) with vision as the within-participants factor, and attentional condition as the between-participants factor using skill level (i.e., handicap) as a covariate. While the three experimental conditions did not differ on overall skill level, handicap was used as a covariate to control for the wide range of skill levels within the conditions.

Three-dimensional movement variability of the golf club trajectory was derived from the raw Cartesian coordinates (i.e., x, y, z positions) generated by SAM PuttLab. The raw data stream was smoothed to remove any inherent noise (random error) using a predefined filter (kernel estimates; filter settings = 50 Hz) within the SAM PuttLab software (see Marquardt & Mai, 1994). Using the smoothed data, each swing trajectory was time-normalized to 100% of the forward swing phase (i.e., from the start of the forward swing to the impact with the ball). The degree of spatial movement variability was calculated for five time points (0%, 25%, 50%, 75%, and 100% of movement time) during the forward swing. For each time point separately, three-dimensional centroids were calculated for each participant based on their averaged x, y, z coordinates. The deviation[3] of each individual trial from the respective centroid was calculated to create a measure of spatial variability over repeated trials for each participant. Finally, the within-participants standard deviations from the centroids were examined via a RM ANOVA[4] consisting of time points (1–5) and visual conditions (full and occluded) as within-participants factors, and attentional conditions (e.g., control, external, and internal) as a between-participants factor.

To examine adherence to the prescribed attentional focus instructions, separate chi-square tests (χ^2) were performed on the distribution of responses to the manipulation check questionnaire for trials with vision and without vision. Furthermore, for the irrelevant focus condition, a paired-samples t test was used to determine whether visual condition impacted the degree to which participants attended to the tones. In addition, a bivariate correlation was performed to determine the degree to which tone-counting accuracy was correlated with putting performance. Procedural adherence to predicting the outcome for every trial in both vision and no-vision conditions was used as an indicator of protocol adherence for the external focus condition.

Results

Manipulation Checks

Nonparametric χ^2 test revealed significant differences in reported attentional focus strategies between treatment conditions in both vision and no-vision trials, $\chi^2(6, N = 30) = 50.182$, $p < .001$, and $\chi^2(6, N = 30) = 44.667$, $p < .001$, respectively. Interestingly, the control group, which was given no attentional focus instructions, consistently adopted a technique/movement-related focus of attention. Specifically, when vision was available, 80% of the participants in the control group adopted a movement-related focus, whereas 100% of them adopted a movement-related focus when vision was occluded. The majority of participants in the external focus condition, regardless of visual manipulation, reported adopting a focus on the outcome/ball going to the hole (90% during trials with vision and 70% when vision was removed). Finally, for the irrelevant focus condition, the majority of participants reported focusing on the audible tones during performance, regardless of visual manipulation (100% during trials with vision, and 80% when vision was unavailable). These findings indicated that the participants focused as instructed.

In addition, the individual posttrial responses for the irrelevant (i.e., number of tones heard) and external focus (i.e., predicted outcome location) conditions were examined as indicators of protocol adherence. For the irrelevant focus condition, a paired-samples *t* test indicated that the number of correct tones reported during full and occluded vision conditions were not significantly different, $t(9) = -.958$, $p = .363$. Furthermore, a bivariate correlation between tone-counting accuracy and the number of putts made indicated a nonsignificant relationship for both vision ($r = .47$, $p = .163$) and occluded vision ($r = .12$, $p = .743$). Consequently, tone-counting accuracy for vision (78%) and occluded vision (81.5%) did not differ. Likewise, tone-counting accuracy was not related to outcome performance.

Posttrial responses for the external focus condition (i.e., predicted outcome locations) were reported for 100% of all trials (both vision and no vision). Thus, participants were considered to have adequately followed the attentional focus protocol.[5]

Outcome Performance

Results from the RM ANCOVA indicated a significant main effect for attention condition, $F(2, 26) = 7.33$, $p = .003$, $\eta_p^2 = .36$ (see Figure 1). Pairwise comparisons revealed that participants in the external focus condition ($M = 12.47$, $SD = 4.11$) made significantly more putts than both the control ($M = 5.54$, $SD = 4.08$) ($p = .001$, $d = 1.69$) and irrelevant task conditions ($M = 7.80$, $SD = 4.08$) ($p = .018$, $d = 1.14$). The control and irrelevant attention conditions did not differ significantly on the number of successful putts ($p = .224$, $d = 0.55$). The main effect of visual condition, $F(1, 26) = 0.75$, $p = .392$, $\eta_p^2 = .03$ and attention by visual condition interaction, $F(1, 26) = 0.95$, $p = .399$, $\eta_p^2 = .07$ were not significant, suggesting that the amount of visual information available did not impact the number of putts made (see Figure 1).

Movement Trajectory Variability

The second aim of the study was to examine the relationship between kinematic variability under conditions altering in vision and attentional focus. Due to violations of sphericity, the Greenhouse–Geisser adjustment to degrees of freedom and significance was employed. Results indicated three significant effects. First, a main effect of visual condition was identified, $F(1, 26) = 9.99$, $p = .004$, $\eta_p^2 = .28$. When putting with vision, participants produced less overall spatial variability across all time points ($M = 11.32$, $SD = 4.33$) than when putting with occluded vision ($M = 13.29$, $SD = 4.22$; $d = -.46$). Second, a main effect of time was revealed, $F(1.3, 33.1) = 58.48$, $p < .001$, $\eta_p^2 = .69$. From the start of the forward swing until impact, the degree of spatial variability decreased according to a significant cubic function, $F(1, 26) = 53.93$, $p < .001$, $\eta_p^2 = .68$. More importantly, however, the RM ANOVA produced a significant interaction effect for attention condition by time, $F(2.6, 31.1) = 4.62$, $p = .011$, $\eta_p^2 = .26$. Visible inspection of this interaction is presented in Figure 2. Follow-up post hoc comparisons indicated that the three conditions did not significantly differ in the degree of spatial variability during the first half of the forward swing (Times 1, 2, and 3). However, at Time Phase 4 (75% of forward swing), participants in the irrelevant condition displayed significantly less spatial variability ($M = 8.73$, $SD = 6.57$) compared with the control condition ($M = 13.25$, $SD = 6.24$), $F(1, 26) = 7.46$, $p = .011$, $\eta_p^2 = .22$, $d = .71$. In addition, significant differences were observed at Time Phase 5 (100% of

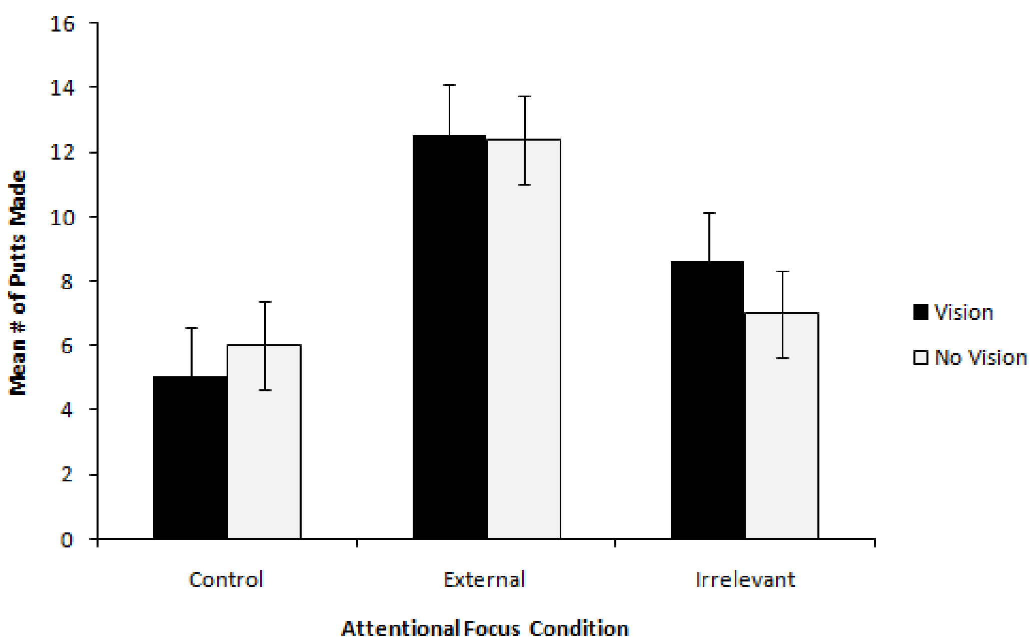

Figure 1 — Average number of putts made across vision and attentional focus conditions. Error bars display standard errors.

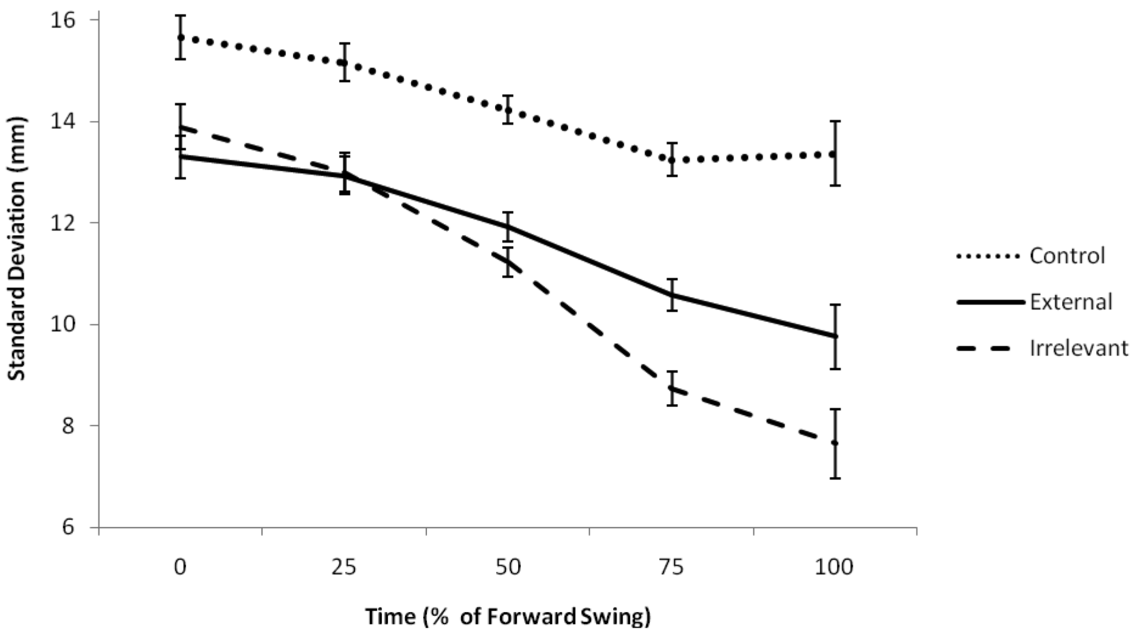

Figure 2 — Mean standard deviations of spatial variability over time for the control, external, and irrelevant condition. Error bars display standard errors.

forward swing) between the control condition ($M = 13.37$, $SD = 6.08$) and both the external condition ($M = 9.75$, $SD = 6.08$) and the irrelevant condition ($M = 7.64$, $SD = 6.41$), $F(1, 26) = 5.29$, $p = .030$, $\eta_p^2 = .17$, $d = .60$ and $F(1, 26) = 12.58$, $p = .002$, $\eta_p^2 = .33$, $d = .92$, respectively. All other post hoc comparisons were not significant (all $p > .05$). Finally, the attention condition main effect and the Attention condition × Visual condition × Time interaction of the omnibus RM ANOVA failed to reach significance, $F(2, 26) = 2.14$, $p = .138$, $\eta_p^2 = .14$ and $F(8, 104) = 0.57$, $p = .804$, $\eta_p^2 = .04$, respectively.

Discussion

The primary aim of the current study was to determine whether the benefit to performance associated with adopting an external focus of attention could be accounted for by the utilization of visual information during movement execution. To this end, two sets of hypotheses were proposed. From a common-coding perspective (Prinz, 1990), it was hypothesized that an external focus would benefit performance regardless of the availability of visual information during movement execution. From this perspective, external focus was suggested to prime action–effect representations before action execution without recourse to online visual information available in the environment. In contrast, if the benefits associated with an external focus were mediated by the online use of visual information, then an external focus would only be advantageous to performance during trials when vision was made available. To test these alternative hypotheses, the current study examined the impact of visual information during task performance while adopting either an external, control, or irrelevant focus of attention. In a second aim, an examination of the kinematic processes underlying task performance was undertaken in an attempt to further distinguish the degree to which external focus relies on visual information.

Results of the current study did not support vision as a mediator of external focus benefits. Specifically, regardless of the availability of visual information, performance during the external focus condition was superior (i.e., greater number of successful putts) compared with the control and irrelevant focus condition (see Figure 1). This finding is consistent with a growing body of research that suggests that external focus facilitates superior performance in skilled performers (see Wulf, 2007a, for a review). Furthermore, the current findings support the growing evidence that focus on the anticipated effects of one's movement in the environment is more advantageous than simply distracting performers' attention externally and away from skill execution (i.e., irrelevant focus) (Castaneda & Gray, 2007; Wulf & McNevin, 2003).

Although results indicated no significant differences in the number of putts made between the control and irrelevant focus conditions, the magnitude of the difference (in favor of the irrelevant focus condition) resulted in a medium effect size (d =.55), on average, two and a half more putts than the control condition. Early research examining the impact of external focus suggested that the benefit was associated with a prevention of an internal focus of attention (e.g., Beilock et al., 2002). Conditions that shift the focus of attention away from an internal focus have, ironically, been termed "nonskill" or "irrelevant" focused attention, and have been shown to facilitate performance (e.g., Beilock, Bertenthal, McCoy, & Carr, 2004). When participants in the current study were given no attentional focus instructions (i.e., control group), they almost solely adopted a movement/technique-related focus (i.e., internal focus). Based on findings from previous studies (e.g., Beilock et al., 2004; Castaneda & Gray, 2007) and the current study (see irrelevant condition), it appears plausible that a nonskill focus is beneficial to some degree because it helps prevent an internal focus of attention (adopted by the control group in this study that performed the worst). However, nonskill-focused attention does not provide the added benefits associated with an external focus directed toward movement effects.

While individuals in the external focus condition outperformed those in the control and irrelevant conditions when vision was unavailable, interestingly, performance (i.e., number of successful putts) in general was not substantially degraded when vision was removed. A similar result was found by Williams, Weigelt, Harris, and Scott (2002), who observed that the ability of 12-year-old skilled soccer players to control a soccer ball was not significantly impacted by the removal of vision. A lack of impact on task performance as a result of the removal of visual information has been claimed to support the notion that skilled performance is mediated via mental representations (Ford, Hodges, Huys, & Williams, 2006). In this regard, extended practice is stated to result in more efficient and refined representations, which place fewer demands on sensory information required during movement execution (Hodges, Huys, & Starkes, 2007). Consequently, the skilled performers in the current study may not have required visual information once the movement had been planned and prepared.

The second aim of the current study was to explore the extent to which external focus is mediated by visual information through examination of between-trial movement variability. In goal-directed movements, a reduction of between-trial movement variability is taken to represent the continuous online control of movement execution as the motor system adapts to changes in system constraints (Davids et al., 2008). Furthermore, vision has been found to facilitate the reductions in between-trial variability as movements approach contact (Khan et al., 2006). Consequently, it was predicted that if the online processing of visual information mediates external focus benefits, then greater reductions in between-trial variability as the time to contact decreases would be observed for the external focus condition compared with the irrelevant and control groups. However, this relative reduction was predicted to be evident only when visual information was available during movement execution.

The analysis of movement variability, however, failed to support the role of vision as a mediator of external focus effects. Examination of movement trajectory variability indicated three main findings. First, a significant change in the degree of spatial variability at different points in the putting stroke was identified. Specifically, early in the forward swing, spatial movement variability was elevated, but decreased as the clubhead approached ball contact (see Figure 2). Typically, a funnel-like expression of variability toward an end point has been taken to imply actions regulated by perceptual information (Button, MacLeod, Sanders, & Coleman, 2003).

Similar descending trends in trial-to-trial movement variability have been observed in sports such as the long jump, triple jump, and table tennis (Davids, Glazier, Araújo, & Bartlett, 2003). However, most closely related, Koenig, Tamres, and Mann (1994) observed similar changes in the variability of ground force productions during a golf swing. Regardless of skill level, Koenig et al. found increased variability at the initiation and midpoint of the downswing, followed by decreased variability through impact. Davids et al. (2003) suggested that the descending trends reflect an apparent “zeroing-in” phase indicative of both inherent and functional movement variability. The reduction in variability at impact is stated to represent a continued attunement of the motor system to continuous perceptual information and environmental constraints (Davids et al., 2008). However, this online attunement need not be exclusively mediated by visual information. Given that the rate of change in the variability profiles in the current study did not differ between vision and no-vision trials (i.e., nonsignificant vision by time interaction) indicates that this decrease in variability approaching contact was not based on the online processing of visual information (Khan et al., 2006). To this extent, Khan et al. (2006) provided evidence that reductions in movement variability toward the end of the movement can also be mediated by proprioceptive information, which would account for the findings in the current study.

More importantly, however, the second main finding from the movement variability data indicated a significant interaction effect between attention condition and the change in variability over the course of the forward stroke (see Figure 2). Contrary to our predictions, the external focus condition did not exhibit larger reductions in movement variability compared with both the irrelevant and control group. Specifically, no significant differences in movement variability were observed between the irrelevant and external focus conditions, whereas both conditions indicated significantly reduced variability approaching clubhead–ball impact compared with the control group. In light of the control group overwhelmingly reporting a technique/movement-related focus, this finding is consistent with other studies that have found increased variability associated with an internal focus of attention (e.g., Gray, 2004; Hossner & Ehrlenspiel, 2010; Zachry et al., 2005). For instance, Gray (2004) found increased dysfunctional variability (i.e., variability in movement dynamics that leads to increased variability in outcome) in batting kinematics when experts adopted a skill-focused attention. More specifically, a return to conscious processing under skill-focused attention was suggested to result in expert performers relying heavily on working memory, subjecting the motor system to increased amounts of noise from delays in reaction times and memory retrieval.

Finally, analysis of movement variability revealed a significant main effect of vision on reducing overall levels of variability during the putting stroke. When vision was available, participants displayed significantly lower levels of movement variability across the entire putting stroke. Reductions in overall movement variability in the absence of a change in the rate at which variability reduces approaching ball contact (i.e., vision by time interaction) reflects offline rather than online processing of visual information (Khan et al., 2003, 2006). In the current study, the removal of visual information before movement execution appears to have influenced the preprogramming or feedforward mechanisms associated with the golf putt, but this lack of vision did not influence the online control of the putting stroke.

Overall, results of the movement variability analysis indicated that online visual information was not the primary mediator of external focus effects. Specifically, an external focus of attention did not result in a change in the rate of reduction of movement variability toward contact with the ball. While the results indicated that vision was associated with the offline processing of visual information, this was not influenced by focus of attention. This finding may provide preliminary evidence that an external focus is also likely not mediated by the offline processing of visual information. However, more research is needed to address the extent to which visual information *prior* to movement execution (during movement planning) may mediate external focus benefits.

Conclusions

While multiple perspectives have been forwarded to account for the advantage of external focus, the results of the current study clearly demonstrate that external focus effects are strong and independent of online visual information. Rather, the results suggest that external focus effects are largely cognitively mediated. However, the exact processes underlying a cognitive approach remain unclear. Future studies are needed to more directly assess the cognitive mechanisms underlying external focus. Specifically, whether external focus aids the retrieval of sensorimotor representations would be one step in confirming the underlying mechanisms espoused by the common-coding perspective. The present study, however, does not rule out the possibility that external focus facilitates attunement to specifying information in the environment by means other than vision (e.g., proprioceptive feedback). Thus, more research is warranted. While the current study does not provide final clarity as to the mechanisms underlying external focus, it does provide important directions from which to continue the search.

Notes

1. By definition, an external focus of attention does not necessitate a visual focus on the effect that is attended. In many cases, a valid external focus of attention may be on movement effects that occur after an action (e.g., trajectory of a basketball free throw). Thus one can have an external focus per se without visual fixation on the attended effect. In this case, an external focus may facilitate attunement to current visual sources of information that may be relevant for the attended effect. For instance, an external focus during basketball shooting on the trajectory of the shot might facilitate attunement and the continuous updating of visual information pertaining to the relation between shooter and rim, which is used for determining force, direction, and velocity (Oudejans, Koedijker, Bleijendaal, & Bakker, 2005).

2. At this point, the ball was roughly just past the left foot of a right-handed golfer.

3. Calculated as the distance in three-dimensional Euclidean space between the centroid and the coordinates for a single trial.

4. Skill level was not used as a covariate due to nonsignificant and low correlations with the dependent variables (all *r*s < .20).

5. No hypotheses were made as to the accuracy of the outcome predictions as an indicator of protocol adherence. It is likely that accuracy of outcome predictions (i.e., outcome error detection) is more of an indicator of skill level rather than level of external focus (e.g., Schmidt & White, 1972).

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