Effects of Vision on Head-Putter Coordination in Golf

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Low-skill golfers coordinate the movements of their head and putter with an allocentric, isodirectional coupling, which is opposite to the allocentric, antidiirectional coordination pattern used by experts (Lee, Ishikura, Kegel, Gonzalez, & Passmore, 2008). The present study investigated the effects of four vision conditions (full vision, no vision, target focus, and ball focus) on head-putter coupling in low-skill golfers. Performance in the absence of vision resulted in a level of high isodirectional coupling that was similar to the full vision condition. However, when instructed to focus on the target during the putt, or focus on the ball through a restricted viewing angle, low-skill golfers significantly decoupled the head—putter coordination pattern. However, outcome measures demonstrated that target focus resulted in poorer performance compared with the other visual conditions, thereby providing overall support for use of a ball focus strategy to enhance coordination and outcome performance. Focus of attention and reduced visual tracking were hypothesized as potential reasons for the decoupling.

Keywords: allocentric coordination, visual attention, focus of attention

Putting is arguably the most important skill in the game of golf, representing the highest proportion of total shots during a round among golfers of all skill levels, including members of the PGA tour (PGA Tour Statistics: 2009 PGA Tour Putts Per Round, 2010). Therefore, acquiring better putting skill is important for any person learning to play golf, or those wanting to improve their score. In a previous study, we found that golfers of high levels of expertise executed putts with a qualitatively different coordination pattern than did golfers of low skill level (Lee, Ishikura, Kegel, Gonzalez, & Passmore, 2008). The experts in that study performed their puts with an allocentric, antidiirectional coordination pattern (moving in mirror symmetry)—as the putter pulled away from the ball during the backswing the motion of the golfer’s head went toward the hole, then reversed direction away from the hole as the putter moved forward to strike the ball. The result was a tightly coupled, negative correlation of the head-putter motions for displacement and velocity profiles. The poor golfers, in contrast, displayed an
allocentric, isodirectional (moving limb segments in same direction in extrinsic space) coordination pattern during their putts—their head and putter moved in the same directions during the backswing and forward swing, resulting in high-positive correlations (see Swinnen, 2002).

One hypothesis that accounts for this difference in coordination patterns between an inherent (or preferred) coordination pattern (in low-skill golfers) and a learned pattern (in experts) concerns a fundamental difference in the manner in which coordination is mediated by vision. In rhythmic coordination of the upper limbs for example, there are two inherent patterns (in-phase and antiphase) that are easy to perform without practice and which dominate all other coordination patterns (Kelso, 1984; Yaminishi, Kawato, & Suzuki, 1980). However, given sufficient practice and information feedback, new coordination patterns can be learned and stabilized (Lee, Swinnen, & Verschueren, 1995; Zanone & Kelso, 1992). Therefore, one hypothesis that could explain the difference in coordination patterns between high- and low-skilled golfers simply reflects the role of practice and learning to decouple the head and putter coordination via visual input. We suggest that vision serves a critical role in the coordination pattern that is spontaneously adopted and that experts have learned to decouple this isodirectional tendency and it is believed that the performance of experts is the gold standard of performance (Datta, Mandalia, Mackay, Chang, Cheshire, & Darzi, 2002; Gonzalez, Carnahan, Praamsma, & Dubrowski, 2007). Therefore it is speculated that adopting an antidirectional pattern similar to experts, would be more beneficial.

Differences in visual attention between high-and low-skilled golfers have been previously demonstrated (Vickers, 2004) as quiet eye affects putting performance—experts have longer quiet eye durations, which are used to focus on the ball just before the stroke is performed. To maintain quiet eye if a head movement occurs during the stroke, a corresponding head movement is required to maintain foveation on the ball once the stroke has begun (Vickers, 2004). However, an isodirectional coordinated head-putter movement would likely result in poor quiet eye due to the movement of the head away from the ball. That is, during this type of movement the head is moved away from the ball and forces the individual to compensate with a visual pursuit of the ball, or it would result in a foveation away from the ball. As well, previous research (Williams & Davids, 1998) suggests that visual attention to relevant detail is attained through expertise as it is a learned skill, thereby suggesting that novice may have difficulties fixating on the proper details. Therefore, it seems plausible that as individuals move their head away from the ball, as lower-skilled players do (Lee et al., 2008), this would result in shorter quiet eye times.

Research on the quiet-eye effect suggests that low-skill athletes, including golfers, are prone to making more frequent eye movements of less duration than experts (Vickers, 2004; Mann, Coombes, Mousseau, & Janelle, 2011). One of the strong attractions in the performance of a putt is to watch the putter during the preball strike and then to watch the ball as soon as it leaves the putter, toward the hole. By this view, the low-skill golfer uses eye and head rotations to track the putter and ball, thus resulting in a tightly-coupled isodirectional coordination pattern. In contrast, the high-skill golfer has learned to avoid this coordination pattern by maintaining, by what would later be termed, quiet-eye (Vickers, 1996) contact with the ball throughout the putt (Vickers, 1992). As well the work of Mann et al. (2011) demonstrated that higher-skilled golfers had longer quiet eye times com-
pared with lower-skilled golfers, which the authors hypothesize for the increase percentage of successful putts. This finding, that longer quiet eye time may reflect increase in performance, is demonstrated in the work of Vine and Wilson (2010) as well as Vine, Moore, and Wilson (2011). Vine and Wilson (2010) trained unskilled golfers to increase their quiet eye, which demonstrate that the individuals who received the quiet eye training improved performance only in the pressure condition (induce levels of cognitive anxiety) and was replicated by the findings from Vine, Moore, and Wilson (2011). Vine, Moore, and Wilson (2011) as well added analysis on distance from the hole which demonstrates an increase in performance for the group that received quiet eye training; however there is no mention to what orthogonal direction the performance increased. Therefore, it seems plausible that manipulating quiet eye can lead to greater performance outcomes in putting, but it is not well understood how this affects behavioral or outcome measures.

Perhaps a function that results from learning to increase quiet eye is to disengage from visually tracking the putter. An added benefit is that increasing the quite eye of participants may lead to an external focus of attention (Wulf, 2007; Wulf, Lauterbach, & Toole, 1999). External focus of attention occurs when participants attend to the effect on the environment as a result of their body movement; therefore if participants increase their quiet eye upon the ball, such a strategy would provide an external object (the ball) to focus their attention while performing their swing. This shift in attention may disengage them from focusing on their own body movements (internal focus of attention). This strategy has been shown to be more advantageous for expert golfers than for less skilled golfers (Perkins-Ceccato, Passmore, & Lee, 2003). However, during external and internal focus of attention studies, the participants are required to pay attention to the motions or outcomes explicitly, which may affect their performance. Therefore providing them with an external focus that they do not need to explicitly maintain may result in a different outcome.

Before disengaging this visual tracking of the putter (and obtaining the added benefits of shifting the focus of attention), the low-skill golfer may have difficulties in performing any pattern other than an isodirectional coordination because of a combined influence of visual dominance during the putt and the absence of a learned alternative coordination pattern. Therefore to achieve the desired coordination pattern of the experts (antidirectional pattern), sufficient practice (Zanone & Kelso, 1992) and perhaps altered feedback (Kovacs, Buchanan, & Shea, 2009) should be given to allow the lower-skilled golfers to learn to transition to an antidirectional coordination pattern. That is, new relative phases can become more stable given sufficient practice (Zanone & Kelso, 1992), as well research has shown that an antiphase coordination pattern became the dominant bimanual coupling if participants saw a representation of their moving limbs as an in-phase pattern (Kovacs, Buchanan, & Shea, 2009). The perceptual feedback had an overriding influence on the movement coordination tendency, and reversed the dominance of in-phase coordination movements that normally occurs in the presence of direct visual feedback. However, it has been revealed that a new (out-of-phase) bimanual coordination pattern can be learned much more rapidly in the absence, than in the presence of vision (Mechsner, Kerzel, Knoblich, & Prinz, 2001). The implication from these studies is that vision tends to stabilize an existing coordination pattern, and that perturbing or altering vision during movement affords an opportunity for
the emergence of new coordination patterns which could prove beneficial to those learning how to putt.

The present study assessed the hypothesis that an isodirectional coordination pattern is adopted by low-skill golfers during natural direct visual feedback and this coordination can be modified by changing visual access to the putt. To assess this hypothesis we asked low-skill golfers to putt balls under four vision conditions: full vision (the condition in which putts are normally performed), no vision (in which vision of the ball and putter was eliminated just before the putt), target focus (in which the golfer fixated vision on the hole during the entire putt), and ball focus (in which vision of the ball was available through a narrow field of view). The three altered-vision conditions were included in this study to assess specific corollaries of the vision hypothesis. The findings of Lee et al. (2008) suggest that novices may visually track the putter which results in the isodirectional coordination. The no vision condition was chosen as the most extreme contrast to the full vision condition by preventing participants from visually tracking the putter. The ball focus condition was included as it was believed that this would increase the amount of quiet eye that is focused on the ball. Therefore this condition would create the advantage proposed by Vickers (1992, 1996) without giving the participants any explicit strategy about what to do with their eyes. The target focus condition also was believed to increase quiet eye as well, except that this would increase the quiet-eye specific to the hole. This fourth condition was included based on previous evidence that suggested a target focus condition benefitted putting performance (Alpenfels, Christina, & Heath, 2008).

We hypothesized that this specific ball-focus condition, which involved restricted vision of the ball, condition might have the largest impact of all on the isodirectional coordination pattern, and result in a more consistent performance. This was hypothesized since the restricted view would force individuals to produce less head movements to maintain the ball in the fovea as well produce a longer quiet eye duration on the ball, which has been shown to be advantageous in a variety of situations (Vickers, 2007).

Method

Participants

Twelve participants (3 males) with minimal golf experience (mean = 25 years; average years of golf experience = 1 yr) from the local community participated in this study. Participants were prescreened, as only those who play less than three rounds per year were asked to participate to ensure that they were novice golfers. All participants were self-reported as right handed and signed informed consents that had been approved by the McMaster University Research Ethics Review committee.

Apparatus

Golf putts were performed on a green indoor carpet (632 cm by 183 cm). Balls rolled on the carpet with a speed that was approximately equal to a stimp reading of 13, which is generally considered to be a “fast” green in the golf industry. Each putt was initiated from a small (6 cm × 6 cm) starting square that was outlined in
chalk in the carpet. All participants putted Titleist NXT golf balls, using a Ping Anser putter, toward one of two targets, located at distances of 3 m and 5 m from the starting square. Each target was the replica of the size of a standard golf hole (108 mm in diameter), drawn in chalk in the carpet.

A 70 cm by 50 cm clear, thin clear plastic sheet, held in place by two wooden supports approximately 90 cm above the ground, was in place for every putt in all conditions. The sheet was placed in such a position relative to the golfer that it: a) would not affect the path of the putter or the swing plane of the golfer’s arms, and b) required the participant to look through the clear plastic sheet to see the ball in the starting square and the path of the putter club head during the stroke. The apparatus allowed control over how much visual information was available to the participants.

Kinematics of the putter’s motion and the golfer’s head were captured with infrared markers (IREDs) using an Optotrak 3020 tracking system (Northern Digital Inc., Waterloo, Canada) at 200 Hz for 3 s (after participants were ready to begin putting). IREDs were placed at the tip of the putter blade and at the brim of a hat that the participants wore during the experimental trials. Distance of the end location of each putt was physically measured to the center of the target hole to the nearest mm.

**Procedure**

The experiment comprised eight separate experimental conditions, involving the performance of putts in four vision conditions at each of the two target distances (3 m and 5 m). Three of the four vision conditions were designed to constrain the amount and nature of visual information available to the participant during the putt, the fourth was designed to allow for unconstrained visual information. Individuals were instructed to putt the ball as they would normally (i.e., with no explicit instruction given regarding how to visually fixate with one notable exception), and told to putt the ball with the intention of stopping it within the outline of the target hole, or as close to it as possible.

Each of the participants performed in all four of the vision conditions (see Figure 1). 1) In the **Full Vision** condition there were no restrictions or constraints in the amount or nature of visual information available to the performer during the putt. Visual feedback of the ball and putter were available to the participant during the entire putt. 2) In the **Target Focus** vision condition, participants were instructed to prepare to strike the putt exactly as in the Full Vision condition, but once they were ready, they were instructed to look at and remain visually fixated on the target immediately before and during the entire execution of the putt. 3) In the **No Vision** condition, participants were instructed to prepare to strike the putt exactly as in the Full Vision condition. At that time they would verbally alert the experimenter of their readiness to perform, who then covered the entire viewing area by placing an opaque cover over the plastic sheet. This cover removed all vision of the ball and immediate area surrounding the target square, the putter head, the entire trajectory of the putter head and most of the shaft of the putter (the golfer’s hands remained visible). 4) In the **Ball Focus** condition a modified opaque cover was placed over the plastic sheet that severely constrained the amount and nature of visual information available during the putt (see Figure 1). The cover was modified
with a (1.5 cm by 20 cm) slit that was cut in the cover and was placed after the participants had verbally alerted the experimenter of their readiness to perform. The slit was constructed such that only a restricted field of view, which included the entire ball and the putter head as it struck the ball by the golfer, could be seen. The putter or the hands could not be seen during the swing until the putter made contact with the ball.

Individuals performed 10 practice trials in each of the different vision conditions before the performance in the experimental trials. After the practice phase, the eight experimental conditions were run in four blocks of trials. Each block consisted of sixteen trials—four putts in each of the four vision conditions (two putts directed at each target distance). The trials were ordered such that four consecutive trials were performed in each vision condition within a block of 16 trials. However, the order of conditions across the four blocks of trials was counterbalanced using a Williams’ square design so that any potential order and carry-over effects were evenly distributed both within and across participants. The resultant data included eight putts under each of the eight experimental conditions.

**Data Reduction**

The data were analyzed separately for the abscissa (in the direction of the putt) and ordinate axes (orthogonal to the direction of the putt), and are presented separately.

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Figure 1 — Illustration of the four vision conditions that were used in the experiment. The size of the viewing area for the limited vision condition was 1.5 cm × 20 cm.
Constant Error (CE) was measured with respect to the target, with the center of the target considered as the origin. The kinematic data were filtered using a second pass Butterworth filter (15 Hz). Correlations and velocities (using a 3 point differentiation) were obtained using custom software, Kinanalysis (7.1, Ottawa, Canada). Each trial was analyzed starting at the point of putt initiation (i.e., the first movement of the putter in the backswing), and ended at the point of ball impact (determined by an IRED on the floor marking the home position of the ball). Following from the results of our previous research, only motions in the direction of the putt were of interest. Within-trial correlations of head and putter velocities were analyzed and transformed to $z$ scores before statistical analyses.

Data Analysis

Averages of the eight trials performed by each participant in the eight experimental conditions were combined with the other participants’ data and analyzed using repeated measures analyses of variance (ANOVAs), with 4 levels of Vision Condition (Full Vision, Ball Focus, No Vision, Target Focus) and 2 levels of Distance (3 m, 5 m) as factors. Significant effects involving more than two means ($p < .05$) were further analyzed using the Tukey HSD method for comparison of means.

Results

Head—Putter Coordination

Head Velocity at Putter Initiation. Only the data pertaining to the direction of the putt was of interest for the kinematic part of the analysis. The ANOVA revealed significant main effects for Vision Condition, $F(3, 33) = 4.24, p < .05$, and a main effect for Distance that just failed to reach significance ($p = .06$). The Full Vision condition had greater negative velocity (-12.09 mm/s, $SE = 6.69$) compared with all other Vision Conditions (Ball Focus = -0.81 mm/s, $SE = 1.75$; No Vision = -2.09 mm/s, $SE = 1.19$; Target Focus = -0.16 mm/s, $SE = 0.85$). The analysis also revealed an interaction between Vision Condition and Distance, $F(3, 33) = 3.41, p < .05$. As illustrated in Figure 2, the influence of the full vision condition on head velocity was larger at the 5 m distance than at the 3 m distance.

Head Movement During Putt. The amount of head movement made during the putt was measured as the point of maximum displacement minus the minimum displacement away from the hole during the putt. The ANOVA revealed a significant effect for Vision Condition, $F(3, 33) = 4.71, p < .01$, but no main effect for Distance ($p = .28$) and no interaction ($p = .53$). The Vision Condition main effect revealed that average head displacement in the Full Vision condition (22.6 mm, $SE = 5.1$) and the No Vision condition (19.0 mm, $SE = 6.5$) were significantly larger than in the Target Focus (11.7 mm, $SE = 2.4$) and Ball Focus conditions (12.1 mm, $SE = 2.9$).

Velocity Correlations. The present study revealed high positive correlations ($r = .87, SE = 0.19$) in the Full Vision condition. High positive velocity correlations were found in the No Vision condition as well ($r = .68, SE = 0.24$). Performance was much more decoupled in both the Ball Focus condition ($r = .30, SE = 0.27$).
and the Target Focus condition \((r = -0.17, SE = 0.25)\). These differences resulted in a significant main effect for Vision Condition, \(F(3, 33) = 22.45, p < .001\). Post hoc analyses revealed that: a) the correlations in the Full Vision condition were significantly higher than the Ball Focus and Target Focus conditions, b) the No Vision correlation was higher than the Ball Focus condition, and c) that the Target Focus condition was significantly different than the other three conditions. Both the main effect for Distance \((p = .33)\) and the interaction between Vision Condition and Distance \((p = .1)\) were not significant.

**Outcome of the Putts**

**Constant Error (CE) along the Direction of the Putt.** The analysis of the final position of the putts in the eight experimental conditions revealed no main effects for either Vision Condition \((p = .41)\) or Distance \((p = .17)\). However, there was a significant interaction between Vision Condition and Distance, \(F(3, 33) = 2.90, p < .05\). The CE performance in the eight experimental conditions is illustrated in Figure 3. Specifically when the individuals were putting under the No Vision condition to the 5 m target they had lower CE compared with all other vision conditions. Also the Target Focus condition had greater CE when putting to the 5 m target when compared with the 3 m target and to the No Vision 5 m condition. All other vision conditions did not differ when comparing the 3 m and 5 m targets (Figure 3). Alongside CE, we report the number of putts that stopped inside the target (see Table 1).
Figure 3 — Effects of vision conditions on constant error (CE) in the direction of the putt. The figure illustrates that when putting to the 5 m target, the ball focus condition produced lower CE compared with all other vision conditions. The target focus condition was the only vision condition that had greater CE when putting to the 5 m target compared with the 3 m target.

Table 1 The Number of Putts that Stopped Inside or Were Close to the Target.

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<td>No Vision</td>
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<td>Ball Focus</td>
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<td>Target Focus</td>
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<td>92</td>
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Variable Error (VE) in the Direction of the Putt. The analysis of VE revealed a main effect for Vision Condition, $F(3, 33) = 5.74, p < .005$. Performance variability in the Target Focus condition ($M = 19.0 \text{ cm}, SE = 2.3$) was larger than in all of the other vision conditions, which were not statistically different from each other (Full Vision = 13.8 cm, $SE = 1.7$; Ball focus = 13.8 cm, $SE = 1.7$; No Vision = 13.4 cm, $SE = 1.8$). A main effect for Distance was also revealed, $F(1, 11) = 24.51, p < .001$, as performance outcome to the 5 m target (17.8 cm, $SE = 2.0$) was more variable compared with the 3m target (12.2 cm, $SE = 1.5$). The interaction between Vision Condition and Distance was not significant ($p = .11$).
Constant Error (CE) Perpendicular to the Direction of the Putt. CE analysis revealed a main effect for Vision Condition, \(F(3, 33) = 4.19, p < .05\). The participants had lower CE in the Ball Focus condition \((M = 0.1 \text{ cm}, SE = 11.9)\) compared with the other three conditions. The Full Vision \((M = 26.3 \text{cm}, SE = 8.7)\), No Vision \((M = 32.3 \text{cm}, SE = 10.8)\), and Target Focus \((M = 23.8 \text{cm}, SE = 8.2)\) conditions were not statistically different from each other. There was no main effect for Distance \((p = .29)\) and no interaction between Vision Condition and Distance \((p = .9)\).

Variable Error (VE) Perpendicular to the Direction of the Putt. There were no significant differences for the analysis of Variable Error (VE) for either the main effect of Vision Condition \((p = .2)\) or Distance \((p = .08)\), or the interaction between Vision Condition and Distance \((p = .9)\).

Sample Head-Putter Profiles. Figure 4 contains representative head-displacement profiles from one of the participants as performed in each of the vision conditions. These figures were based on the average of the head and putter displacements samples in the abscissa axis collected during all of the putts in each of the four vision conditions. The four profiles in Figure 4 are representative of the following results: a) head movement in the Full Vision and No Vision conditions was greater than in the Target Focus and Ball Focus conditions, and b) the head and putter velocity profiles were more tightly coupled in the same direction in the Full Vision and No Vision conditions, compared with less coupling in the Target Focus and Ball Focus conditions (especially so nearer the completion of the putt). Figure 5 contains representative head-velocity profiles. The different allocentric patterns are more prominent in the velocity profiles, and an isodirectional pattern is apparent in the full vision and no vision conditions. A tendency toward an antidirectional pattern is apparent for the ball focus and target focus condition.

Discussion

One of the most frequently used strategies when teaching low-skill golfers is to compare their swing to the swings of expert golfers. The premise is that the movement pattern of a skilled golfer represents a desirable “blueprint” to achieve, which will lead to game improvements in the low-skilled golfer. In a previous study, it was found that low-skill golfers putted with a fundamentally different coordination pattern than experts (Lee et al., 2008), which would be desirable to change to improve performance. In the current study, we hypothesized that vision would serve a key role in this difference, and several vision conditions were experimentally manipulated to assess the hypothesis that a change in vision would significantly alter the coordination pattern. Specifically we hypothesized that a ball focus vision condition would result in a greater change in coordination pattern between head and putter, which may result in better outcome measures (CE and VE), due to an enhanced external focusing of the visual attention of the participants. Indeed, the ball focus condition did produce greater changes to the coordination patterns of the participants, but had mixed results in the outcome measures. The ball focus condition significantly reduced the amount of head movement during the putt, decoupled the head—putter velocity correlation to 0.3, resulted in average putt locations as close to the hole as the other vision conditions, and produced consis-
tent putt outcomes orthogonal to and in the direction of the putt that were better than the other vision conditions.

To summarize the results, the different vision conditions resulted in varying effects on the head-putter coordination pattern and the outcome of the putts. Replicating our previous findings (Lee et al., 2008), we found that the full vision condition resulted in considerable head movement before the initiation of the putt and during the putt, and a tightly coupled, isodirectional head-putter coordination pattern throughout the putt. It was mildly surprisingly however, that the full vision condition did not facilitate the final outcome of the putt, either with regard to closeness to the hole or consistency of the putts. Eliminating vision of the putting environment had no effect on reducing the amount of head movement during the putt, nor the isodirectional coordination pattern, compared with the full vision condition, but positively influenced the final average location of the putt relative
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to the target in the 5m condition. The target focus condition reduced the amount of head movement during the putt and had the largest effect on the head-putter coordination pattern, producing a slightly isodirectional coupling (which typified the coordination pattern of the experts in our previous study). However, the target focus condition produced relatively poor performance outcomes, especially with respect to average closeness to the hole and outcome consistency in the direction of the putt. These results stand in contrast to some suggestions made (Alpenfels, Christina, & Heath, 2008), as it was advocated that individuals should look at the target (the hole) during the entire putt. However, in our findings both ball focus and target focus do produce better coordination between head and putter, therefore with more practice perhaps both ball focus and target focus could result in better outcome measures as well. Our findings also support the findings of Vine, Moore, and Wilson (2011) as well as Vine and Wilson (2010), that visual fixation on the ball provides better coordination and does not hinder outcome measures of the

Figure 5 — Sample head-putter velocity profile for one of the participants in each of the four vision conditions. The putter velocity curve is in black and corresponds to the left vertical axis. The head velocity curve is in gray and corresponds to the right vertical axis. Time is represented along the horizontal axis, beginning with the initiation of the putt on the left side of the axis and the completion of the putt on the right side. Each data point represents an average of all trials conducted in that vision condition (including both 3 m and 5 m distance targets) for one participant.
putt. Perhaps with increased practice, that focusing on the hole would be more beneficial than or as beneficial as the ball focus, as both ball focus and target focus did produce better head-putter coordination compared with the no vision and full vision conditions.

One possible explanation of why the ball focus condition may have resulted in better coordination patterns is due to longer quiet eye duration (Vickers, 1992, 1996, 2004) which could have helped the participants focus on the ball without explicitly instructions. This increase in quiet eye could help the participants concentrate on striking the ball correctly instead of moving their head in an isodirectional coordination with the putter. We provide evidence that better coordination is established by restricting vision of the ball, therefore reducing the amount of head movement allowed by restricting vision of the intended object to be struck (ball). This may be a beneficial method of teaching novices and may lead to improvement of their putting skills (outcome measures) with more practice.

Although there were differences produced in the coordination patterns, the outcome measures did not reflect the same trends. There were no differences revealed in the outcome and performance measures for the 3m putting, which we argue could be a result of the task being equally hard or easy to perform. However, the longer distance, 5m, there is greater chance of the trajectory having a bigger influence on radial error. That is, if the trajectory of the ball is skewed either left or right this would be more pronounced over a longer putt as well there is more chance of under or overshooting the ball. There are, however, some limitations to the experimental procedure as in a real life game the players aim at a hole. This hole may slow down the ball a bit to allow for harder putts to go in compared with aiming toward an outlined target. Although we were able to measure the number of “hits” and “misses” there are some putts that potentially could have gone inside the hole that were not measured. Also if the ball hits the hole and does not go in, this may alter the trajectory. We argue though that because this is a within experimental design, if the participants are using a strategy to putt harder they would use the same strategy across all the conditions which would hopefully not interfere with the comparisons.

Overall however, we consider the head—putter coordination pattern to be the most important of the dependent variables in the present experiment, since a repeatable action should result in more accurate and consistent putt outcomes as the golfer learns to scale the action to the changing distances of the putt. Thus, we argue that the ball focus and target focus conditions were both successful in reducing one of the major limitations to successful putting by decoupling the degrading effects of an isodirectional coordination pattern. However, target focus lead to a decrease in performance outcome (had lowest VE), thereby leading us to believe that ball focus was optimal for this experiment. We argue that learning to continuously produce a coordination pattern will ultimately lead to better performance outcome, as the individuals will be better able to reproduce a movement suited for the task. This has been the premise of motor learning, as teaching individuals to tune their motor outputs via perceptual inputs to perform the desired task quicker and better (Wolpert, Gharamani, Flanagan, 2001; Zanone & Kelso, 1992) has been at the forefront of research.

Of course, it remains to be determined exactly why these two vision conditions were successful. One hypothesis might suggest that the target focus and ball focus conditions eliminated the opportunity to track the putter during the stroke,
which reduced the isodirectional coordination sway that accompanied the putt. An alternative hypothesis however, might argue that the vision conditions resulted in a shift in the golfers’ focus of attention. Although this experiment did not directly deal with external versus internal focus of attention, perhaps by adjusting the visual focus to the ball or to the target, this could have created a more external focus of attention. Indeed recent golf studies have shown that an internal focus of attention produced less successful performance than an external focus of attention (Wulf, 2007; Wulf, Lauterbach, & Toole, 1999), especially so for better golfers (Perkins-Ceccato, Passmore, & Lee, 2003). One reciprocal benefit of an external focus of attention could be a heightened visual attention—we suggest “reciprocal” in the sense that an external focus might enhance visual focus on a target, and/or that a visual focus on a target might enhance an external focus of attention (it remains unclear as to which is the cause and which is the effect). This is also consistent with the quiet eye hypothesis proposed (Vickers, 1996, 2004), as an increased external focus of attention on the ball would result in a weakened isodirectional coordination pattern by changing the movement of the head to try and maintain visual fixation on the ball. Regardless, the role of attention could have been a significant factor in the effectiveness of the target focus and ball focus manipulations in the present experiment.

**Conclusion**

The present experiment provided support for the hypothesis that vision, or the use of visual strategies, plays a role in the coordination of head and putter motions during the putting stroke. Obviously, there is much more to becoming an expert putter than simply changing the nature of head-putter coupling during the swing and these findings certainly do not undermine the influences of practice, feedback, instruction and other traditions supported by motor learning research. Although certainly no panacea for golf performance, we feel that the effects of the target focus and ball focus vision conditions in the present experiment may provide some hope of relief to the difficulties that low-skill golfers must endure in golf putting.

**Note**

1. This was termed the egocentric condition in our previous paper (2). Hereafter we refer to head and putter movements in the same direction as “isodirectional” and head-putter movements in the opposite directions as “antidirectional”.

**References**


