Head–Putter Coordination Patterns in Expert and Less Skilled Golfers

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ABSTRACT. The authors examined the patterns of expert and less skilled golfers in putting on an indoor surface to 1 of 3 circular targets (1, 3, and 5 m away) in trials with a ball present (and putted) or not present (a practice stroke). As expected, the experts performed better than the less skilled golfers on a large number of outcome and kinematic measures. Displacement and velocity profiles of the head and putter revealed high positive correlations for the less skilled golfers, indicating a dominant allocentric coordination pattern, but high negative correlations for the expert golfers, indicating a dominant egocentric coordination pattern. The observed coordination patterns did not interact with the distance of the intended putt or the presence/absence of a ball. These findings offer preliminary evidence that, although contrary to traditional beliefs, fundamental differences exist in putting coordination modes between expert and less skilled golfers.

Keywords: allocentric, coordination, egocentric, putting

Many actions that require simultaneous movement of two or more degrees of freedom have a natural coordination pattern. According to Swinnen (2002), there are two basic constraints or “elementary coordination rules” (p. 350): (a) the egocentric principle, in which the body achieves coordination by activating similar muscle groups in spatial–temporal synchrony about a body midline; and (b) the allocentric principle, in which two body parts move in the same direction. For example, Kelso (1984) found that rhythmic actions of the index finger on each hand were more strongly coupled according to an egocentric principle than to an allocentric principle, especially when the system was stressed by a forcing function (e.g., speed). Coordination of upper body parts on opposite sides of the midline appears to be strongly influenced by such a principle (Swinnen, 2002). In contrast, coordinating the actions of upper body parts with lower body parts appears to conform to an allocentric principle. For example, Baldissera, Cavallari, and Civaschi (1982) found that spatial–temporal coordination of ipsilateral limbs was stronger when moving in the same direction than when moving in different directions in extrinsic space. Research has extended these findings to other coordination acts (Kelso, 1995; Swinnen, 2002; Swinnen & Wenderoth, 2004).

Egocentric and allocentric constraints represent only two of the myriad possible coordination patterns. The acquisition of a new coordination pattern that does not conform to either constraint requires learning (e.g., Lee, Swinnen, & Verschueren, 1995; Zanone & Kelso, 1992) and is often a requirement for skill development in sport (e.g., Seifert, Boulesteix, Chollet, & Vilas-Boas, 2008). The sport of golf offers many such coordination challenges. The pattern studied in the present research concerns putting; specifically, the coordination of the putting stroke action with the movement of the golfer’s head. Regardless of skill level, the putting stroke is used more frequently than any other during a round of golf. In 2007, putts represented 41.3% of the total strokes taken by members of the PGA tour (PGA Tour Statistics: 2007 PGA Tour Putts Per Round, 2007), 40.0% for members of the LPGA (LPGA: Stats and News, 2007), and 41.2% for the Champions tour (PGA Champions Tour Statistics: 2007 Champions Tour Putts Per Round, 2007). And although most amateur golfers often make 30–60 more total strokes than a professional in a round of golf, it is estimated that the relative frequency of putts remains about the same, 43% ± 2% (Pelz & Frank, 2000). Consequently, instructors of the game give high priority to putting

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practice and provide many different types of advice for making improvements.

One of the most widely held views among instructors is that movement of the head during the putting stroke is a leading cause of poor technique. For example, Jack Nicklaus suggested that “the premier technical cause of missed putts—especially short putts—is head movement” (Nicklaus & Bowden, 1974, p. 238). To avoid this problem, the most common advice is to keep the head as motionless as possible during the execution of the putting stroke. Tiger Woods stated the case more bluntly:

Every good putter keeps the head absolutely still from start to finish. Every bad putter I know moves the head to some degree. It’s as simple as that. If I move my head even a fraction, it’s almost impossible to keep my putting path stable and true. It’s hard to hit the ball solidly, too. More than likely I’ll open my shoulders on the forward stroke, causing me to pull the putter across the ball from out to in. I practice keeping my head dead still until well after the ball is gone. (2001, p. 37)

Despite these claims, we are aware of no experimental evidence regarding the dominant or natural tendencies that exist concerning the coordination of head movement during the execution of the putting stroke. In accepting the conventional wisdom offered by golf instructors, researchers would expect that the typical pattern exhibited by high-handicap (i.e., relatively poor) golfers is a coordination of head and putter movements according to an allocentric constraint. Specifically, the prediction would be that both the head movement and the putter movement would move away from the ball together and toward the ball together. The advice suggested in the quotes above from Jack Nicklaus and Tiger Woods might suggest that to become a better putter, one must decouple the allocentric constraint, to keep the head fixed while the putter moves away from and then toward the ball.

In the present study, we examined these predictions by comparing expert and less skilled golfers performing putts on an indoor surface. To exert a forcing function on the coordination pattern, we examined putting strokes aimed toward a target that was 1, 3, or 5 m away. In addition, we wished to examine whether the presence of a ball influenced the nature of the coordination pattern adopted by the golfer. Therefore, we examined golfers when making a simulated putting stroke (similar to a practice putt) and when actually putting a golf ball.

**Method**

**Participants**

Participants were 11 less skilled golfers (defined as having handicaps between 12 and 40; age range = 21–56 years, $M = 32$ years) and 5 expert golfers (3 professionals, 1 amateur with a 1 handicap, and 1 amateur with a 5 handicap; age range = 24–52 years, $M = 35$ years) from the local community. All participants signed a university-approved ethical consent form and received a compensation of $10 Canadian plus expenses on completion of the study.

**Apparatus and Task**

Participants performed on a green indoor carpet, which produced a fast putting surface (approximate stimp of 13). A small starting square (6 × 6 cm) drawn in white chalk on the carpet was used as the standardized starting position for all putts. Three target circles were drawn on the carpet at distances of 1 m, 3 m, and 5 m from the starting square. Each target circle was the size of an actual golf hole (108-mm diameter).

We used an infrared (IRED) tracking system (Optotrak 3020, Northern Digital Inc., Waterloo, ON) to record three-dimensional analyses of the putter and the golfer’s head at a rate of 120 Hz. Two IREDs were affixed on the putter head, one at the front tip of the putter blade and one at the bottom of the shaft, just above the putter blade. Another IRED was attached to the brim of a baseball-style cap that participants wore during the experiment, which provided data regarding head movement. All IREDs were attached to a marker strober that clipped onto the participant’s belt, below the lower back, and out of the way of the putting action. A stationary IRED was placed on the carpet, in line with the putter blade’s starting position, and approximately 1 mm behind the point on the ball that the blade of the putter would contact. Each putting stroke was recorded and stored in a 3-s digital file.

**Procedure**

Participants began the experiment with a demonstration of how the equipment was to be worn. Once they were familiar with the setup, a variable practice period allowed participants the opportunity to become accustomed to the equipment, speed, and general conditions of the putting surface. Experimental trials began once the participant self-declared comfort with the equipment and putting conditions.

The experiment was run in 10 blocks of six trials, each block representing an entire replication of the experimental design. A block of trials consisted of one simulated putt (without a golf ball) followed by one actual putt (with a golf ball) to each of the three targets. Target distance was selected according to a predetermined random order. In total, each participant performed 60 strokes: 10 simulated putts and 10 actual putts at each of the three targets. Participants could take a break after the completion of any block of trials.

**Dependent Measures**

We marked the final location of every putted ball with 19-mm diameter, color-coded stickers, which were measured in x and y coordinates from the center of the goal target. Radial error scores were computed from these x and y values, and measures of mean radial error and the standard deviation of the mean radial error (hereafter called variable radial error) were computed from these 30 locations (10 trials at each of three target distances).

We collected kinematic measures of head movement and putter movement in each of three dimensions: along
the intended direction of the putted ball toward the target (\(x\)), perpendicular to the intended direction (\(y\)), and in the vertical dimension (\(z\)). Each file contained a record of these \(x\), \(y\), and \(z\) coordinates, beginning just prior to the start of the backswing and ending at impact (or simulated impact) of the ball. To standardize the length of the file clips, each file was cropped manually by graphically detecting when movement of the club began in the negative \(x\)-direction until the IRED at the tip of the club crossed the stationary IRED (i.e., at impact or simulated impact). Measures of putter displacement and velocity and head displacement and velocity were determined from these cropped data files. An important measure that was also analyzed was the within-trial correlations of head and putter movements (for both displacement and velocity measures). These individual correlation measures were transformed to \(z\) scores prior to statistical analyses.

We analyzed dependent measures in mixed model analyses of variance. The analysis of putted ball outcome error scores involved two factors: The between-participants factor was skill (2 levels: expert and less skilled), and the within-participant factor was target distance (3 levels: 1 m, 3 m, and 5 m). The analysis of movement kinematics included the additional within-participant factor of putt type (2 levels: with or without a ball). The level for acceptance of significance (\(\alpha\)) was set at .05. The Tukey HSD procedure was used for post-ANOVA comparisons of means.

**Results**

**Putt Outcomes**

The analysis of mean radial error produced significant main effects for group, \(F(1, 14) = 5.71, MSE = 210.9\); and distance, \(F(2, 28) = 13.91, MSE = 116.9\); and a Group \(\times\) Distance interaction, \(F(2, 28) = 6.50, MSE = 116.9\). A similar set of results was found for the analysis of variable radial error: significant effects for group, \(F(1, 14) = 15.66, MSE = 58.9\); distance, \(F(2, 28) = 16.45, MSE = 50.6\); and a Group \(\times\) Distance interaction, \(F(2, 28) = 6.75, MSE = 50.6\). The means are presented in Table 1. The between-group differences in both the mean and variable radial error were significant at target distances of 5 m and 3 m, but not at 1 m. These findings (as well as other error measures not reported) confirmed that the experts were more accurate and consistent in putting the ball at the medium and far targets, though perhaps a floor effect precluded a similar finding at the near target.

**Putter Kinematics**

Instead of reporting all significant effects for the mean and standard deviation of all three coordinates of all kinematic variables measured, we focused our attention on skill level differences, and we reported significant effects of distance and putting condition only when these effects interacted with golfer skill level. For most analyses, between-group differences did not interact with the other experimental variables.

**Displacement**

We measured the total distance traveled by the putter from the start of the backswing to the point of impact (or simulated impact in the no-ball condition) in the \(x\), \(y\), and \(z\) dimensions and reduced it over trials to mean and standard deviation values. In the \(x\) dimension, although the experts (\(M = 182.3\) mm) and less skilled golfers (\(M = 199.2\) mm) were not significantly different in mean total displacements, the experts were more consistent (\(SD = 14.8\) mm) from trial to trial than the less skilled golfers (\(SD = 22.2\) mm), \(F(1, 14) = 6.76, MSE = 166.7\). In the vertical (\(z\)) dimension, experts kept the club closer to the ground during the swing (\(M = 8.2\) mm) than did the less skilled golfers (\(M = 18.2\) mm), \(F(1, 14) = 9.17, MSE = 227.2\), and the experts were also less variable (\(SD = 1.7\) mm) than the less skilled golfers (\(SD = 4.1\) mm), \(F(1, 14) = 9.54, MSE = 12.2\). Differences in the deviation of the putter from the intended line of the putt (\(y\)) were not significant between the experts (\(M = 9.6\) mm) and the less skilled golfers (\(M = 12.3\) mm). However, the experts were more consistent (\(SD = 2.8\) mm) than the less skilled golfers (\(SD = 4.5\) mm), \(F(1, 14) = 5.09, MSE = 12.5\). These group differences did not interact with either the distance of the putt or the putt type for any of the reported measures.

**Velocity**

The velocity of the putter at impact (or simulated impact in the no-ball trials) was not significantly different between

| Table 1. Putt Outcomes for Expert and Less Skilled Golfers at Distances of 1 m, 3 m, and 5 m |
|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|
| Group                                   | Mean radial error                        | Variable radial error                    |                                          |                                          |                                          |                                          |                                          |                                          |
|                                          | \(1\) m \(SD\) | \(3\) m \(SD\) | \(5\) m \(SD\) | \(1\) m \(SD\) | \(3\) m \(SD\) | \(5\) m \(SD\) | \(1\) m \(SD\) | \(3\) m \(SD\) | \(5\) m \(SD\) | \(1\) m \(SD\) | \(3\) m \(SD\) | \(5\) m \(SD\) | \(1\) m \(SD\) | \(3\) m \(SD\) | \(5\) m \(SD\) |
| Expert                                  | 22.4 | 4.7 | 22.9 | 8.9 | 29.2 | 5.2 | 8.9 | 1.3 | 12.4 | 4.2 | 14.5 | 5.0 |                                          |                                          |                                          |
| Less-skilled                            | 17.4 | 4.9 | 34.8 | 14.3 | 53.9 | 18.1 | 8.7 | 2.5 | 21.2 | 6.7 | 34.3 | 12.4 |                                          |                                          |                                          |

Note. All values are reported in cm from center of target.
the experts and less skilled golfers. There was a three-way interaction between group, distance, and putt type, $F(2, 28) = 4.15$, $MSE = 3131.7$, in which the experts exerted more velocity at simulated impact for the no-ball trials compared to the putted ball trials, whereas the novices exhibited similar velocities under both conditions. The analysis of mean maximum velocities revealed no group differences or interactions. However, the experts were less variable ($SD = 68.3$ mm/s) in their maximum velocities than the less skilled golfers ($SD = 98.5$ mm/s), $F(1, 14) = 9.03$, $MSE = 2082.1$. Again, there was a three-way interaction between group, distance, and putt type, $F(2, 28) = 3.70$, $MSE = 483.0$. Expert and less skilled golfers produced equally consistent maximum velocities under the no-ball trials at all distances. However, when a ball was to be struck, the experts’ maximum velocity remained consistent at all distances (1-m $SD = 41.3$, 3-m $SD = 40.7$, 5-m $SD = 49.1$ mm/s), whereas the less skilled golfers’ variability increased with target distance (1-m $SD = 55.9$, 3-m $SD = 83.5$, 5-m $SD = 123.0$ mm/s).

**Time**

We divided the putt into two time intervals—backswing and downswing durations—and analyzed mean and standard deviation values for these intervals. Experts (639 ms) were similar to the less skilled golfers (669 ms) in backswing durations. However, experts (39 ms) were more consistent than less skilled golfers (62 ms), $F(1, 14) = 7.97$, $MSE = 1428.4$. The experts had shorter mean downswing durations than had the less skilled golfers (312 vs. 354 ms), $F(1, 14) = 5.86$, $MSE = 6073.6$, and these were less variable too ($SD = 17$ vs. 27 ms), $F(1, 14) = 4.57$, $MSE = 434.6$. These group differences did not interact with distance or putt type.

**Head Kinematics**

**Displacement**

Both expert and less skilled golfers moved their heads during the execution of putts, regardless of distance of the target and whether a ball was to be putted. In the direction of the putt ($x$), the mean amount of head movement by the experts ($M = 11.2$ mm) was slightly smaller than that for the less skilled golfers ($M = 16.6$ mm), but this trend was not significant, $F(1, 14) = 1.81$, $p = .20$. There was also a trend for experts to be more consistent in their head movements ($SD = 2.3$ mm) than the less skilled golfers ($SD = 5.7$ mm), although this too failed to be statistically significant, $F(1, 14) = 3.96$, $p = .066$. None of the interactions approached significance. In the vertical ($z$) dimension, again there was a trend that approached significance, as the experts moved their heads in the up–down direction slightly less ($M = 4.1$ mm) than did the less skilled golfers ($M = 8.1$ mm), $F(1, 14) = 3.60$, $p = .079$. There were no variability differences between experts and less skilled golfers in the $z$ dimension and no mean or variability differences in the $y$ dimension.

**Velocity at Putter Initiation**

One finding that we noticed in the examination of our data was that both the expert and less skilled golfers tended to initiate their head movements prior to the initial backswing component of the putter. Because our file management procedure initiated data analysis on first movement of the putter, we were able to examine the instantaneous head velocity at the point of the initiation of the putt. We found a striking difference: less skilled golfers’ heads were moving with a velocity of $-5.7$ mm/s (i.e., moving away from the target), whereas the expert golfers’ heads were moving with a velocity of $6.4$ mm/s (i.e., toward the target) at the initiation of putter backswing. This difference was statistically significant, $F(1, 14) = 7.24$, $MSE = 412.1$, and did not interact with the other variables. There were no significant effects of the variability of these head velocity measurements.

**Putter–Head Coordination**

We calculated within-trial correlations of the putter and head movement by using each successive data point sampled after the initiation of the backswing. Typically, we used between 100 and 120 pairs of data points to compute each correlation coefficient.

**Displacement Correlations**

Figure 1A illustrates the head and putter displacement profiles of a representative trial for a less skilled golfer. As the putter moved away from the target, the less skilled golfer’s head movement also moved away from the target. Then, as the putter stopped and reversed directions, so did the less skilled golfer’s head movement. This allocentric coordination pattern was typical of the group of less skilled golfers. The group of less skilled golfers resulted in an average displacement correlation coefficient of .45.

A representative trial of an expert golfer’s putter and head movements is illustrated in Figure 1B. Again, these movements were highly coordinated. However, unlike the less skilled golfers, the expert coordinated the movements in an egocentric pattern: During the putter’s backswing, the expert’s head moved toward the target. Then, during the putter’s downswing, the expert’s head reversed direction. This egocentric coordination pattern was typical of the group of expert golfers, resulting in an average correlation coefficient of $-63$ for the expert group. The analysis of the $z$-transformed data resulted in a highly significant difference, $F(1, 14) = 22.80$, $MSE = 2.77$. This group difference did not interact with either putt type or target distance.

**Velocity Correlations**

Correlation of the velocity profiles of both head and putter movements also resulted in a highly significant group effect, $F(1, 14) = 49.36$, $MSE = 3.41$. The experts’ egocentric correlation coefficient was $-.70$. The less skilled golfers’ allocentric correlation coefficient was $.78$. We found no interactions or trial-to-trial variation in these results.
Table 2 presents a breakdown of the velocity correlation means by group at each putting distance and for each trial type. The table also presents the standard deviation of each individual trial correlation relative to the block mean, within a participant. Two findings are of particular interest. First, the group means remained remarkably consistent across all conditions: Every expert revealed a strong negative correlation, and every less skilled golfer revealed strong positive correlations. The second finding of interest was that these within-trial correlations were maintained with very high consistency across all trials, both within individuals and across individuals within a skill group.

**Discussion**

What is a natural coordination tendency? Research suggests that humans possess many different styles of coordination patterns, most of which conform to either an egocentric or an allocentric principle (Swinnen, 2002). The capability to coordinate degrees of freedom that conform to an alternative constraint requires considerable practice. In the present study, we found that less skilled golfers coordinated the movements of their head and putter in a tightly organized manner that conformed to an allocentric constraint. This finding corroborates the comments made by golf instructors who suggest that putting errors often result from moving the head while putting. However, these same instructors have suggested that expert golfers combat the allocentric head–putter problem by keeping the head motionless. Our results suggest that this is not so. Instead, experts use an egocentric coordination pattern: moving the head and putter in a tightly coupled but opposing-direction constraint.

Why might experts adopt an egocentric coordination coupling? We hypothesize four explanations. One possibility is that a decoupling of head and putter motions is neither possible nor desirable. Although we did not record center-of-pressure measurements in this study, it is conceivable that a head–putter egocentric strategy is the best coordination route to the stabilization of the body core during a shot. Perhaps a decoupled head–
TABLE 2. Within-Trial Correlations of Head–Putter Velocities

<table>
<thead>
<tr>
<th>Group</th>
<th>No ball</th>
<th></th>
<th></th>
<th></th>
<th>Ball putted</th>
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<tbody>
<tr>
<td></td>
<td>1 m</td>
<td>3 m</td>
<td>5 m</td>
<td></td>
<td>1 m</td>
<td>3 m</td>
<td>5 m</td>
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<tr>
<td></td>
<td>M  SD</td>
<td>M  SD</td>
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<td>M  SD</td>
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</tr>
<tr>
<td>Expert</td>
<td>-.76 .16</td>
<td>-.77 .15</td>
<td>-.67 .15</td>
<td></td>
<td>-.69 .19</td>
<td>-.73 .13</td>
<td>-.59 .10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Less-skilled</td>
<td>.77 .18</td>
<td>.73 .22</td>
<td>.74 .19</td>
<td></td>
<td>.82 .16</td>
<td>.77 .20</td>
<td>.82 .15</td>
<td></td>
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</tr>
</tbody>
</table>

Note. Means are reported as averages across trials within each individual and then across individuals with each group. Standard deviations represent the variability of the correlations across trials relative to the block mean within each individual, then averaged across individuals within each group.

The decoupled head–putter coordination pattern destabilizes the base of support that optimizes performance. A second possibility is that keeping the head motionless during the execution of a putt requires a very specific type of learning to completely decouple the head and putter motions. Previous research has shown that the acquisition of very difficult coordination patterns can sometimes be achieved only with practice that is augmented by very specific feedback (Lee et al., 1995)—feedback that likely was unavailable to the experts whom we examined here. Moreover, when one coordination constraint tends to dominate performance (e.g., allocentric), the easiest method to break away from the constraint is to move to the opposing constraint (egocentric). Therefore, a decoupled head–putter pattern may not have been learned unless it had specifically been practiced, with augmented feedback about the specific relationship between the moving parts. A third possibility is that the head–putter coordination patterns either influence or are influenced by eye movement search strategies, which Vickers (1992) found to differ between experts and less skilled golfers. The relationship between perceptual and motor anticipation in putting is a fruitful area for further research. A fourth possibility is that experts simply are not aware that they are moving in an egocentric coordination pattern. In a follow-up interview after completion of the experiment, 1 of the professional golfers expressed surprise regarding the nature of his coordination pattern. Perhaps no corrective action had been taken to try to decouple the head and putter because such a relationship had not previously been identified.

We suggest that the decoupled head–putter coordination pattern may be a myth. Moreover, advice to golfers to keep their head still not only may be incorrect but also may prevent golfers from practicing a coordination pattern (egocentric) that is both more natural to perform and easier to learn. We are currently studying (a) strategies that affect the domination of allocentric head–putter coordination patterns in less skilled golfers and (b) routes to learning that might accelerate the acquisition of putting skill.

Biographical Notes

Timothy D. Lee is a professor in the Kinesiology Department at McMaster University.

Tadao Ishikura was a visiting professor at McMaster University in 2007–2008.

Stefan Kegel was a McMaster University undergraduate student when this research was conducted.

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272 Journal of Motor Behavior