Visual perception and action in golf putting.

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Summary and conclusions

The current dissertation scrutinized the engagement of visual perception in golf putting action. It considered three pertinent empirical and theoretical issues. First, it attempted to identify the crucial sources of information for accurate putting (i.e., the hole, ball and green), among others by measuring low- and high-skilled golfers’ gaze patterns. Second, it examined the role of visual perception (as distinguished from the visual control of movements) in the putting action. To this end, it examined how golfers deal with a well-known distortion in the perception of direction by comparing errors of low- and high-skilled golfers in perceived direction of the perfect aiming line and errors in the direction of the putt. Finally, it was investigated how novice golfers learn to improve direction accuracy of putting. In particularly, it was examined whether skill-differences and learning reflect processes of education of attention and/or calibration, which are the main processes of change posited by the ecological approach. In the remainder of this Epilogue, I first summarize the key findings of the current dissertation and briefly elaborate its theoretical and practical implications and suggest directions for future research.

Identifying the pertinent sources of information for accurate putting.

Chapter 2 compared the effectiveness of a proximal external focus (i.e., attention directed at the ball) to a distal external focus of attention (i.e., attention directed at the hole) in novice and high-skilled golfers performing a golf putting task at three different distances (1.8, 2.7 and 3.6 m) from the hole. The results showed that among the high-skilled golfers putting performance was significantly enhanced for the distal focus of attention compared to a proximal focus but only at 1.8 m distance. The locus of attention did not affect performance
of the novice golfers. Thus, contrary to golfers’ present believe to focus on the ball while putting, a more distal focus may lead to superior performance. The findings provide partial support for the constrained action hypothesis, and underline the pertinence of obtaining information related to the target relative to information about the ball.

Chapter 3 further investigated the pertinent sources of information for an accurate putt by measuring golfers’ gaze patterns as a function of task complexity. Introducing a sideward slope varied the task complexity. Slope did not affect the number of holed putts, but it did significantly influence the type of miss. A significantly higher proportion of balls was missed at the low side than at the high side of the hole, the effect being more pronounced for the group of less successful participants. It was found that the main adaptation in gaze to the increase in task complexity (i.e., slope) was of a spatial nature. Thus, increasing the steepness of the slope resulted in more fixations to the high side of the hole. Noticeably, the participants also spent less time viewing the ball for the steeper slopes. The final fixation durations were not affected by steepness of slope. It is concluded that in dealing with a sloped green, the prime adjustment in gaze is in the spatial rather than temporal domain. Moreover, it shows that the sources of information that are exploited by golfers are dependent on task complexity.

At this place, it is relevant to refer to a recent study by Wilson and Pearcy (2009) who also compared golfers’ gaze patterns for different sideward slopes. Wilson and Pearcy (2009) reported that the only gaze variable to distinguish between successful and unsuccessful putting outcome was the final gaze fixation prior to the initiation of the putter movement (i.e., quiet eye, see Vickers, 1992, 1996). This contradicts the observations in Chapter 3, in which the duration of the final gaze fixation duration was not related to successfulness of the putt nor affected by steepness of slope. A possible explanation for the differences might be the lack of spatial orientation points in our experimental paradigm, preventing participants to align their movements to these spatial anchors.
The engagement of visual perception in the putting action.

Milner and Goodale (1995, 2008) have argued that the use of information in visual perception is neuro-anatomically and functionally different from the use of information in the visual control of action. In Chapter 4, the impact of a well-known error in visually perceived direction for putting accuracy was examined in both novice and skilled players. First, it was shown that novice golfers indeed made systematic errors in the perception of the direction of the perfect aiming line between the ball and the hole. These perceptual errors were destroyed, however, when movement of the head (and eyes) was constrained such that the line of sight remained in the plane perpendicular to the green (i.e., the plane in which the directional judgment is made). Although novice golfers did show analogous systematic errors in putting direction, these were not affected (i.e., annihilated) by head position. The more accurate putts of skilled golfers were also immune to variation in head position.

The discrepancy in the pattern of errors in perceived direction and the pattern of errors in putting are consistent with arguments by Milner and Goodale (1995, 2008) that the use of visual information in the control of action (i.e., control of the orientation of the club head relative to the ball) operates relatively independent of the use of visual information for perception (i.e., the perception of the direction of the perfect aiming line). Chapter 5 provided additional evidence for this contention. Improvements in the accuracy of the perception of the direction of the perfect aiming line did not translate into an increased accuracy in putting, and vice versa, an increase in the directional accuracy of putting did not result in concomitant reductions in the error of perceived direction.

Learning to putt accurately
Ecological psychology proposes two processes of change that underlie improvements in the use of visual information in the control of action. Education of attention refers to a change in the informational variable that is used, whereas calibration implies a change in how the information variable is scaled to the pertinent movement control variables. Chapter 4 investigated the possible contributions of both processes in acquiring putting skill. First, it was hypothesized that increases in putting accuracy may be related to a change in head position that allows for picking up better specifying informational variables. Although low- and high-skilled golfers spontaneously adopt different head positions when putting, head position did not affect putting accuracy. Therefore, the hypothesis that education of attention underlies improvements in directional putting accuracy was not confirmed. However, it was reasoned that a process of calibration may have occurred, since compared to low-skilled golfers, the high-skilled golfers not only showed a leftward shift in putting direction (i.e., novices made a rightward error, while expert golfers were accurate) but also a leftward shift in perceived direction (i.e., while novices made rightward errors, expert golfers tended to make leftward errors). Presumably, with learning the relation between directional information and the control of the orientation of the club head relative to the ball was adjusted or re-scaled. Chapter 4 also proposed that this parallel leftward shift in perception might suggest that this calibration of putting action has transferred to the perception of direction (but see the Section above). Chapter 5 aimed to test these contentions by directly assessing changes during the learning, instead of comparing golfers of different skill levels. Hence, two groups of novice golfers either practiced to improve their perceptual judgments of direction of the perfect aiming line or their directional putting accuracy. During practice, the participants received augmented feedback on the magnitude and sign of the directional error, while vision was occluded the moment they completed the perceptual judgment or hit the ball. This seemed a potent way to quickly induce accuracy and consistency improvements, which were
preserved for at least one week. The demonstrated increases in accuracy and consistency (i.e., for both the perception of the direction of the perfect aiming line and the putting performance) are consistent with a process of calibration in motor- and perceptual learning. Admittedly, to prove that calibration indeed occurred, future research must use designs in which the informational variable of interest is varied over larger ranges. Intriguingly, calibration appeared specific to the practiced task. This is in line with the proposal that distinct systems for the use of visual information in action and perception exist (Milner & Goodale, 1995, 2008), although from Chapter 5 it could not be ruled out that over longer time-scales (i.e., months or years rather than days or weeks) transfer from action to perception might occur.

Future research

The current thesis clearly demonstrates the importance of information pickup and use in the control of the putting stroke. Novice golfers make systematic directional errors that are only annihilated with practice. Learning to putt accurately encompasses a process of recalibration, during which information variables are more adaptively scaled to the movement variables (Chapters 4 and 5). Possibly, this goes along with alterations in patterns of gaze as well (Chapter 3). Finally, we have seen that establishing and maintaining an adaptive scaling between informational and movement variables is functionally specific (Chapter 5).
Yet, these findings can only be considered a first step in understanding the visual guidance of putting (or any other far aiming task) and expertise therein. That is, the thesis demonstrates that some of the properties of the environment-actor system (i.e., differences in spatial locations of the ball and hole, height differences) are important for visual control of the putting movement (see Figure 1), but as yet, it did not identify the exact optic variables that relate to these properties, nor did it make out the movement variables that are coupled to these informational variables. From an ecological perspective, however, it is pertinent to precisely depict the informational and movement variables that enter the law of control (Warren, 1988). Bootsma (1998), for instance, describes a general research agenda for ecological psychological research into perception and action. First, identify the informational variables that carry the relevant properties of the environment to act on. This necessitates an analysis of the optic (and haptic) variables that may be used by a golfer in a putting situation to detect the
relevant properties that influence the putter–ball interaction (i.e., the impact) and the ball–green interaction (i.e., the ball roll) (Figure 1).

![Diagram of candidate optic variables](image)

Figure 2: Diagram of candidate optic variables. ζ: the angle subtended between the pointer and the target. Ω: the orientation of the line of sight and the perfect aiming line. Also shown E: representing the error in perceived direction (Adapted from Cuijpers et al. 2000).

This requires a geometrical or optical analysis of the putting situation analogous to the analysis of Cuijpers et al. (2000), which indicates that the perception of direction (i.e., exocentric pointing) relates to optic variable ζ that is defined by the angle subtended between the pointer (which observers had to rotate so as to indicate the direction of a line) and the target subtended by the eye, and by the optical variable ω that specifies the orientation of the pointer-target (i.e., perfect aiming line) and the line of sight (see Figure 2). Cuijpers et al. (2000) also suggest that the available binocular equivalents of these monocular optic variables may independently contribute to perceived direction as well. Finally, variables relating to the distances between the point of observation and the pointer and the target (i.e., r_p and r_t respectively) are likely to be involved as well (Cuijpers et al., 2000; see also Exp. 1 in Chapter 5). Furthermore, although not explicitly recognized by Bootsma (1998; but see Jacobs & Michaels, 2006), the first step in a future research agenda should also include
identifying the relevant movement variable that the informational variable controls. Relevant movement variables for the putting action include direction, amplitude and tempo of the downswing movement together with the orientation of the hands during the downswing. These movement parameters control impact point, path, velocity and face angle during impact determining initial speed and direction of the ball roll (see Karlsen, 2008, Pelz, 2000). After having identified the relevant informational and movement variables, the second step is to reveal the sensitivity of the actors to this particular informational variable. Subsequently, it must be demonstrated that the informational variables to which the actors are sensitive are actually used in controlling the movement variable. It seems pertinent to add a fourth step to this agenda (see also Bootsma, Fayt, Zaal, & Laurent, 1997). For a given action, the changes in the informational and movement variables and their relationship must be charted as a function of skill. Chapter 5 points to calibration, but was not conclusive in that respect. Manipulating the optic variables that specify the orientation of the club head (or alternative variables that highly correlate with the orientation) at different stages of skill acquisition may prove very insightful in this respect.

Future research should also take into account that the initial direction of ball roll is not solely specified by the spatial locations of the ball and the hole. For instance, as was shown in Chapter 3, with a slanted surface initial ball direction has to be towards the high side. Further environmental properties that are of relevance are irregularity of the green, humidity, grain, length of the grass and wind. As an example, wind clearly effects how the ball rolls; it may accelerate or decelerate the ball and change the direction of ball roll. In turn, the magnitude of these effects is also dependent on the speed of the green. Intriguingly, skilled golf players must thus be able to detect optical (and possibly tactile) variables that relate to this effects of wind on ball roll and map them to movement variables such as the amplitude, tempo and
direction of the down swing. A real challenge for future research would be to identify those informational variables. Finally, a similar analysis can and should be made with respect to the initial speed of the ball. Again, this is not solely determined by the spatial locations of the target and the ball, but also by the other properties of the green and the weather. Moreover, also strategic factors are important. For instance, the ball speed should be such that whenever the ball misses the target it will not roll more than leaving a lie from which the golfer will certainly be successful in the next putt. The identification and assessment of optical variables that are used to control the velocity of the club head at impact can be informed by a long research tradition within ecological psychology that has examined the perception of distance in quite some detail, but not in the context of control of putting movement (Gibson & Bergman 1954; Lessard, Linkenauger, & Proffitt, 2009).

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