Visual perception and action in golf putting

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Visual perception and action in golf putting

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1 Introduction

Wim H. van Lier
Introduction

Golf is a rather straightforward sport in which the purpose is to hole the ball in as few strokes as possible. The stationary ball can only be moved by hitting it with an implement, called the club. As a matter of fact, the velocity and direction in which the ball will move are determined during approximately 1 millisecond of impact, in which the club contacts the ball. The speed and direction in which the ball will move, depend on the center of the contact area on the ball (depending on the club face angle), the club head velocity and the club face path (the direction in which the club face travels) at the moment of impact. To move the ball with an appropriate speed and direction, two kinds of aiming are crucial. First short aiming, which is about making contact between the club and the ball, and second far aiming, that is projecting the ball towards a location (the hole). This thesis focuses on visual perception to gather the information about the hole location in order to control the direction the ball has to be putt, that is, it addresses the role of visual perception in far aiming.

The Dutch graphic artist Maurits Cornelis Escher (1898-1972), who in many of his drawings experimented with projective geometry, might have been suspecting that in real life visual perception is not always accurate and sometimes even may be misleading. In his litho Hand with reflecting sphere (Figure 1), he unintentionally (Hazeu, 1998 p. 374) gave an aggregation of both Euclidian space and Riemannian space. By doing so, the litho beautifully depicts the problem of the intrinsic curvature of the visual field, a topic that has a long tradition in vision research (e.g., Luneburg, 1947; Battro, Di Piero Netto, & Rozestraten, 1976) and has recently been addressed in detail by Koenderink and colleagues (e.g., Cuijpers, Kappers & Koenderink, 2003; Koenderink & Van Doorn, 2000). Their investigations suggest that visual space is intrinsically curved, and that this curvature changes from elliptic (i.e., positively curved) in near space (i.e., up to 10 meters) to hyperbolic (i.e., negatively curved) in far space.
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Figure 1: Lithograph: “Hand with reflecting sphere” by M.C. Escher 1935, beautifully portraying the intrinsic curvature of the visual field.
For example, it is as if a triangular Euclidian visual field in near space is projected on the outside of a sphere (Figure 2), whereas the same field in far space appears to be projected on the inside of a sphere.

According to the rules of golf, the golfer is not allowed to stand astride over the ball when the putting stroke is performed, instead it is mandatory to stand aside the ball. This constraint for putting defines that the directional judgments the golfer makes when addressing the ball in order to perform a putting stroke is liable to similar errors as observed in the research paradigm of Koenderink and colleagues. Moreover, putting targets are in near space and based on the work of Koenderink it may therefore be expected that the visual field is positively curved resulting in systematic biases of perceived directions.

In this thesis the role of visual perception in far aiming is investigated. Among others, the occurrence of the above mentioned visuospatial distortions are addressed in some detail. More specifically, it is examined how golfers control the direction of putting when aiming for a hole at a distance. How do golfers obtain information about the direction of a putt? Should they actually focus attention to the target, or is it preferable to allocate attention to the ball? Are directional judgments of golfers indeed non-veridical? And if so, how do golfers manage to overcome these fundamental visuospatial distortions, that is, how does the role of visual perception change with skill? What learning processes underlie the changes in the role of visual perception? To answer these questions, the work in this thesis uses an ecological approach to perception and action together with recent insights about the organization of the visual brain as the theoretical background. These will be shortly introduced in the next two sections.

The ecological approach to perception and action

To understand visual perception and action during performance and learning to putt a ball, our studies are embedded within the ecological
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Figure 2: The odd twisted triangles represent perceptual judgments of direction. They show that straight lines are perceived as curved. At short distances a straight line is perceived as convex, whereas at larger distances a straight line is seen as concave. Note, the observer is located at the origin (i.e., 0,0). (adapted from Koenderink, & Van Doom, 2000).
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approach to perception and action that was introduced by Gibson (1966, 1979). This approach holds that information in the optic array about the environment is meaningful and directly guides our actions and perceptions (i.e., without intervention of mental processes). This contrasts significantly with the more traditional cognitive approaches (e.g., Neisser 1967) in which meaningless sensory input impinges on the retina to subsequently be selected, transformed, and enriched to form perceptual representations of the environment in order to decide upon and plan an appropriate action.

Gibson (1979) describes the optic array as the carrier of the information in the environment. This optical information is immediately meaningful because it relates one to one with the environment (i.e., specification). Ecological psychologists postulate that for actions and perceptions lawful relations exist between optical information and the corresponding movement or perception. For action this has been denoted as the ‘law of control’ (Warren, 1988), for perception this has been referred to as a ‘single valued function’ (Jacobs & Michaels, 2007). Most generally, these relations can be formally expressed as;

\[ T(t) = a + b \times I(t) \]

The function is a conceptualization of the immediate link between information and task (i.e., movement or perception) in which a particular movement or perception \( T(t) \) is a function of a particular optical information variable \( I(t) \), with constants \( a \) and \( b \) specifying the precise relationship between the movement or perception and the information variable (e.g., the club face angle in relation to the information specifying the direction towards the hole).

Two processes of change can be distinguished that enhance the adaptability of the coupling between information variables on the one hand, and the intended movement or perception on the other hand (e.g., Jacobs & Michaels, 2007; Withagen & Michaels, 2005). The first process, ‘education of attention’, encompasses a change of the optical
information variable \( I(t) \) that enters a particular control law. Motor learning through education of attention (or ‘attunement’) means that a more useful or better specifying variable comes to be exploited in the control of movement (Gibson, 1966; see also Michaels & Beek, 1995; Savelsbergh & Van der Kamp, 2000). The second process, ‘calibration’, refers to the change in the relation between the movement or perception and the optic variables by tuning of the constants \( a \) and \( b \). In other words, motor learning by calibration comes about by (re-)scaling the relationship between the movement or perception and the exploited optic variable (e.g., Withagen & Michaels, 2005).

The use of visual information for perception and action

Proponents of the ecological approach to perception and action usually make no distinction between the use of visual information for the control of movement and the use of visual information for the perception of the environment. Recently however, neuro-scientific evidence from both humans and monkeys (Rizzolatti, & Craighero, 2004) has shed new light on how vision contributes to perception and the guidance of actions. This evidence points to the existence of distinct visual pathways in the primate cerebral cortex (Milner & Goodale 1995, see also Baiser, Ungerleider, & Desimone 1991) that independently support the use of visual information for perception and the use of visual information for the control of movement.

That is, according to a neuro-anatomical scheme originally proposed by Ungerleider and Mishkin (1982), the visual cortical areas comprise two major processing pathways, or streams (see Figure 3). One pathway starts at the primary visual cortex and leads to the posterior parietal cortex. Milner and Goodale (1995; see also Milner & Goodale, 2008) argue that this dorsal stream plays an important role in the visual control of movement. The second pathway also originates at the primary visual cortex but projects to the inferior temporal cortex. This ventral stream plays an important role in obtaining knowledge about objects, places and
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Figure 3. Schematic representation of the cortex cerebri, showing the ventral (lower arrow) and dorsal (upper arrow) pathways transferring visual information in the brain.
events in the environment. According to Milner and Goodale (1995), both streams process information about the structure of objects and about their spatial locations - and both are subject to the modulating influences of attention. However, Milner and Goodale (1995) also propose that given the distinct functions they subserve, these streams process the information in a different way. Hence, the dorsal stream deals with moment-to-moment information about the location and size of objects relative to the action system to visually control movements directed at those objects. In contrast, the ventral stream is assumed to process information in quite a different way. It does so over longer time scales, and information about location size and other properties, like for instance color, are relative to other objects in the environment. This enables the perceiver to distinguish or identify objects, to attach meaning and significance to them, and to establish their causal relations - operations that are essential for accumulating knowledge about the world. Evidence shows that because these two distinct visual systems function (partly) independently and have different characteristics, action and perception may sometimes result in apparently incongruent outcomes. For example, there is ample evidence to suggest that a visual illusion results in clear perceptual biases in estimating the size of an object, while the grasping of that object remains relatively unaffected (for recent overview see e.g., Milner & Goodale, 2008; Bruno & Franz 2009). Even though they function differently, the two visual systems have to work together in the production of adaptive behavior. Selection of appropriate goals and adequate actions to be performed, depend on the perceptual machinery of the ventral stream, but the execution of a goal-directed action is carried out by dedicated on-line control systems in the dorsal stream (Milner & Goodale, 2008; Van Doorn, Van der Kamp & Savelsbergh, 2007).

Theoretically, it is important to acknowledge that Milner and Goodale have conceptualized the workings of vision in perception and action within the traditional cognitive approaches. Consequently, they tell apart vision for perception and vision for action in terms of the different
kinds of transformations of the visual input that results in fundamentally different representations for perception (i.e., in allocentric coordinates) and action (i.e., in egocentric coordinates). Clearly, such a conceptualization runs against the ecological approach developed by Gibson. Hence, proponents of the ecological approach have re-conceptualized the distinction between vision for perception and vision for action in terms of the type of the visual information sources that is used (i.e., allocentric versus egocentric information) and the manner in which the information is used (e.g., slow and explicit versus fast and implicit) (for an elaboration of these theoretical arguments, see e.g., Michaels, 2000; Van der Kamp et al. 2003, 2008). This ecological conceptualization will be the main theoretical perspective in the present thesis.

Overview of the thesis

The main purpose of the present thesis is to scrutinize the role of visual perception in the guidance of the putting action, in particular with respect to the directional accuracy of the stroke. Three aspects are considered. First, it is explored towards what sources of information (e.g., hole, green, and/or ball) attention is allocated, among others by scrutinizing patterns of visual search. Second, it is examined how golfers deal with perceptual distortions. The two-visual system model of Milner and Goodale will serve as theoretical backdrop to this question. Thirdly, it is investigated how golfers learn to improve direction accuracy of putting. To this end, the contribution of education of attention and calibration, as proposed by the ecological approach, are investigated.

Specifically, the aim of the study in Chapter 2 was to examine the effect of proximal and distal external attentional foci in a golf putting task among novice and skilled golfers. Participants performed golf puts while instructed to focus on the ball (i.e., proximal focus) and while instructed to focus on the hole (i.e., distal focus). The questions to be scrutinized are whether a distal focus is superior in enhancing novices’ and skilled golfers’
putting performance compared to adopting a proximal external focus.

Chapter 3 presents a study that examined the effects of task complexity on the pick up of visual information in order to control the direction of putting among high skilled golfers. It does so by charting patterns of visual search during puts on a level green. In addition, it examines how spatial and temporal adaptations in visual search, if any, are made when putting on a sloped green. In particular, do players direct visual attention towards different locations (e.g., ball, hole, green) at different times for different durations during the putting stroke? And if so, can successful and less successful golfers be distinguished on the basis of patterns of visual search or information pick up strategies?

Chapter 4 focuses on the role of visual perception in the putting task. Previous work showed that visual perception is not always veridical, and that golfers may make systematic errors in perceiving the direction of the perfect aimline (Johnston, 2003). This raises the issue of the role of visual perception in putting. Where do these perceptual errors originate, and do they also affect the putting action (cf. Milner & Goodale, 2008)? Do they affect putting accuracy of low and high skilled golfers similarly, or have experts learned to cope with these perceptual inaccuracies? To this end, Chapter 4 reports a series of three experiments that scrutinizes the role of perceptual errors among novice and high-skilled golfers in the perception of the direction of the perfect aimline when they act to hole a ball. In doing so, the experiments also touch upon the learning processes (i.e., education of attention and/or calibration) that may underlie improvements in putting skill.

Chapter 5 continues with the issue of the possible independency of perception and action among golfers, but rather than comparing novices and high-skilled golfers to infer if learning involves education of attention or calibration, the main experiment in this chapter involved extended practice with augmented feedback to either improve perception of the direction of the perfect aimline or the control of putting direction. It was asked whether practice with feedback encouraged learning through calibration, and more
pertinently, whether any transfer occurred from perception to action after perceptual practice, or vice versa, from action to perception after motor practice.

Finally, in the epilogue (Chapter 6) the theoretical implications of the various studies are discussed. In addition suggestions are brought up for future work.

References


Effects of proximal and distal external foci of attention in novice and expert golfers

Van Lier, W.H., van der Kamp, J., & Savelsbergh, G.J.P. Effects of distal external foci of attention in novice and expert golfers. (manuscript to be submitted for publication).
Abstract

The constrained action hypothesis (Wulf, 2007; Wulf, McNevin, & Shea, 2001) predicts a superior performance of a distal external focus of attention over a proximal external focus of attention irrespective of skill level. Thus far, this prediction has not been directly tested. Hence, the present study 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 novices (N = 20) and high-skilled golfers (N = 20) performing a golf putting task at distances of 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 belief to focus on the ball while putting, a more distal focus may lead to superior performance. The findings partly support the constrained action hypothesis.
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Introduction

In golf practice, “keep your eyes on the ball” is an uncontested adagio. It reflects the belief that, in order to be successful, golfers must look at the ball from the start of the backswing, at the latest, until impact. This includes putting as well: it is hard to find a single coach who does not teach novice golfers to look at the ball from the start of the putting movement and to maintain gaze at the ball through impact until the end of the forward swing (e.g., Pelz, 2000, p. 231). Consequently, each and every golfer is aware that it is of utmost importance for accurate putting to contact the ball with the putter face at the right place and in the right direction. The best chance to achieve this, so it is believed, is by looking at the ball during the putting movement, and to focus attention to hitting the ball behind its center along a (virtual) line through the ball and the hole.

Intriguingly, however, recent theories and experimental studies that address attentional focus in sports sciences, indicate that for complex actions, such as they occur in golf, performance and learning are significantly enhanced the farther away (i.e., the more distal) from the movements attention is directed (e.g., Wulf & Su, 2007; Wulf & Prinz, 2001; McNevin, Shea, & Wulf, 2003; see also Peh, Chow, & Davids, 2011). Thus, in her constrained action hypothesis, Wulf posits that an internal focus of attention to movements potentially disrupts the automatic movement control processes that best regulate movements (Wulf, McNevin, & Shea, 2001). By contrast, an external focus of attention to the effects of the movements (e.g., an implement that is moved, the ball’s path or the target) is presumed to promote automatization. Indeed, although there are some issues as to whether performance benefits from an external focus of attention also includes novice golfers (see Perkins-Ceccato, Passmore, & Lee, 2003, Beilock, & Carr, 2001), there is now a reasonable amount of evidence that learning and performance of golf strokes are superior with external foci as compared to internal foci of attention (Bell, & Hardy,
Two studies did directly compare the effects of different external attentional foci. Wulf et al. (2000, Experiment 2) compared two groups of novice golfers, who produced pitching1 shots with a proximal external focus with attention directed to the club movement (i.e., participants were asked to concentrate on letting the club perform a pendulum motion) or with distal external focus with attention directed at the ball's trajectory and the target (i.e., participants were asked to anticipate the ball's arc and imagine the ball landing on the target). Novice golfers performed more accurate when attention was directed proximal (i.e., closer to the body movements), suggesting that a technique-related external focus is more effective than a distal focus to the outcome of the movement. Recently, however, Bell and Hardy (2009) have reported contradictory effects of proximal and distal external foci of attention in golf chipping shots. Performance of a group of skilled golfers with a proximal external focus to the position of the clubface through the swing (i.e., participants repeated the phrase 'square face' prior to the execution of the shot) was inferior to the performance of a second group of skilled golfers who were instructed to direct attention more distal to the ball's trajectory after it had left the clubface (i.e., participants repeated the phrase 'straight flight' prior to the execution of the shot). Bell and Hardy (2009) argued that, not unlike the differential effects observed for internal and external attentional foci (e.g., Perkins-Ceccato et al., 2003), the discrepant effects for proximal and distal

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1 It seems that in the discussed studies (Bell & Hardy, 2009; Wulf et al., 2000) there is a confusion of tongues over the actions of 'chipping' and 'pitching'. Most likely, the novice participants performed chip shots using a pitching wedge. In chipping the wrists are kept firm all the time, while in pitching a wrist cock and forearm roll must be made during the backswing followed by reverse movements in the downswing. The latter technique is in general too difficult for novices to perform.
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external foci of attention are skill-dependent. The more distal focus on the ball’s trajectory would be more beneficial for skilled golfers, because it is less directly related to the spatio-temporal characteristics of the movement and therefore less likely to interfere with the automatized movement control (Bell & Hardy, 2009, p. 173). Moreover, for novice performers a proximal external focus may be advantageous, exactly because a more direct movement-related focus may better channel the less automatized movement control processes compared to a more distal attentional focus. However, before such a conclusion can be accepted, it is pertinent to assess and compare the performance differences between proximal and distal attentional foci as a function of skill. That is, the studies of Wulf et al. (2000) and Bell and Hardy (2009) not only differed with respect to the participants skill level, but also with respect to potentially mediating factors such as different tasks (i.e., pitching versus chipping, see also McNevin et al., 2003) and different procedures for inducing the external attention.

The aim of the current study was therefore to examine the effect of proximal and distal attentional foci in a golf putting task among novice and skilled golfers. Specifically, participants performed golf puts while instructed to focus on the ball (i.e., proximal focus) and while instructed to focus on the hole (i.e., distal focus). Based on the empirical observations (but not completely in line with the constrained action hypothesis), we expected the proximal focus to enhance novices’ putting performance, while the distal focus was anticipated to lead to better putting performance among skilled golfers.

Notice that we use different proximal and distal foci than Wulf et al. (2000) and Bell and Hardy (2009). We choose not to use an attentional focus directed to the club, as there are strong reasons to suspect that for skilled performers, implements become part and parcel of the action system. Merleau-Ponty (1945/2002), for instance, argued that “to get used to a hat, a car or a stick is to be transplanted into them, or conversely, to incorporate them into the bulk of our own body.” (see for some empirical evidence, Longo & Lourenço, 2006, Dotov, Nie, & Chemero, 2010). If correct, a (proximal external) focus on the clubface would in fact be internal. We also choose not to use an attentional focus to the ball’s trajectory, because it only channels attention after impact with the ball, while other foci (e.g., on the putting movements or target) potentially constrain the putting movements prior to and after impact.
Method

Participants

Twenty self-acclaimed right-handed university students (10 female and 10 male; age: mean = 23.4; s = 2.1 years) without golf experience and twenty right-handed teaching golf professionals (3 female and 17 male; age: mean = 30.6; s = 8.1 years; handicap: mean = 3.3; s = 1.3) participated in the experiment. Participants signed an informed consent prior to the experiment, which was approved by the local institute's ethical committee.

Material and apparatus

The experiment was conducted in a large laboratory, using a triangular platform, 4 m long and 4 m wide, covered with synthetic turf and artificial grass (GreenFields®, Genemuiden, The Netherlands). The speed of the artificial green was very fast (i.e., 14 Stimp\(^2\)). Ball locations at distances of 1.8, 2.7 and 3.6 m were marked on the green in such a way that the roll of the ball was not influenced. All participants used the same standard putter and high quality golf balls.

Procedure and task

The participants were required to putt golf balls from 1.8, 2.7 and 3.6 m distance from the front edge of the hole with both a proximal and a distal external focus of attention. Before the start of the experimental trials the experimenter spent about 10 minutes with each participant to explain and  

\( ^2 \) To measure the speed of a golf course putting green, a Stimpmeter is used. It applies a known force to a golf ball and measures the distance the ball travels in feet. The fastest greens in the world have readings of 13-15 feet (i.e., Stimp 13-15).
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demonstrate the basic technique of the putt stroke (for similar procedures, see Wulf et al., 1999; 2000, Exp. 2). For this purpose an instruction video was made in which the most important features of a putting stroke were demonstrated. Four points were explained: the reversed overlapping grip; the movement of the shoulder-line in the putt direction; clubface square to the putting line; and the posture with the head directly above the ball. To get acquainted, participants performed ten practice putts before the experiment started. In addition, the participants were instructed to putt the ball in, or as close as possible to, the hole. They were also told that an overshoot was to be preferred over an undershoot (i.e., a ball not reaching the front edge of the hole). To encourage the participants to putt at their best according these instructions, a competition was organized among participants, in which they could earn a maximum of 720 points. For each of in total 144 putts, they were awarded 5 points for each putt that was holed, 2 points for missed putts that ended not further than 30 cm past the hole, and 1 point for missed putts that ended within 30 cm short of the hole. The scoring was done online.

The general instruction and familiarization trials were followed by the experimental trials. Before each experimental trial the participant was told to step aside, turn his back towards the hole and start addressing the ball. Next, the experimenter signaled the participant to either look at the ball or at the hole. This was a shorthand for achieving respectively a proximal external or distal external focus of attention, the full instructions of which were given before the experiment:

**Proximal external focus:** the participants were instructed to look at the ball from the beginning of the backswing until the end of the foreswing (i.e., until after impact). It was emphasized that participants did not look away from the ball until the putting movement was entirely completed.

**Distal external focus:** participants were instructed to look at the hole from the beginning of the backswing until the ball neared the hole. It was emphasized that participants did not look away from the hole until they had completed the putting movement.
Notice that this instructional set to direct attention diverges somewhat from previous studies by Wulf et al. (2000) and Bell and Hardy (2009). Instead of telling participants to direct attention to some location, the participants were instructed to fixate these locations. This allowed us to directly control whether or not participants complied with the instructions, which for the attention instruction can only be assessed in an indirect way (e.g., by having participants repeat a phrase related to the attended location). In the case the experimenter observed that the participant did not comply with the instruction, the trial was repeated. Nevertheless, it should be kept in mind that a drawback of this procedure is that gaze fixation at a certain location does not necessarily mean that attention is directed to that location.

The participants performed a total of 144 putts, 24 repetitions for each of three distances with both a proximal and distal external focus. They were presented in three blocks of 48 putts. There were short breaks between series of 8 putts and somewhat longer breaks [2 minutes] between the blocks of 48 putts. The order of the three distance conditions was counterbalanced, while the proximal and distal external focus conditions were alternated. No feedback regarding the technique or score was provided until the experiment was concluded.

Data reduction and analysis

The putting percentage (i.e., the number of putts sunk divided by the total number of putts performed multiplied by 100) and the average putting score (i.e., the sum of the total number of points awarded for all putts divided by the total number of putts performed) were calculated for each distance and attentional focus condition and served as dependent variables.

The two dependent variables were submitted to separate 2 (expertise: skilled, novice) x 3 (distance: 1.8 m, 2.7 m, 3.6 m) x 2 (focus: proximal, distal) ANOVAs with repeated measures on the last two factors.
Partial eta-squared ($\eta^2_p$) values were computed to determine the proportion of total variability attributable to each factor or combination of factors. Finally, Tukey HSD post hoc test procedures ($p < .05$) were used as follow up.

**Results**

Figures 1 and 2 show the putting percentage and the average putting score as function of distance and attention allocation for both groups of participants. The figures show that the putting percentage of the skilled golfers tripled that of the novices’, while the putting score was approximately doubled. The ANOVAs confirmed this supremacy of the skilled golfers for putting percentage, $F(1, 38) = 219.8, p < .001, \eta^2_p = 0.85$, and for average putting score, $F(1, 38) = 168.8, p < .001, \eta^2_p = 0.82$.

As was expected, there were also clear effects of distance for both putting percentage, $F(2, 76) = 104.3, p < .001, \eta^2_p = 0.73$, and average putting score, $F(2, 76) = 136.0, p < .001, \eta^2_p = 0.78$. Post hoc comparisons indicated that performances decreased with increasing distances. In addition, significant interactions between distance and expertise were revealed for putting percentage, $F(2, 76) = 8.38, p = < .01, \eta^2_p = 0.18$, and average putting score, $F(2, 76) = 5.67, p < .01, \eta^2_p = 0.13$. Post hoc comparisons indicated that for all distances putting percentages and scores of the skilled golfers were superior to those of novices, except when comparing performance of the skilled golfers at the longest distance with performance of the novices at the shortest distance.

The most pertinent analyses involve the factor focus. The ANOVAs for putting percentage and average putting score did not reveal significant effects of focus ($F(1, 38) = 0.36, p = .55, \eta^2_p = 0.009$, and $F(1, 38) = 0.17, p = .68, \eta^2_p = 0.005$, respectively), nor were there significant interactions between focus and expertise ($F(1, 38) = 0.03, p = .88, \eta^2_p =$ $...
Figure 1: Putt percentage for novice (left panel) and skilled golfers (right panel) as a function of distance and attention focus. Error bars indicate variable error and asterisks indicate putt percentages that are significantly different for focus (* p < .05).

Figure 2: Average putting score for novice (left panel) and skilled golfers (right panel) as a function of distance and attention focus. Error bars indicate variable error and asterisks indicate average putting scores that are significantly different for focus (* p < .05).
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0.001, and $F(1, 38) = 2.19, p = .15, \eta^2 = 0.06$) or focus and distance ($F(2, 76) = 2.96, p = .06, \eta^2 = 0.07$. and $F(2, 76) = 2.16, p = .12, \eta^2 = 0.05$). However, there were significant higher order interactions between focus, distance and expertise for putting percentage, $F(2, 76) = 4.48, p < .05, \eta^2 = 0.11$, and average putting score, $F(2, 76) = 4.80, p < .05, \eta^2 = 0.11$. Post hoc comparisons for the putting percentage and average putting score confirmed a difference between proximal and distal foci at 1.8 m for the skilled golfers, but did not indicate differences as a function of attention allocation among novice golfers.

The goal of the current study was to examine the effects of proximal and distal external attentional foci in a golf putting task among novice and skilled golfers. According to the constrained action hypothesis (e.g., Wulf et al., 2001, Wulf & Su, 2007; see also Wulf, 2007), an external focus of attention promotes an automatic movement control by allowing unconscious, fast and autonomous processes to control the movement, in contrast to an internal attentional focus during which movement control is more conscious and effortful. For the same reason, Wulf and Su (2007) further argued that a more distal focus of attention is superior relative to a proximal external attentional focus, provided that there is a relation with the movement effects. Importantly, this benefit should occur irrespective of skill level. There is, however, ample evidence for differential effects of internal and external foci of attention between novice and high skilled performers, indicating that novices benefit from an internal focus (e.g., Perkins-Ceccato et al., 2003; Beilock & Car, 2001). The topic under study here is whether analogous patterns become apparent when comparing proximal and distal external foci of attention in novice and high skilled golfers.

The results show that the high skilled golfers performed indeed better with a distant focus of attention, at least when putting at a 1.8 m

Discussion

The goal of the current study was to examine the effects of proximal and distal external attentional foci in a golf putting task among novice and skilled golfers. According to the constrained action hypothesis (e.g., Wulf et al., 2001, Wulf & Su, 2007; see also Wulf, 2007), an external focus of attention promotes an automatic movement control by allowing unconscious, fast and autonomous processes to control the movement, in contrast to an internal attentional focus during which movement control is more conscious and effortful. For the same reason, Wulf and Su (2007) further argued that a more distal focus of attention is superior relative to a proximal external attentional focus, provided that there is a relation with the movement effects. Importantly, this benefit should occur irrespective of skill level. There is, however, ample evidence for differential effects of internal and external foci of attention between novice and high skilled performers, indicating that novices benefit from an internal focus (e.g., Perkins-Ceccato et al., 2003; Beilock & Car, 2001). The topic under study here is whether analogous patterns become apparent when comparing proximal and distal external foci of attention in novice and high skilled golfers.

The results show that the high skilled golfers performed indeed better with a distant focus of attention, at least when putting at a 1.8 m
distance. This finding supports the predictions of the constrained action hypothesis. This is remarkable, given that the high skilled golfers, in all likelihood, have always been putting with the focus directed at the ball, resulting in the more proximal focus being their preferred focus. In other words, a distal focus of attention may also have resulted in a de-automatization of putting habits and hence a deterioration of putting performance. This did not occur: also not for the longer distances during which the distal focus did not result in superior performance. Interestingly, in a recent study Weiss, Reber, and Owen (2008) showed (in inexperienced darters) that a switch from a preferred to a non-preferred focus of attention did in fact enhance performance in the case this induced a change from an internal to an external focus of attention. An opposite switch from an external to an internal attentional focus, however, led to a breakdown of performance. Also Weiss et al. (2008) called for the explanation that an external focus of attention promotes automatized control. It seems worthwhile therefore, to verify that an external focus of attention relative to an internal focus, and more pertinent to our finding, a distal external focus relative to a proximal external focus indeed induces more automatic control in putting. For example, the amount of EMG-activity (Zachry, Wulf, Mercer, & Bezodis, 2005) and/or smoothness of the movement kinematics (e.g., Maxwell, Masters, & Eves, 2003) may reflect the degree of automatization of the putting movement. Finally, it remains unclear why the distal focus only led to superior putting performance at the shortest distance. Possibly, it allowed the high skilled to unconsciously monitor the ball’s position in the peripheral visual field, allowing them to extract information from both distal and proximal sources. Yet, this would not explain why, at the shortest distance, the benefits of the distal focus did not emerge among novices as well.

Unfortunately, we were not able to independently assess the preferred focus of the participants.
For the novice golfers, no differences were observed between the two external foci of attention. This finding is not consistent with the constrained action hypothesis, although it also does not necessarily contradict it. Yet, it does not rule out that the optimal external focus of attention may differ as a function of skill level. To shed further light on this issue, future work should include more external foci, such as the clubface (but see footnote 2), the ball, an intermediate target, the ball’s path, and the target.

In conclusion, we provide evidence to suggest that contrary to golfers’ present belief to focus on the ball while putting, a more distal focus leads to superior performance (see also Bell & Hardy, 2009). If confirmed, then it would be valuable to make an effort training golfers to use a distal focus to increase their chances for higher scores.

References


Effects of proximal and distal external foci of attention in novice and expert golfers

years of research. E-Journal Bewegung und Training, 1, 4-11.
Gaze in golf putting
Effects of slope

Abstract

The aim of this study was to examine the effects of task complexity on visual search behaviour during a putting task in golf. Task complexity was varied by introducing sideward slope to the putting surface (i.e., 0%, 1% and 2% slopes). The high skilled golf players (N = 20) were divided into two groups on the basis of their overall putting performance. 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. With respect to gaze, it was found that increasing the steepness of the slope resulted in more fixations to the high side of the hole. Furthermore, 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 argued that in dealing with a sloped green, the prime adaptation in gaze is in the spatial domain rather than in the temporal domain.
Introduction

A major subject of sport sciences is the impact of visual search behaviour on performance. The main assumption in this field of research is that success or skill in performance is associated with more efficient strategies of visual search. The research has therefore predominantly been focused on comparisons of visual search between athletes of diverse skill levels and between successful and unsuccessful performances. The purpose of the present study, following an earlier lead of Williams et al. (2002), is to add a new dimension to this field of research by assessing the relation between visual search behaviour and performance in tasks that have different degrees of complexity.

We investigated the visual search behaviour of skilled golf players as they performed putts from a distance of 1.8 m on a green with different sideward slope. Golf putting is a far aiming task that entails a player pacing and aligning the direction of the swing through the ball with the distant target hole. In our experiment, task complexity is manipulated by varying the sideward slope angle of the green. The larger the sideward slope angle of the green the more the ball will be deflected from its straight line by gravity, which makes it necessary for the player to adjust both the direction and the velocity of the swing. Consequently, to successfully perform this task, the player not only needs information about the distance to the target hole, but also about the steepness of the slope. Hence, golf players must move their gaze over the putting surface to assess its slope, but also over the target, the club, the ball and perhaps the feet, which serves to prepare the direction and velocity of the swing and the orientation of the club head at the moment of impact. In this regard, an impressive body of work by Proffitt and colleagues (e.g., Proffitt, 2006; Proffitt et al., 1995; Witt, & Proffitt, 2007; see also Feresin, & Agostini, 2007) shows that perceived slant of sloping surfaces are usually overestimated, albeit that the magnitude of the overestimation is dependent...
on the type of judgment. A translation of such perceptual overestimations into putting, especially during the preparation phase, would result in a high proportion of errors to the high side of the hole.

In a recent meta-analysis, Mann et al. (2007) found systematic and consistent differences in visual search behavior between sports players of different skill levels, the nature of these differences being highly task-dependent. They discerned interceptive, strategic and far aiming tasks. These tasks have different characteristics and were shown to constrain visual search in a different manner. For instance, the visual search strategy of high-skilled sports players can be characterized by fewer fixations of longer duration as compared to low-skilled players. However, these skill-related differences are much more pronounced in strategic tasks (e.g., passing a ball in soccer) than in interceptive tasks (e.g., returning a tennis serve), a difference that is attributed to distinct temporal constraints of the two types of tasks. With this task-dependency of visual search in mind, we restrict further discussion to far aiming tasks such as basketball free throwing (Vickers 1996a, 1996b), pistol and rifle shooting (Ripoll et al. 1985; Janelle et al. 2000), dart throwing (Vickers 2000), playing billiards (Williams et al. 2002) and golf putting (Vickers 1992, 1993; Naito et al. 2004).

Based on a detailed analysis of gaze during putting, Vickers (1992) argued that as skill improves, golf players develop a more efficient visual search strategy. She reports that high skilled golfers (i.e., handicap 0-8) exhibit fewer gazes combined with faster gaze shifts than less skilled players (i.e., handicap 10-16). These gazes are directed to more critical locations (i.e., ball and hole, but not club head, feet and putting surface) and are of longer duration. In particular, the final gaze fixation before contact with the ball was found to be an important predictor of skill level and putting accuracy. That is, the final gaze to the ball was almost twice as long among the high skilled players as compared to the less skilled players. As an explanation for these skill-related differences in visual search behavior, Vickers (1992) hinted that longer periods of steady gaze
enhances the precision of the control of the arms (club). In her subsequent work using other far aiming tasks (e.g., basketball, Vickers 1996b; darts, Vickers 2000), Vickers provided additional evidence for the existence of a relation between the duration of the final gaze before movement onset (which she denoted 'quiet eye') and aiming skill. In billiards, Williams et al. (2002) found final gaze duration to vary as functions of both skill level and successfulness compared to unsuccessful shots in billiards: longer final gaze duration was associated with more accurate performance. It is argued that these longer final gazes allow players to better set and attune the parameters of the ensuing movement, which in turn results in an increased aiming accuracy. In other words, the final gaze duration is considered an important constituent of a successful visual search strategy in far aiming tasks.

In sum, the inter-individual differences in visual search behavior are thought to be reliably related to skill level and/or success during performance (Mann et al., 2007). Indeed, previous explanations of the link between visual search behavior and performance are almost solely based upon comparisons of players of different skill levels or comparisons between successful and unsuccessful performances. The generalisability of these explanations would be further enhanced if it could be demonstrated that similar differences in visual search behavior occur across different levels of task complexity. Williams et al. (2002) manipulated the complexity of a billiards task by having participants sink balls under different spatial constraints. They found longer final gaze durations with increasing task complexity among both the less skilled and the skilled players. They argued that the prolonged final fixation duration reflects that more complex aiming tasks require longer times to set and attune the parameters of the movement. The effects of complexity on the other visual search characteristics (e.g., mean fixation durations, number of fixation, fixation location) were not directly compared, however.

The present study aims to further examine the effects of task complexity on visual search behavior by increasing the number of variables...
(or sources of information) that need to be taken into account. To this end, we increased the complexity of putting by introducing a sideward slope to the putting surface. We assumed that with a sloping surface golfers need to gather more information in the preparation phase, and hence, it was expected that they need more and longer fixations to extract the relevant information from the environment (e.g., areas surrounding the ‘aimline’ and break, Pelz, 2000; for further explanation see also Figure 1). More successful golfers were expected to execute fewer visual fixations of longer duration on relevant locations than less successful golfers, which would demonstrate that more time is taken to get informed on relevant cues. We further expected longer duration of final gaze due to increased slope angle of the green, because the time needed to set the parameters is thought to vary as a function of task complexity.

We also examined how visual search behavior relates to expertise and success during performance. We reasoned that as high skilled golf players (i.e., with low-handicap) are not necessarily proficient putters (e.g., Pelz, 1999 p.37), it would be appropriate to employ a within task criterion (i.e., the percentage of putts holed) to demarcate successful and less successful golfers (Whiting, 1986; Savelsbergh et al., 2005). As slope effects on breaking of the ball are usually underestimated (Pelz, 2000 p. 151; cf. Proffitt, 2006), we expected the more successful golfers to fixate more at the high side of the hole on sloped greens (i.e., with the ball breaking from right to left more to the right side of the hole). In addition, we expected the successful golfers to make less fixations of longer duration. In particular, it was hypothesized that duration of the final gaze fixation would be longer for this group. We also expected temporal differences in gaze behavior: as is the case in putting on a flat green (Vickers, 1992), the more successful putters were expected to use less gaze shifts of longer duration from ball to hole and vice versa, thereby using a visual search strategy characterized by more economy and efficiency. Similar differences were expected when comparing holed putts to missed putts.
Figure 1: A schematic representation of the putting surface, including the aimline, break (i.e., distance of the aimline to the hole) and entry point (see text for further explanation).
Participants

Twenty right-handed teaching golf professionals volunteered to participate (2 female and 18 male; age: mean = 36.9; s = 6.5 years; handicap: mean = 3.4; s = 2.0). Three participants were excluded because of technical failure. Six participants were assigned to the successful group (age: mean = 40.7; s = 8.3 years; handicap: mean = 3.8; s = 2.3) and six others to the less successful group (age: mean = 36.0; s = 6.7 years; handicap mean = 2.5; s = 1.5). Classification was based on the proportion of holed putts across the three slope conditions (i.e., > 0.56 and < 0.47 for the successful and the less successful group respectively). We only considered visual search behaviours for these twelve participants; the visual search behaviour of the five remaining participants was not analyzed. Participants were treated in accordance with the local institution’s ethical guidelines.

Material and apparatus

The experiment was carried out in a large laboratory using a triangular platform, 4 m long and 4 m wide, covered with synthetic turf and artificial grass (GreenFields®, Genemuiden, The Netherlands). The speed of the artificial green was fast (i.e., 14 stimp). The platform could be tilted to create slopes of 1 and 2% (i.e., sideward slope perpendicular to the putting direction). All participants used the same standard putter and high quality golf balls.

Gaze behavior was registered using an eye tracking system (Applied Science Laboratories 501, Bedford, MA) that consisted of a head-mounted scene camera and a monocular corneal reflection system (see Savelsbergh et al., 2002). The eyetracker system works by collecting
three pieces of information: displacement between the left pupil and cornea reflex (reflection of the light source from the surface of the cornea), position of eye in the head, and position and orientation of head in space. The relative position of these features is used to compute visual point-of-gaze with respect to a pre-calibrated 9-point grid built up near the hole on the green. A video image of the scene including the point-of-gaze cursor, captured with a miniature scene camera, was then stored using a JVC BR-DV3000U digital video recorder for further analysis (25 Hz). The accuracy of the system was ± 1-degree visual angle, which from the point of observation of the participant amounts to an accuracy of approximately 2.6 cm at the ball and 4.4 cm at the hole. The system’s calibration was checked before each trial. If necessary (i.e., once or twice every 10 trials) the system was recalibrated using the quick and manual recalibration procedure. The eyetracker was connected to the main computer with a 6-m long cable. The cable was attached to the waist of the participant using a waistband in such a way that it did not interfere with putting. A LED, which was located on the green at 1 m behind the ball (i.e., seen from the perspective of the participant), served as a visual signal indicating the start of each trial and the triggering of the ASL and video registration.

Procedure and task

First, the participants were informed about the procedures of the experiment, and the ASL helmet was fixed and calibrated. The participants then received the task instructions. They were instructed to start their habitual preparations to execute the putt (e.g., address the ball by setting up behind the ball) when a visual signal was given. They were instructed to try to hole the ball, or at least try to let the ball terminate as close as possible to the hole. The later instruction was given to prevent participants from making a fast straight shot, which would reduce the effect of slant on the ball’s trajectory. Yet, to prevent them from playing consistently short, participants were also told that an overshot was to be preferred over an
undershot. To encourage the participants to putt at their best according to these instructions, a competition was organized among participants, in which they could earn a maximum of 225 points. For each of the 45 putts, they were awarded 5 points for each putt that was holed, 2 points for missed putts that ended not further than 30 cm past the hole, and 1 point for missed putts that ended within 30 cm short of the hole. After each trial, the participant had to step aside, turn away from the hole and wait for the experimenter to announce the next trial. The participants then waited for the visual signal to perform the next trial.

Design

All participants performed 45 golf putts from 1.8 m (i.e., 6 foot) in three different slope conditions: 0% (i.e., a flat green), 1%, and 2% slope with the ball breaking from right to left (i.e., from the participants perspective, the right side of the hole was higher than the left side). Slope conditions were presented in blocks, the order of which was randomized across participants. Participants were allowed to take a short rest period between trials.

Data reduction

During the experiment, we scored whether the putt was holed or missed. A miss was further categorized as a miss to the left or as a miss to the right (i.e., the ball passed the hole to the left or the right). Next, the proportion of balls holed (i.e., the number of balls holed divided by the total number of trials), and the proportion of misses to the left or the right (i.e., number of misses to the left or the right divided by the total number of trials) was calculated for each slope condition separately.

The recordings of ASL-scene camera were used to determine the moments of initiation of the backswing and downswing, and the moment of impact. From these measures, we calculated the total preparation
Gaze in golf putting: Effects of slope

(i.e., the time between the visual signal and the onset of the backswing), backswing and downswing times. To address visual search behavior, point-of-gaze was analyzed frame-by-frame from the moment the visual signal was turned on until putter-ball contact. We coded gaze fixations and gaze shifts. A fixation was coded when point-of-gaze was directed at the same location for at least 3 consecutive frames [i.e., 120 ms]. Four locations were distinguished: the hole including the surrounding areas 18 cm to the left and right of the hole (hole fixations); the area between the hole and the ball; the ball and putter head; and a rest category, which comprised fixations to locations deemed irrelevant for task execution (e.g., the visual signal, areas outside the artificial green) and missing out of range samples (e.g., blinking). This rest category [i.e., 1.6% of all coded frames] was excluded from further analysis.

The number of gaze fixations, the mean fixation duration, and the percentage of viewing time to the hole, to the area between the hole and the ball, and to the ball and putter were determined (i.e., time spent viewing at the particular area divided by total fixation time). We also determined the duration for the final fixation on the ball until the onset of the backswing, the duration between the end of the last hole fixation until the onset of the backswing, and the duration of the final fixation on the hole. Finally, the precise location of the fixations to the hole area was established. To this end, we subdivided the hole and its surrounding area in ten areas categorized between 0 and 9. Each location was 5.4 cm (i.e., a half hole width) in width. Areas 0 to 3 were located left to the hole, 4 and 5 were located in the hole, and areas 6 to 9 were located to the right of the hole. With these categories we determined the location of the final hole fixation per trial and the location of the highest hole fixation [i.e., farthest to the right of the hole]. We also calculated the average location of all hole fixations per trial by dividing the sum of the product of each hole fixation duration and hole fixation location by the total hole fixation duration.
Chapter 3

Statistical analysis

For the performance measures two separate repeated measures ANOVAs were conducted. The proportion of balls successfully putted was submitted to a 2 (group: successful, less successful) x 3 (slope: 0%, 1%, 2%) analysis of variance with repeated measures on the last factor, whereas the proportions of misses to the left and right were submitted to 2 (group: successful, less successful) x 2 (type of miss: left, right) x 3 (slope: 0%, 1%, 2%) analysis of variance with repeated measures on the last two factors. For the dependent variables that are indicative for the temporal characteristics of putting (i.e., preparation, backswing and downswing times) and visual search behaviour (i.e., number and mean duration of gaze fixation and gaze shifts, percentages of viewing time, final fixation durations and locations) 2 (group: successful, less successful) x 2 (success: holed, missed) x 3 (slope: 0%, 1%, 2%) analyses of variance with repeated measures on the last two factors were conducted. We applied Greenhouse-Geisser corrections to the degrees of freedom in the case of any violations of sphericity and computed partial eta-squared ($\eta_p^2$) values to determine the proportion of total variability attributable to each factor or combination of factors. Finally, Tukey HSD post hoc test procedures were used as follow up.

Results

Putting performance

Table 1 presents the results for putting performance. Obviously, the analysis of variance confirmed a significant effect for group on the proportion of balls successfully putted ($F(1, 10) = 19.5, p < .001, \eta_p^2 = 0.66$). By contrast, there was no effect of slope on the proportion of balls that
was successfully putted ($F(2, 20) = 0.014$), nor was there a significant interaction between group and slope ($F(2, 20) = 0.69$). The analysis of variance for the type of miss revealed that a significantly higher proportion of balls were missed to the left of the hole (i.e., under the hole) than to its right ($F(1, 10) = 18.7, p < .01, \eta^2_p = 0.65$). This effect was mediated by group ($F(1, 10) = 4.99, p < .05, \eta^2_p = 0.33$), but not by slope. Post hoc analysis indicated that only the less successful golfers putted more balls to the left than to the right of the hole.

Table 1: Proportions of holed balls (SD), misses to the left, and misses to the right as function of slope and putting skill

<table>
<thead>
<tr>
<th>Slope</th>
<th>Holed puts</th>
<th>0%</th>
<th>1%</th>
<th>2%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Successful</td>
<td>0.59</td>
<td>0.65</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>Less successful</td>
<td>0.45</td>
<td>0.37</td>
<td>0.40</td>
</tr>
<tr>
<td></td>
<td>Misses to the left</td>
<td>0.32</td>
<td>0.20</td>
<td>0.18</td>
</tr>
<tr>
<td></td>
<td>Successful</td>
<td>0.45</td>
<td>0.45</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>Less successful</td>
<td>0.45</td>
<td>0.45</td>
<td>0.41</td>
</tr>
<tr>
<td></td>
<td>Misses to the right</td>
<td>0.09</td>
<td>0.14</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>Successful</td>
<td>0.11</td>
<td>0.19</td>
<td>0.19</td>
</tr>
<tr>
<td></td>
<td>Less successful</td>
<td>0.11</td>
<td>0.19</td>
<td>0.19</td>
</tr>
</tbody>
</table>

1 We also analyzed the effect of slope for all participants (N = 17), but again, the analysis of variance did not reveal a significant effect of slope on the proportion of balls successfully putted ($F(2, 32) = .095$).
Chapter 3

Temporal aspects of putting

The results for the preparation, backswing, and downswing times as a function of group, slope and performance are shown in Table 2. The analyses of variance did not reveal any significant differences for these dependent variables.

Table 2: Temporal organization of the putting action as a function of slope and putting success and putting skill

<table>
<thead>
<tr>
<th>Slope</th>
<th>Holed</th>
<th>Missed</th>
<th>Holed</th>
<th>Missed</th>
<th>Holed</th>
<th>Missed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Preparation time (s)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>Successful</td>
<td>11.2 (4.9)</td>
<td>11.5 (4.5)</td>
<td>11.7 (4.5)</td>
<td>11.9 (4.2)</td>
<td>10.9 (5.3)</td>
</tr>
<tr>
<td></td>
<td>Less</td>
<td>10.0 (3.4)</td>
<td>9.3 (2.8)</td>
<td>9.3 (2.8)</td>
<td>9.3 (2.8)</td>
<td>8.5 (2.8)</td>
</tr>
<tr>
<td>1%</td>
<td>Successful</td>
<td>0.68 (0.13)</td>
<td>0.62 (0.10)</td>
<td>0.58 (0.15)</td>
<td>0.67 (0.14)</td>
<td>0.67 (0.14)</td>
</tr>
<tr>
<td></td>
<td>Less</td>
<td>0.69 (0.13)</td>
<td>0.68 (0.13)</td>
<td>0.58 (0.21)</td>
<td>0.67 (0.13)</td>
<td>0.65 (0.10)</td>
</tr>
<tr>
<td>2%</td>
<td>Successful</td>
<td>0.27 (0.04)</td>
<td>0.32 (0.11)</td>
<td>0.34 (0.14)</td>
<td>0.28 (0.03)</td>
<td>0.29 (0.05)</td>
</tr>
<tr>
<td></td>
<td>Less</td>
<td>0.30 (0.05)</td>
<td>0.31 (0.02)</td>
<td>0.35 (0.09)</td>
<td>0.31 (0.03)</td>
<td>0.31 (0.03)</td>
</tr>
</tbody>
</table>

NB. For both groups, values are based on n=6, except the successful group preparation time, where n=5.
Visual search behavior

Table 3 presents the temporal characteristics of visual search behaviors during the preparation of the putt as a function of group, slope and success. Analyses of variance for the number of fixations and the mean fixation duration did not reveal significant effects for group (\(F(1, 10) = 0.27\) and \(F(1, 10) = 0.40\) for number and duration respectively), slope (\(F(2, 20) = 0.12\) and \(F(2, 20) = 1.50\), respectively), nor for the group by slope (\(F(2, 20) = 0.20\) and \(F(2, 20) = 0.52\), respectively). For the percentage of viewing time at the three fixation locations three separate a 2(group: successful, less successful) x 2(success: holed, missed) x 3(slope: 0%, 1%, 2%) analyses of variance with repeated measures on the last two factors were performed. These analyses showed a significant effect of slope on the viewing time at the ball and putter (\(F(2, 20) = 6.30, p < .01, \eta^2_p = 0.39\)). Post hoc tests indicated that the time spent viewing to the ball and putter was less in the 2% slope than in the 0% and 1% conditions (see Table 3). The effects of slope on the percentage viewing time at the hole (\(F(2, 20) = 0.99\)) and at the green between ball and hole (\(F(2, 20) = 2.52, p = 0.12, \eta^2_p = 0.20\)) were not significant.

Finally, neither the effects for group, nor for success, nor any interaction was found significant (\(F(1, 10) = 2.00; F(1, 10) = 1.63; F(1, 10) = 0.02\)) for the effect of success on the viewing time at the ball and putter, the hole, and the green between ball and hole, respectively.

In nearly all trials (i.e., 98.1% in both groups) the final gaze fixation before onset of the backswing was directed toward the ball and putter head. Table 4 reports the duration of the final gaze fixations for these trials. No significant effects on the duration of the final fixation on the ball and putter were found for the factors group (\(F(1, 10) = 0.65\), slope (\(F(2, 20) = 0.84\) and success (\(F(1, 10) = 1.96\), nor were there any significant interactions.
Table 3: Temporal characteristics of gaze behaviour (SD)

<table>
<thead>
<tr>
<th>Slope</th>
<th>0%</th>
<th>1%</th>
<th>2%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Holed</td>
<td>Missed</td>
<td>Holed</td>
</tr>
<tr>
<td></td>
<td>Number of fixations (#)</td>
<td>Fixation duration [s]</td>
<td>Viewing hole (%)</td>
</tr>
<tr>
<td>Successful</td>
<td>7.9 (2.1)</td>
<td>8.3 (1.8)</td>
<td>8.4 (1.6)</td>
</tr>
<tr>
<td>Less</td>
<td>9.5 (3.7)</td>
<td>9.3 (4.2)</td>
<td>9.4 (4.9)</td>
</tr>
<tr>
<td>Successful</td>
<td>8.8 (2.3)</td>
<td>8.6 (2.6)</td>
<td>8.6 (2.6)</td>
</tr>
<tr>
<td>Successful</td>
<td>1.10 (0.35)</td>
<td>1.06 (0.33)</td>
<td>1.17 (0.45)</td>
</tr>
<tr>
<td>Less</td>
<td>1.11 (0.32)</td>
<td>1.11 (0.25)</td>
<td>1.07 (0.40)</td>
</tr>
<tr>
<td>Successful</td>
<td>1.06 (0.32)</td>
<td>1.06 (0.25)</td>
<td>1.06 (0.25)</td>
</tr>
<tr>
<td>Successful</td>
<td>36 (20)</td>
<td>36 (14)</td>
<td>36 (14)</td>
</tr>
<tr>
<td>Less</td>
<td>29 (17)</td>
<td>28 (17)</td>
<td>29 (17)</td>
</tr>
<tr>
<td>Successful</td>
<td>60 (15)</td>
<td>60 (12)</td>
<td>58 (9)</td>
</tr>
<tr>
<td>Less</td>
<td>63 (15)</td>
<td>65 (15)</td>
<td>67 (16)</td>
</tr>
<tr>
<td>Successful</td>
<td>4 (6)</td>
<td>4 (4)</td>
<td>6 (8)</td>
</tr>
<tr>
<td>Less</td>
<td>8 (8)</td>
<td>7 (8)</td>
<td>4 (8)</td>
</tr>
<tr>
<td>Successful</td>
<td>8 (8)</td>
<td>8 (8)</td>
<td>8 (8)</td>
</tr>
</tbody>
</table>
Table 4: Final fixation durations (SD)

<table>
<thead>
<tr>
<th>Slope</th>
<th>Holed</th>
<th>Missed</th>
<th>Holed</th>
<th>Missed</th>
<th>Holed</th>
<th>Missed</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>1.3 (0.8)</td>
<td>1.3 (1.1)</td>
<td>1.3 (0.8)</td>
<td>1.1 (0.8)</td>
<td>1.3 (0.9)</td>
<td>1.1 (0.8)</td>
</tr>
<tr>
<td>1%</td>
<td>1.7 (1.6)</td>
<td>1.9 (1.9)</td>
<td>2.1 (1.5)</td>
<td>1.9 (2.3)</td>
<td>2.0 (1.3)</td>
<td>1.5 (1.4)</td>
</tr>
<tr>
<td>2%</td>
<td>1.5 (1.5)</td>
<td>1.5 (1.7)</td>
<td>1.6 (2.3)</td>
<td>1.5 (1.9)</td>
<td>1.6 (1.0)</td>
<td>1.1 (1.0)</td>
</tr>
</tbody>
</table>

The factor success did significantly affect the duration between the end of the last hole fixation until the onset of the backswing ($F(1, 10) = 8.00, p < .05, \eta^2_p = 0.45$), the duration being longer for the holed (1.74 s) than the missed putts (1.58 s). The analysis of variance did not reveal significant effects for group ($F(1, 10) = 1.28$) and slope ($F(1, 20) = 0.38$), nor was there any interaction between these factors. Finally, the duration of the final hole fixation was not affected by group ($F(1, 10) = 1.88$), slope ($F(2, 20) = 1.66$), success ($F(2, 20) = 1.41$) nor were any interactions found.

Table 5 reports the location of the fixations surrounding to the hole. Analysis of variance on the average hole fixation revealed a significant...
main effect of slope \( F(2, 18)^2 = 4.91, p < .05, \eta_p^2 = 0.35 \), while the
effect of success just failed to reach significance \( F(1, 9) = 2.77, p = .13, \eta_p^2 = 0.24 \). The ANOVA on the location of the highest hole fixation also
revealed significant effects of slope; \( F(1, 18) = 8.28, p < .01, \eta_p^2 = 0.48 \) and success \( F(1, 9) = 5.59, p < .05, \eta_p^2 = 0.38 \).

The location of the final hole fixation was also significantly affected
by slope \( F(2, 20) = 5.16, p < .05, \eta_p^2 = 0.34 \), whereas the effects of
success \( F(1, 10) = 3.82, p = .08, \eta_p^2 = 0.28 \) and the slope by success
interaction \( F(2, 20) = 3.41, p = .06, \eta_p^2 = 0.25 \) both just failed to
reach significance (however, both effects showed a large effect size). No
effect of group was present \( F(1, 10) = 1.94 \). Post hoc analysis showed
that the steeper the slope, the further to the right of the hole the participants
directed their gaze (Figure 2). These effects were more pronounced for the
holed putts.

### Discussion

We explored the relationship between task complexity in a golf putting task
and visual search behaviour for two groups of different levels of putting
skill. Task complexity was varied by having participants putt on flat (i.e.,
0%) and sloped (i.e., 1% and 2%) greens, varying the amount of break
(see Figure 1) from right to left on the putted ball. Participants of both
groups were quite capable of dealing with the increase in task complexity
as the number of successfully putted balls was not significantly affected by
the steepness of the slope. This is perhaps surprising, because people tend
to perceptually overestimate the slant of a slope (e.g., Priftit et al., 1995).

\(^2\) We were unable to categorize the hole fixation location in approximately half of the trials
for one participant in the successful group and therefore decided to exclude this participant
from the present analysis. Additional analysis suggested, however, that inclusion of the data
of this participants would not lead to a different pattern in the outcomes for the hole location
fixations.
Figure 2: Percentage of viewing time to the locations surrounding the hole. Each location is 5.4 cm (i.e. a half hole width) in width. Location 0 is 21.6 - 16.2 cm to the left of the hole, 4.5 is the centre of the hole, and location 9 is 21.6 - 16.2 cm to right of the hole.
Chapter 3

Table 5: Hole fixation locations (SD)

<table>
<thead>
<tr>
<th>Slope</th>
<th>0%</th>
<th>1%</th>
<th>2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holed</td>
<td>Missed</td>
<td>Holed</td>
<td>Missed</td>
</tr>
<tr>
<td>Successful*</td>
<td>4.0</td>
<td>3.8</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>(0.4)</td>
<td>(0.4)</td>
<td>(0.3)</td>
</tr>
<tr>
<td>Less Successful</td>
<td>4.5</td>
<td>4.6</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>(0.3)</td>
<td>(0.4)</td>
<td>(0.3)</td>
</tr>
</tbody>
</table>

Location of highest hole fixation

<table>
<thead>
<tr>
<th>Slope</th>
<th>0%</th>
<th>1%</th>
<th>2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holed</td>
<td>Missed</td>
<td>Holed</td>
<td>Missed</td>
</tr>
<tr>
<td>Successful*</td>
<td>4.5</td>
<td>4.2</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>(0.3)</td>
<td>(0.4)</td>
<td>(0.4)</td>
</tr>
<tr>
<td>Less Successful</td>
<td>5</td>
<td>5</td>
<td>5.3</td>
</tr>
<tr>
<td></td>
<td>(0.3)</td>
<td>(0.3)</td>
<td>(0.3)</td>
</tr>
</tbody>
</table>

Location of final hole fixation

<table>
<thead>
<tr>
<th>Slope</th>
<th>0%</th>
<th>1%</th>
<th>2%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holed</td>
<td>Missed</td>
<td>Holed</td>
<td>Missed</td>
</tr>
<tr>
<td>Successful*</td>
<td>4.0</td>
<td>3.8</td>
<td>4.7</td>
</tr>
<tr>
<td></td>
<td>(0.4)</td>
<td>(0.4)</td>
<td>(0.4)</td>
</tr>
<tr>
<td>Less Successful</td>
<td>4.7</td>
<td>4.7</td>
<td>4.8</td>
</tr>
<tr>
<td></td>
<td>(0.4)</td>
<td>(0.4)</td>
<td>(0.4)</td>
</tr>
</tbody>
</table>

NB. n=5

These perceptual overestimations, provided they were present in the current situation, did not influence the participants’ putting actions, as this would have resulted in balls to be aimed at the high (i.e., right) side of the hole. By contrast, the missed balls more frequently passed the hole at its low side (i.e., to the left), in particular among the less successful participants. Milner and Goodale (2008; see also Van der Kamp, Rivas, Van Doorn, & Savelsbergh, 2008) argued that the use of visual information for making perceptual judgments (i.e., gathering knowledge about objects, events and places) and the use of visual information to guide action (i.e., movement control) are neuro-anatomically and functionally dissociated. Consequently, inaccuracies in perception do not necessarily crop up in action and vice
versa. Accordingly, perceptual overestimations of the slant of a slope do not necessarily have to translate into the truly visuomotor task of putting (see also Witt, & Proffitt, 2007). It further appears that the successful adaptation to a more complex environment was primarily brought about by an alteration in visual search behaviour, as we found no changes in the organization of the putting action itself. Participants did not take more time to prepare the putting movement and also the (relative) durations of the backswing and downswing were not affected by slope.

The most obvious adaptation to the increase in task complexity was a shift of the location within the hole area at which the participants were looking. As slope increased, participants were looking more to the high side of the hole (i.e., the right side), albeit that the lateral shift was rather small. This was true for the final hole fixation location as well as for the average and highest hole fixation locations. On the flat green, participants looked slightly to the left of the center of the hole, whereas for the 1% and 2% slopes, they fixated the right half of the hole and slightly to the right of the hole, respectively (Figure 2). In addition, participants spent less time focusing at the ball and putter for the steepest slope. Although this effect failed to reach significance, participants tended to look marginally longer (i.e., approximately 3-5%) at the green between the ball and hole for the steepest slope, which comprises areas surrounding the future ball track and the point to which participants direct their putt, i.e., the ‘aimline’ (Pelz, 2000).

Pelz (2000) stressed the importance of gazing along the aimline for accurate putting on a sloped green. We therefore anticipated a comparatively high proportion of viewing time to a point on the aimline

---

3 Without artificial reference points on the green, we were unable to determine the exact location of the fixation locations between the ball and the hole. Hence, it remains unclear at what exact point (e.g., on the aim-line or future ball track) on the green between the ball and the hole the participants’ gaze resided.

4 The ‘aim-line’ is the initial direction of the ball and depends on the amount of break, which in turn depends on the slope of the green. (Pelz, 2000) [Figure 1].
at considerable distance to the side of, and aligned with, the hole. Yet, the participants were found to spend much more time viewing at or in the near proximity of the hole, the exact location of which was dependent on the amount of break. This suggests that accurate putting on a sloped green critically depends on fixating the point at which the ball will enter the hole (i.e., the entry point, Figure 1). With increasing steepness of the green, the entry point shifts to the high side of the slope, and participants were found to adjust gaze accordingly. This is not to say that a quick glance along the aimline would be entirely irrelevant; nonetheless, perusal of the gaze recordings showed that participants performed a considerable amount of putts without fixation of the green between the hole and the ball.

Williams et al. (2002) reported longer final gaze durations with increasing task complexity among billiard players. They argued that the prolonged final fixation duration reflects that more complex aiming tasks require longer times to set the parameters of the movement (see also Vickers, 1996b). In the present study, however, temporal adjustments associated with increasing task complexity, such as an increase in final fixation durations, were not found. Nor were there any differences in the number of fixation or fixation durations, which are assumed to reflect the efficiency of visual search. Instead, task complexity in the current study primarily resulted in spatial adjustments of visual search.

Obviously, the absence of a relation between task complexity and the temporal parameters of visual search, such as final fixation duration, does not necessarily imply that these parameters should be deemed irrelevant for accurate performance. After all, the importance of these parameters has been established by comparing visual search behaviors as a function of skill and performance (Mann et al., 2007). Hence, we also compared visual search behavior between the most successful and least successful golf players that participated in our study. A distinction on the basis of putting performance was more justified, because it is plausible that players with similar levels of golf skill (i.e., indicated by their playing handicap) have rather disparate success rates in putting (Pelz, 1999; see
The scoring percentage for a 1.8 m putt among golf professionals is approximately 50% (Pelz 1999, p. 28). Hence, out of our sample of low-handicap golf players, we defined two subgroups that putted significantly above and below 50% (i.e., on average 62% and 40% respectively). The successful participants not only holed a higher proportion of balls, they also made a lower proportion of misses to the left side of the hole (i.e., the low side) than the unsuccessful participants. For a slope with a break from right to left, this side of the hole is considered to be the ‘amateur side’.

A relationship between putting skill and visual search behavior was not immediately apparent, however. Neither the temporal, nor the spatial parameters of visual search could account for the difference in putting skill between the groups. Nevertheless, we did discern differences in visual search that were related to putting success on individual trials (i.e., independent of putting skill). These differences were partly analogous to the effects of task complexity: participants looked slightly further to the left of the centre of the hole (i.e., the balls entry point) on holed as compared to missed putts. This was particularly true for the final fixation on the hole. Once more, this underlines the importance of adjusting the spatial properties of visual search. Intriguingly, the time between picking up pertinent information about the entry point (i.e., the end of the final hole fixation) and the onset of the swing was significantly longer for the holed as compared to the missed putts. In contrast, the other temporal parameters of visual search (i.e., number and duration fixation, final fixation duration toward the hole, and the final fixation duration to the ball and putter) did not vary as a function of performance on individual trials. Vickers (1996b) argued that increased performance is associated with a prolonged time of picking up the final relevant information and setting the movement parameters. In golf putting, she found that a longer final fixation on the ball resulted in higher accuracy of putting (Vickers 1992). We were not able to replicate this finding and thus failed to find strong support for a relation between final gaze duration and performance accuracy (see also
In sum, we examined the effects of task complexity on visual search behavior in golf putting. It is concluded that the prime adjustments to different amounts of task complexity are spatial (i.e., fixation locations) rather than temporal (i.e., fixation durations) in nature.

References


Chapter 3

Gaze in golf putting: Effects of slope
Perception and action in golf putting
Skill differences reflect calibration

Chapter 4

Abstract

We assessed how golfers cope with the commonly observed systematic overshoot errors in the perception of the direction between the ball and the hole. Experiments 1 and 2, in which participants were required to rotate a pointer such that it pointed to the center of the hole, showed that errors in perceived direction (in degrees of deviation from the perfect aimline) are destroyed when the head is constrained to move within a plane perpendicular to the green. Experiment 3 compared the errors in perceived direction and putting errors of novice and skilled players. Unlike the perceived direction, putting accuracy (in degrees of deviation from the perfect aimline) was not affected by head position. Novices did show a rightward putting error, while skilled players did not. We argue that the skill related differences in putting accuracy reflect a process of recalibration. Implications for aiming in golf are discussed.
Introduction

The golf instructional literature conventionally ascribes great significance to movement technique, yet also increasingly emphasizes perception as key to success in golf putting (e.g., Farnsworth, 1997; Mangum, 2008; Pelz, 2000). Pelz (2000), for instance, elaborately discusses the importance of visual perception in relation to green reading and for determining the direction of the putt. Likewise, also there is an increasing awareness in sport science that successful putting entails more than proficient movement control, but requires, apart from many other factors, skillful perception. Thus, Karlsen, Smith, and Nilsson (2008) have recently argued that stroke execution has a relatively minor influence on direction consistency in golf putting among elite players. Moreover, there is now compelling empirical evidence for skill-related differences in visual search strategies for a range of precision-aiming tasks in ice hockey (Panchuk, & Vickers, 2006), the soccer penalty kick (Wilson, Wood, & Vine, 2009), and basketball free throw (Wilson, Vine, & Wood, 2009), as well as in golf putting (Van Lier, Van der Kamp, & Savelsbergh, 2010; Vickers, 1992, 1993) (for an overview see Mann, Williams, Ward, & Janelle, 2007).

Despite this growing awareness of the importance of skilled visual perception, sport scientists and pundits alike have typically neglected that perception is not always veridical; it is easily fooled by visual illusions. A handball goalkeeper, for instance, can create a size illusion by assuming postures that mimic Müller–Lyer configurations. Van der Kamp and Masters (2008) demonstrated that these illusionary postures affected the direction of penalty free throw without the penalty taker being mindful of this influence. To further the understanding of how non-veridical perception affects sports performance, the current study scrutinizes the impact of errors in the perception of direction of the aimline in golf putting. That is, when addressing the putt most golfers look back and forth between the ball and the hole, standing parallel to the left (for a right-handed player) of the
line between the ball and the hole before they actually perform a swing. Intriguingly, Johnston, Benton, and Nishida (2003) observed that golfers, whether skilled or not (i.e., handicaps ranging between 0 and 30), make systematic overshoot errors in the perception of the direction of the aimline between the ball and the hole. That is, the participants in the study of Johnston et al. (2003) had to align a pointer in the direction of the hole. Standing to the left of the pointer resulted in clockwise alignment errors, while standing to the right resulted in counter-clockwise alignment errors.\footnote{These are both dubbed overshoot errors, because the pointer must be turned back toward the observer to accurately point at the target.}

This effect is consistent with observations of Koenderink and colleagues (Cuijpers, Kappers, & Koenderink, 2000, 2003; Koenderink & Van Doorn, 1998; Koenderink, Van Doorn, & Lappin, 2000, 2003) for direction judgments in the near field (i.e., distances smaller than 10 m.). They report that people make consistent and systematic perceptual errors when judging the direction of a pointer relative to a target object when the point of observation is not aligned with the pointer and the target (i.e., exocentric pointing). It is not particularly clear why a physically straight line between the two objects is not perceived as straight. Nevertheless, it can be shown geometrically that the perceived direction depends on the ratio of the distances of the pointer and the target to the observer (see Koenderink et al., 2003). One hypothesis is that the perceptual errors are associated with the detection of information that relates to the distance of the pointer, which may to some extent be indistinct due to the pointer’s rotation in depth relative to the observer’s line of sight (i.e., toward and away). This is consistent with the finding that, under binocular viewing, the variability in perceived directional error is reduced as compared with monocular viewing, possibly because it enhances the pickup of information that specifies the pointer’s rotation in depth (Cuijpers et al., 2000). The conclusion is that when the rotation of the pointer occurs in a plane perpendicular to the observer’s line of sight (i.e., no motion in depth...
Perception and action in golf putting: Skill differences reflect calibration

Figure 1: Schematic representation of the line of sight in relation to the ground plane and the true line between the ball (or pointer) and the hole as a function of head position. With the eyes above the hand, i.e., inside the true line, the angle between the line of sight, the ground surface and the true line between the ball and hole (i.e., perfect aimline) is non-perpendicular (left panel); with the eyes straight above the ball (middle and right panels) the angle is perpendicular. The right panel shows the head position in Experiments 2 and 3 in which the head was restricted such that the head was constrained to move in the plane perpendicular to the ground surface.
relative to the observer), this perceptual error will vanish (compare left and middle panel of Figure 1).

Except for golfers making systematic overshoot errors in the perception of the direction of the aimline between the ball and the hole, Johnston et al. (2003) reported two more remarkable findings. First, the perceptual errors made in the pointing task did not translate into putts missed from the practiced side, as the error in the pointer alignment did not correlate with the putting error. Yet, for the unpracticed side a correlation became apparent between putting variability and the errors in perceived direction error. It seems that practice or skill in some way make the putting actions refractory to perceptual distortions. Johnston et al. (2003) did not address this issue in detail. Therefore, the aim of the current series of experiments is to ascertain how skilled golfers have managed to overcome the systematic perceptual distortions when performing putting actions.

The relation between perception and action is a key issue in Gibson’s (1986) ecological approach. Proponents of the ecological approach hold that for any action a lawful relation exists between optical information and movement (Warren, 1988; see also Van der Kamp, Oudejans, & Savelsbergh, 2003). In its simplest appearance, this so-called law of control can be formally expressed as

\[ M(t) = a + b \cdot I(t) \]

in which \( M(t) \) stands for a particular movement variable (e.g., the orientation of the club head at impact), \( I(t) \) stands for a particular optical information variable (e.g., specifying the direction toward the hole), and \( a \) and \( b \) stand for constants that reflect the precise relationship between the movement and information variables. Two processes of change are discerned that enhance the adaptability of the law of control (e.g., Jacobs

\[ \text{We restrict ourselves to vision, yet it should be clear that this lawful relation may include proprioceptive, haptic or tactile, and auditory information as well.} \]
Perception and action in golf putting: Skill differences reflect calibration

& Michaels, 2007; Withagen & Michaels, 2005). First, the education of attention comprises a change of the optical information variable that enters a particular control law. During learning, the more useful or specifying variables come to be exploited (Savelsbergh & Van der Kamp, 2000). Secondly, calibration refers to a change in the relation between the movement and optic variables by tuning of the constants $a$ and $b$. Hence, the skill-related differences such as observed in the golfers by Johnston et al. (2003) may reflect the use of different optical variables in guiding the putting actions, or alternatively, a difference in how the relation between the movement and optic variables is tuned or calibrated.

In this respect, it is pertinent that golfers are insistently told to position their eyes straight above the ball while addressing it for putting, while gaze is at the ball until impact (e.g., Farnsworth, 1997; Pelz, 2000). Novice players tend to position their eyes roughly above their hands on their own accord. In golf this is referred to as inside the target line (see Figure 1, left panel). Consequently, the point of observation relative to the aimline between the ball and the hole is likely to be different dependent on skill level. With the eyes above the hands, the player’s line of sight is not perpendicular to the plane (i.e., ground surface) through the true line between the ball and the hole (i.e., perfect aimline), increasing the likelihood of errors in perceived direction. Possibly, these errors are minimized when placing the eyes straight above the ball, as this head position results in the line of sight being perpendicular to the ground surface (see Figure 1). In other words, dependent on the angle between the line of sight, the ground surface and the true line between the ball and hole, more reliable optical information may become available that specifies the direction of the line between the ball and the hole and the required

3 Actually, golf players are urged to keep their eyes straight above the ball for a slightly different reason. Pelz (2000), for instance, argues that golfers have the tendency to modify their aim based on their alignment angle, i.e., the angle between the eyes and the hole on the one hand and the ball and the hole on the other. As this alignment angle is a function of distance Pelz advises to keep the eyes vertically above the aimline, as only in this way it does not vary as a function of distance.
orientation of the club head during the swing. This is not unlike perceptual errors among assistant referees in soccer who, dependent on their position relative to the attacking and defending players, can or cannot access information that specifies offside (Oudejans, Verheijen, Bakker, Gerrits, Steinbruckner, & Beek, 2000; but see Catteeuw, Helsen, Gilis, Van Roie, & Wagemans, 2009). Skilled golfers therefore may have to overcome the (initial) errors in perceived direction by learning to position the head and eyes directly above the ball enabling them to detect and use specifying information, a change which is reminiscent of education of attention. Johnston et al. (2003) did not report the head position, but it is not unlikely that the players did not maintain the head directly above the ball during the perceptual task (i.e., orienting the pointer in the direction of the hole). Obviously, the untested proposition that errors in perceived direction are a function of head position (or more precisely, the line of sight) relative to the ball (and ground surface) makes or breaks these conjectures. Therefore, Experiments 1 and 2 evaluated, by varying head position relative to the ball, whether the perceived direction of the aimline between the ball and the hole is biased as well as whether this bias is mediated by head position.

A second explanation, which also calls upon the education of attention to distinguish novice and skilled putting performance, is granted by the two-visual systems model proposed by Milner and Goodale (1995, 2008; for ecological conceptualizations of this model, see Michaels, 2000; Van der Kamp et al., 2003; Van der Kamp, Rivas, Van Doorn, & Savelbergh, 2008). The two-visual systems model distinguishes between the detection and use of optical information for perception and the detection and use of information for action (i.e., movement control). These two functions engage separate cortical areas of the brain (i.e., the posterior parietal cortex for action, and the inferior temporal cortex for perception), and much more pertinent to the present concerns, they exploit different sources of optical information. The automated, unconscious guidance of actions primarily relies on egocentric information, that is
specifying objects and places dependent of viewpoint in absolute metrics. However, conscious perception first and for most involves the use of allocentric information (i.e., specifying objects and places independent of viewpoint and in relative metrics). It is for this reason that perception is much more susceptible to optical illusions than action (e.g., Bruno, Bernardis, & Gentilucci, 2008).

Yet, it has been argued that only with an increased efficiency and automatization of action during learning, actors come to fully rely on egocentric information. By contrast, the initial conscious guidance of action that characterizes novice performance is thought to be much more subject to allocentric information (Willingham, 1998; Van der Kamp et al., 2003). Gonzalez, Ganel, Whitwell, Morrissey, and Goodale (2008), for example, found that unfamiliar awkward grips were much more susceptible to a size-contrast illusion than the precision grips that participants habitually used to grasp small objects, suggesting a change in the contribution of illusion inducing allocentric information. In other words, skilled golfers may exploit different sources of optical information for making conscious perceptual judgments on the direction of the (virtual) line between the ball and hole than in the control of club head orientation during the putting action, irrespective of the position of the head (and the eyes). Yet, putting from the unpracticed side may induce conscious engagement of the perception system, increasing the likelihood of perceptual error (see Johnston et al., 2003; Van der Kamp et al., 2008). Again, the assumption here is that with increases in skill, golfers allocate attention to different optical variables to guide their putting actions. The aim of Experiment 3 was to test this hypothesis.

Finally, the errors in perceived direction may evaporate from the putting action because the skilled golfers have learned to correct for the perceptual distortion (Johnston et al., 2003). This would point to a process of calibration, in which the relationship between the movement and optic variables is adjusted based upon error feedback from prior actions (Bedford, 1999; Withagen et al., 2005). This account differs from the
former two in that calibration does not presume a change in the variable that is used, which characterizes education of attention. Rather, it suggests that the initial overshoot is overcome by aiming the ball slightly to the opposite side of the hole. Nonetheless, Withagen and Michaels (2005; see also Rieser, Pick, Ashmead, & Garing, 1995) found that calibration is functional, and not effector specific. In other words, in skilled golfers, the calibration should have transferred to the unpracticed side as well. For now, we will leave further evaluation of the skilled golfers dealing with the errors in perceived direction during action through a process of calibration, to Experiment 3.

To sum up, we conducted three experiments to assess how skilled golfers managed the systematic error in perceived direction of the aimline between the ball and the hole when performing a putting action. Experiments 1 and 2 examined the role of head (and eyes) position in the occurrence of the perceptual distortion. This sets the stage for Experiment 3, in which we directly assessed whether the skill-dependent difference between perception and action can be understood as a consequence of education of attention and/or calibration.

**Experiment 1**

Experiment 1 had two aims. First, we aimed to replicate the previously reported (Johnston et al., 2003) systematic errors in perceived direction in a group of participants that had no experience playing golf. Secondly, we aimed to test the proposition that errors in perceived direction are dependent on the angle between the observer’s line of sight, the ground surface, and the true line between the ball and hole. To this end, non-golf-playing participants performed an exocentric pointing task, in which they judged the direction of the aimline between the ball and hole with their head positioned either directly above or next to the ball when standing to either the left and right of the ball (Figure 2). We expected clockwise and
counterclockwise errors when the participants stood to the left and right side of the ball respectively, but only in the conditions where their heads were positioned roughly above the hands, in any case next to ball (see Johnston et al., 2003). By contrast, we expected the perceptual errors to reduce to zero when the participants kept their head directly above the ball, as only in this situation the line of sight would be perpendicular to the ground surface (Figure 1). This would allow the exploitation of more useful information that veridically specifies the direction between the ball and hole.

Method

Participants

Twelve university students (mean age 20.6 ± 2.1 years) with no previous golf experience, two of which were self-described left-handers, participated in this experiment. All participants had normal or corrected to normal vision. The participants were unfamiliar with the aims of the experiment, and provided written consent before the start of the experiment. The experiment was approved by the local ethics committee.

Material and Apparatus

The experiment was carried out in a large laboratory using a triangular shaped level platform, which was covered with synthetic turf and artificial grass (Greenfields®, Genemuiden, The Netherlands). The speed of the artificial green was fast (i.e., 14 feet on the Stimpmeter). The pointer that

4 The number of participants was determined with bootstrap simulations on the perceived direction. Bootstrap simulations indicate that adding more participants would not result in a 5% or more reduction of between participant variance (see Hoozemans, Burdorf, Van der Beek, Frings-Dresen & Mathiassen, 2001).
Figure 2: Top view of the experimental setting. Shown are the green with the hole and the ball (or pointer) at a distance of 2.70 m from the hole. The participant in plain lines stands to the left (i.e., the preferred side of righthanded players), whereas the participant in dashed lines stands to the right. Also shown are the down the line camera (dl) and the photoelectric light switch (pls), as per Experiment 3.
was used comprised of a perforated golf ball through which a 3 mm thick needle protruded 15 cm from the ball’s front (i.e., toward the hole) and 10 cm from the ball’s back. The pointer was placed 2 cm above the artificial green at a distance of 2.70 m from the hole (13.4 cm in diameter) (Figure 2). The pointer could be rotated in a stepwise fashion by two hand-held switches that fed into a computer. The hand-held switches controlled a servomotor which was connected to the pointer and placed underneath the green. If the pointer was more than 20° off-target at the time the switch was pressed, the rotation speed of the pointer was 6°/s. However, the rotation speed was reduced to 1°/s when the pointer was within 20° of the target. The precision of the pointer was 0.06°. The irregularly shaped green was approximately 4 m long and 2 m wide. The edges of the green were covered by black plastic sheeting which hung from the ceiling. The plastic sheeting was wrinkled, creating irregular cavities and protrusions so as to minimize any salient reference points for the participants. In addition, the green was thoroughly cleaned before each participant began putting to prevent the presence of any textures on the green that might be used as a target reference.

Procedure and Design

At the start of each trial, the pointer was automatically placed in a random orientation between 30° and 60° to either the right or left of the hole (this was interchanged from trial to trial). This was done to prevent the participants from making judgments relative to the initial pointer orientation in the current trial and/or the final pointer orientation in the previous trial. Participants were first instructed on how to rotate the pointer by pressing the two hand-held switches. Pressing the switch in the left hand resulted in the pointer rotating in a clockwise direction, while pressing the switch in the right hand made the pointer rotate in an anticlockwise direction. Participants were then instructed to rotate the pointer such that it pointed to the center of the hole. To assist the participants, the center of the hole
was indicated by the foot of a flagpole. Once the participants verbally indicated that the pointer was positioned correctly, the computer registered the pointer’s exact orientation with respect to perfect aimline (i.e., the true line between the ball and hole).

The experiment consisted of four conditions. The participants stood either to the left or right side of the ball with their head either directly “above,” or “next to” the ball (i.e., roughly where the hands are would they have putted a ball) (see Figure 1 and 2). The experimenter monitored the head position online via a camera located 3 m behind the ball (in line with the hole). Participants were instructed to stand either nearer or closer to the ball, such that in the “next to” condition their head was positioned approximately 40 cm away from the ball, and in the “above” condition, the head was positioned directly above the ball. Participants were allowed to turn their heads freely in both conditions (i.e., to look from the ball to the hole and vice versa). In the “next to” conditions, the line of sight was approximately at an angle of 75° with the ground surface. The four conditions were administered in blocks of 10 trials (i.e., this number was verified with bootstrap simulations) and counterbalanced across participants. Participants did not receive augmented knowledge of results during the experiment.

Data Reduction and Statistics

The error in perceived direction served as the dependent variable. It was defined as the angle between the direction of the pointer and the direction of the true line between the ball and the hole. A negative angle indicated a counter-clockwise error (i.e., pointing to the left of the hole), whereas a positive angle indicated a clockwise error. The error in perceived direction was submitted to a 2 (side: left, right) x 2 (head position: next to, above) ANOVA with repeated measures on both factors. A Huynh–Feldt correction to the degrees of freedom was applied in the case of any violations of sphericity and partial eta-squared (\( \eta^2_p \)) values were computed to determine
Figure 3: Errors in perceived direction as a function of head position for Experiment 1 when participants stood to the left (left panel) or to the right of the ball (right panel). Positive and negative errors indicate clockwise and counterclockwise errors, respectively (** p < .01).
the proportion of total variability attributable to each factor or combination of factors. Post hoc comparisons were made using the Tukey’s HSD test.

Results

The ANOVA revealed a significant effect of side only, $F(1, 11) = 22.29, p < .01, \eta^2 = .67$, indicating that standing to the left resulted in a clockwise error (i.e., positive angles), whereas standing to the right resulted in counterclockwise error (i.e., negative angles) (see Figure 3). Neither the effect for head position, $F(1, 11) = 2.77$, nor the side by head position interaction, $F(1, 11) = .19$, reached significance. In addition, one sample t tests confirmed that the error in perceived direction differed significantly from zero in each condition, $t's > 3.38, p's < .01$, except when participants stood to the left with their head above the ball, $t(11) = 2.09, p = .06$.

Discussion

Experiment 1 replicated the previous observations by Johnston et al. (2003; see also Koenderink et al., 2000) of systematic errors in perceived direction on an exocentric pointing task. Participants made clockwise errors when they stood to the left of the ball, and counterclockwise errors when they stood to the right side. In short, the error in perceived direction was an overshoot as would be predicted when the line of sight is not perpendicular to ground plane and the true line between the ball and the hole. We also expected that this perceptual error would reduce or even vanish when the line of sight is perpendicular to the green. However, Experiment 1 did not provide unambiguous evidence for the conjecture that perceptual error is reduced when the head is positioned directly above the ball. That is, the error with the head positioned above the ball was not significantly smaller.
than the perceptual error made with the head positioned next to the ball. Moreover, the error in perceived direction with the head above the ball when standing to the right of the ball was greater than zero. One reason that the perceived error had not vanished may have been that participants could move their head freely, due to which the eyes (i.e., the line of sight) may not have moved in a plane perpendicular to the ground surface. Hence, in Experiment 2 the head movements were constrained in such a way that the eyes could only move in a plane perpendicular to the green through the true line between the ball and hole.

Experiment 2

Experiment 2 aimed to further test the conjecture that the observed errors in perceived direction (i.e., overshoot) reduce or even vanish, when the head and eyes are positioned directly above the ball and constrained to move in the plane perpendicular to the plane in which the directional judgments are made. The same conditions were used as in Experiment 1, but in the “above” condition the participants placed their head in a head mount that only had one axis of rotation (Figure 1, right panel). As per Experiment 1, when participants positioned their head next to the ball, we expected clockwise and counter-clockwise errors in perceived direction when the participants stood to the left and right side of the ball respectively. These errors were expected to be reduced or vanish when the participants positioned the head directly above the ball and were constrained to move the head and eyes in the plane perpendicular to the green.
Method

Participants

Fifteen students with no previous golf experience (mean age 25.5 ± 6.8 years), including three self-described left-handers, participated in this experiment. The volunteers had not participated in Experiment 1, nor were they familiar with the purpose of the experiment. All participants had normal vision or corrected to normal vision and signed an informed consent before the start of the experiment. The experiment was approved by the local ethical committee.

Material and Apparatus

The apparatus and material were the same as in Experiment 1, with the addition of a helmet-like head mount that was used to constrain head position and movements (Figure 1, right panel). On top of the head mount was a rotating metal pin that fixed the head mount to a pole hanging from the ceiling. The head mount could be adjusted to the height of each individual participant. The exact location of the head mount could be adjusted such that the participants were limited to rotate their head from a position directly above the ball, in a plane perpendicular to the ground plane in which they had to judge the direction of the true line between the ball (i.e., the pointer) and the hole. Again, head position and movements were monitored online.

Procedure and Design

As in Experiment 1, there were four conditions with the participants standing either to the left or right of the ball, with their head positioned either “next to” or “above” the ball. Conditions, each consisting of 10 trials, were counterbalanced across participants.
Perception and action in golf putting: Skill differences reflect calibration

Figure 4: Errors in perceived direction as a function of head position for Experiment 2 when participants stood to the left (left panel) or to the right of the ball (right panel). Positive and negative errors indicate clockwise and counterclockwise errors, respectively (* p < .05).
Chapter 4

Results

The ANOVA with repeated measures on the error in perceived direction did reveal a significant effect for the side by head position interaction, $F(1, 14) = 6.58, p < .05, \eta^2_p = .32$. The main effects were not found significant. Tukey post hoc comparisons indicated that with the head next to the ball, the perceived errors for standing to left and to right of the ball were significantly different. By contrast, with the head positioned above the ball, there were no differences in perceived direction as a function of side (Figure 4). One-sample t tests revealed that with the head above the ball, the error in perceived direction did not differ from zero, $t's < .27, p's > .79$. With the head next to the ball the perceived error differed significantly from zero when standing to the right to the ball, $t(14) = 2.44, p < .05$, but not when standing to the left, $t(14) = 1.42, p = .18$.

Discussion

Experiment 2 physically constrained the observers’ head to rotate from a position directly above the ball in a plane perpendicular to the ground surface (i.e., green) through the true line between the ball and the hole. Clearly, this restriction in head position and movement led to errors in perceived direction being destroyed. However, with the head positioned to left or right of the ball (i.e., roughly at the position over the hands would the participants have putted a ball), similar overshoot errors in perceived direction were observed as in Experiment 1 as well as those previously reported by Johnston et al. (2003). We therefore conclude that the errors in perceived direction are a function of head position. This suggests that to access available information that veridically specifies the direction between the ball and hole, a player should prepare for the putting action with the head positioned directly above the ball, and the eyes moving in
a plane perpendicular to the green. In contrast, in case the head is not directly above the ball, the golfer can only access less reliable information. Experiment 3 tries to establish whether head position assists golfers in neutralizing the systematic errors in perceived direction while putting.

**Experiment 3**

Johnston et al. (2003) observed that golfers of differing skill levels made directional errors in the perception of the line between the ball and the hole, and yet these errors did not show up in their putting performance when putting from the preferred side. By contrast, the perceptual errors became apparent in putting when the players putted from their less skillful, non-preferred side. It seems that the degree to which the perceptual errors manifest themselves in action depends on the level of skill. The purpose of Experiment 3 is to explicate these skill-related differences.

The first hypothesis is that unlike novice players, skilled golfers have learned to position their head directly above the ball in a plane perpendicular to the green. Putting errors reduce to zero, because this head position grants more veridical information about the direction between the hole and the ball. By contrast, novice players [and, presumably skilled players who putt from their non practiced side] may tend to keep their head above the hands (i.e., inside the target line), and hence, fall foul to the perceptual distortion. Hence, it is surmised that systematic directional errors in putting accuracy would in fact be a function of head position rather than skill level. To examine this conjecture, in Experiment 3 we required the novice and high skilled golfers to putt balls toward the hole and perceptually judge the direction of the aimline between the ball and the hole with the head positioned either directly above the ball or inside the target line (i.e., the head positioned to the left of the ball) (as per Experiment 2). If indeed head position is critical, we expected that irrespective of the participants’ skill level, the directional errors would
materialize in the putting as well as in the judgment task with the head positioned inside the target line. Yet, these errors were anticipated to reduce or vanish when the tasks are performed with the head directly above the ball.

The second hypothesis refers to the task-dependent pickup and use of information as pointed out by the two-visual systems model (Milner & Goodale, 1995, 2008). According to this model, the errors in perceived direction do not translate into skilled putting, because perception and action do not necessarily rely upon identical sources of optical information. Furthermore, an auxiliary hypothesis holds that unlike for skilled, automatized actions, novice performance entails considerable contribution of conscious perception processes (Gonzalez et al., 2008; Willingham, 1998). Consequently, putting performance of novice players would be much more susceptible to perceptual error than putting performance of high skilled players (see Van der Kamp et al., 2008). On basis of these conjectures, we expect that among both the novice and high skilled participants’ errors in perceived direction would depend on head position (see above). We further predicted that only putting performance among novices would reflect these perceptual errors. Putting performance of the high skilled participants, by contrast, was expected to be accurate irrespective of head position.

Finally, skilled golfers may have learned to overcome the (purported) initial directional errors in putting through a process of calibration based upon visual feedback from prior putts. That is, golfers learn to reduce the initial directional errors by aiming slightly to the side of the hole opposite to the error, or stated differently, by adjusting the coupling between the putting movements (e.g., orientation of the club) and the optic variable that is specific to the direction between the ball and the hole. It follows that directional putting errors among both the novice and high skilled participants are a function of head position, but with the size of the errors depending on the degree of calibration. Moreover, for the high skilled participants in the perceptual task, an error in perceived direction
is expected that is opposite to the direction of calibration (i.e., an initial clockwise or overshoot error in putting would result in a counterclockwise error in perceived direction), whereas for the novice participants the perceptual directional errors should be similar as the putting errors. Notice that under this scenario the degree of calibration is dependent on (initial) head position. Hence, we also determined the preferential unconstrained head position for the novice and high skilled participants from a short pre experimental familiarization session.

Method

Participants

Eleven golf teaching professionals (mean age 34.9 ± 6.9 years; handicaps ranging from 0 to 5) and 11 novice golfers (mean age 27.0 ± 4.4 years, with no previous golf experience) participated. All participants were unfamiliar with the aims of the experiment, were right handed, and had normal or corrected to normal vision. They were treated in accordance with the local institution’s ethical guidelines and gave written consent before the start of the experiment.

Material and Apparatus

The experiment was performed on the same platform as in Experiment 2 with the hole at a distance of 2.70 m from the ball. Again, the perceived direction between the ball and the hole was determined with the pointer. For the putting task, a standard peripheral weighted putter and ball were used. Participants wore Plato Liquid Crystal goggles (Translucent Technologies, Toronto, Canada) to remove vision of the ball after it started rolling. The goggles turned opaque after the ball interrupted a light beam of a photoelectric switch (Omron E3S-R 30E4) that crossed the ball path.
40 cm from the initial ball position. The removal of vision ensured that participants did not receive visual feedback of the outcome of the putt so they could not optimize the subsequent ones. During the perceptual task, the goggles were closed 250 ms after the participants indicated that they had positioned the pointer correctly.

A digital video recording (25 Hz interlaced PAL) from the top camera was used to determine the initial direction of the ball roll. We used a custom-made motion analysis program HiSpVideo, which is based on the Matlab Image Processing Toolbox, to digitalize ball roll off-line. A second video camera was placed in line with the ball–hole direction to monitor head position of the participants.

Procedure and Design

The experiment started with a familiarization session in which participants performed 10 consecutive putts without any constraints on the head position. Participants wore goggles to eliminate visual feedback. The puts from this familiarization session were used to determine the participants’ preferential head position. Next, the participants performed the perceptual judgment and putting tasks standing on the left side of the ball with the head either “next to” (i.e., inside the target line, approximately above the hands) or directly “above” the ball. In the latter condition, the participants positioned the head in the helmet-like head mount that was fixed to a pole, such that they were constrained to rotate their head from a position directly above the ball in a plane perpendicular to the ground plane (as per Experiment 2). In both tasks, they were instructed to perform as accurately as possible without any time constraints. Participants performed 10 repetitions for each blocked task and condition, the order of which was counterbalanced across participants.
Data Reduction and Statistics

Preferential head position was categorized by means of video recordings from the camera placed behind the ball. The head position at the onset of the back swing was determined by measuring the distance between the edge of the eye and the vertical perpendicular to the ball in cm. A distance within 5 cm off the perpendicular line through the ball was categorized as the head being positioned above the ball. A one-way ANOVA was used to compare preferential head position between groups. An ANOVA with repeated measures was conducted to compare the number of putting errors to the right and left of the hole between the groups during the familiarization session.

The error in perceived direction (in degrees) was defined as the angle between the direction of the pointer and the direction of the perfect target line between the ball and the hole. For the error in putting direction, a custom-made semiautomatic video-analyzing program was used to determine the angle between the initial direction of ball roll and the true line between the ball and hole from the top camera with the overhead view. The angle was defined as the average angle for the first 10 frames (i.e., 400 ms) after the ball started moving. Negative angles for the errors in perceived and putting direction indicated a counter-clock wise error (i.e., undershoot), while positive angles indicated a clockwise error (i.e., overshoot). The errors were submitted to a 2 (skill level: novices, high skilled) by 2 (task: perceptual judgment, putting) by 2 (head position: next to, above) ANOVA with repeated measures on the last two factors. A Huynh-Feldt correction to the degrees of freedom was applied in the case of any violations of sphericity and partial etasquared ($\eta^2_p$) values were computed to determine the proportion of total variability attributable to each factor or combination of factors. Post hoc comparisons were made using Tukey’s HSD test.
Figure 5: Alignment error as a function of task and head position for novice (left panel) and high skilled participants (right panel) for Experiment 3. Positive and negative errors indicate clockwise and counterclockwise errors, respectively. (* $p < .05$).
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Results

Preferential head position during the unconstrained familiarization trials showed that the high skilled golfers kept their head predominantly straight above the ball, while the novice participants did so only in the minority of trials [i.e., M = 88.8%, SD = 31.8 and M = 25.6%, SD = 41.6 for the high skilled and novice participants respectively]. A one-way ANOVA indicated that this difference was significantly different, $F(1, 16) = 12.13, p < .01, \eta^2 = .45$. In addition, during the initial 10 familiarization trials, the high skilled participants made an equal amount of putting errors to the right ($M = 2.9, SD = 3.0$) and to the left of the hole ($M = 2.3, SD = 3.1$), whereas for the novices the frequency of errors to the right ($M = 5.2, SD = 2.4$) was numerically higher than the frequency of errors to the left ($M = 2.0, SD = 2.2$). Yet, the repeated-measures ANOVA did not confirm that these differences were statistically reliable. Both the main effect of group, $F(1, 15) = 3.97, p = .06, \eta^2 = .21$, as well as the interaction between group and type of error, $F(1, 15) = 1.18, p > .10, \eta^2 = .15$. Figure 5 shows the alignment errors for the novice and high skilled golfers as a function of task and head position. The pattern of errors in perceived direction for the novices compared well to the perceptual errors found in Experiments 1 and 2 when participants stood at the left hand side (see the left bars in Figures 3–5). With the head next to the ball, they were inclined to make rightward errors, albeit that in the present experiment the two-tailed $t$ test did not confirm that the error differed significantly from zero, $t(10) = 1.81, p = .10$. The directional

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5 Due to equipment failure, the head position of one high skilled participant could not be determined.

6 The number of participants was mainly derived from the bootstrap analyses performed in Experiments 1 and 2. Hence, we cannot exclude the possibility that Experiment 3 is somewhat underpowered and that statistically different patterns may emerge in studies with greater power.
error is clearly destroyed with the head positioned straight above the ball, \( t(10) = .29, p = .77 \). Nonetheless, Figure 5 suggests that the alignment errors are not only affected by head position, but also by task and skill level. That is, the analysis of variance not only revealed a significant effect for head position, \( F(1, 20) = 4.80, p < .05, \eta^2_p = .19 \), but also significant effects for task, \( F(1, 20) = 14.81, p < .01, \eta^2_p = .43 \), and task by head position, \( F(1, 20) = 5.48, p < .05, \eta^2_p = .22 \). Post hoc analysis indicated that with the head positioned straight above the ball a leftward (i.e., clockwise) shift occurred in the alignment relative to when the head is positioned next to the ball (i.e., above the hands). For the high skilled participants this shift even resulted in a significant leftward bias in the perception task with the head straight above the ball, \( t(10) = 2.72, p < .05 \). This shift as a function of head position, however, only occurred in the perception task and not in the action task, resulting in aligning more to the right for the action task compared with the perception task. These effects were not mediated by skill level, yet the analysis of variance did show a significant main effect of skill level, \( F(1, 20) = 7.06, p < .05, \eta^2_p = .26 \), indicating that the novices golfers aimed more to the right than the high skilled golfers in both tasks. Consequently, whereas the alignment bias during putting among the high skilled participants did not significantly differ from zero, the novice participants putted the balls significantly to the right of the hole for both head positions, \( t(10)'s > 3.1, p's < .05 \).

**Discussion**

There are two important findings of Experiment 3 that come to the fore. First, the discrepancy in the patterns of errors that were revealed in the perception of direction and in putting accuracy, and second, the disparity in the patterns of error among the novice and high skilled participants. We start with the former.

The two-visual systems model (Wilner & Goodale, 1995; 2008)
proposes that the pickup and use of visual information is task dependent. More precisely, vision to control movement execution (i.e., action) operates relatively independent of vision to obtain knowledge of the environment (i.e., perception). The discrepancies in directional errors observed in the present experiment are consistent with this task dependency. Thus, relative to perceived direction, during putting the balls were consistently aimed more rightward during actual putting. More importantly, the position of the head did not affect alignment in putting, whereas it had a clear impact on perceived direction (as per Experiment 1 and 2). We make two inferences. First, the high skilled participants’ greater putting accuracy is not merely due to the high skilled participants maintaining their head (and eyes) directly above the ball, whereas novices hold their head inside the true line. On the contrary, the skill-related differences in putting accuracy were independent of head position. Consequently, we do not find evidence to support the contention that high skilled players have annulled the (initial) errors in putting by positioning head and eyes directly above the ball, thereby enabling them to exploit better specifying information for the true line between ball and hole. The apparent disparity in preferred head position between the novice and high skilled players has most likely arisen for reasons other than aligning the orientation of the club head to the ball. Second, the task-dependent findings point to the pickup and use of different information for the perception of the direction of the hole and the control of the orientation of the club head relative to the ball in putting. As matter of fact, this difference occurred irrespective of skill level. This questions the hypothesis that with increase in putting skill the extent to which conscious perceptual processes contribute to action decreases (cf. Gonzalez et al., 2008; Van der Kamp et al., 2008). In sum, we did not find evidence that the observed skill-related difference in putting accuracy is associated with a change in the allocation of attention to better specifying information.
In both the perception and the putting task, the high skilled golfers aimed more to the left than the novices. Novices, on average, putted the ball to the right of the hole, reflecting an alignment error that is in line with the error in perceived direction, albeit somewhat exaggerated. By contrast, the high skilled were more accurate in putting direction. Relative to the novices, they had learned to aim the ball more to the left, thus achieving much more accurate putts. Notably, a comparison of the errors in perceived direction between the high skilled and novice participants revealed a similar directional difference as in putting. This skill-related leftward difference supports the hypothesis that with practice, the high skilled players have canceled out the initial rightward errors in putting through a process of calibration based upon visual feedback from prior putts. Perceiving that the ball tends to miss the hole to the right may result in the novice players aiming the next putt slightly more to the left, therewith scaling the relation between the optic variable that specifies the direction of the putting movement. Intriguingly, the concomitant leftward shift in perceived direction suggests that this calibration is not restricted to action, but may generalize to perception as well. The broader significance of this transfer will be discussed in the next section.

In sum, consistent with Johnston et al. (2003), we found that errors in perceived direction of the hole did not simply translate into putting, particularly among the high skilled participants. For the novices, similar rightward errors were found in perception and putting, although of a different magnitude. It seems that high skilled players become refractory to the initial alignment errors through a process of calibration, rather than using different optical sources of information.

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7 As control of the stroke is poor among novice golfers, one might argue that putt direction may not accurately reflect aiming. However, presuming that poor control results in stochastic errors in direction, the average of series of putts will reflect direction of aiming.
Perception and action in golf putting: Skill differences reflect calibration

Figure 6: Schematic representation of the serial view (top) and parallel view (bottom) of perception and action.
General Discussion

Visual perception does not always result in veridical awareness of the environment. Perceivers occasionally do not exploit optic variables that accurately specify objects, events and places either because the specifying information is not available or because the perceiver is not attuned to it. The present study addressed how non-veridical perception affects sport performance in general, and golf putting in particular. In agreement with previous reports by Koenderink and colleagues (Cuijpers et al., 2000, 2003; Koenderink & Van Doorn, 1998; Koenderink et al., 2000, 2003; see also Johnston et al., 2003), the current study shows that one property for which observers may make systematic perceptual errors is the direction of a line. Although, the nature of this error in perceived direction is not well understood, one suggestion is that it depends on the ratio of the distances of the two end points of the (virtual) line (i.e., the true line between ball and hole) to the observer (Koenderink & Van Doorn, 1998; Koenderink et al., 2003). Hence, more precise information concerning these distances should reduce errors in perceived direction. Accordingly, we demonstrated that with the head positioned directly above the ball the perceptual error is nullified. We argued that the angle between the line of sight, the ground plane and the true line between the ball and the hole is critical for the directional error to disappear, but also note that alternative explanations (e.g., the absolute or lateral distance between the observer and the ball) cannot be ruled out based on the current study alone.

Whatever the exact cause, the non-veridical perception of direction poses difficulties for accurate guidance of a putting action, and raises the issue of how skilled golfers overcome the perceptual distortions. At heart of this issue is the relationship between perception and action. In this respect, Rossetti (1998) distinguishes two general theoretical views (see Figure 6). The serial view, which seamlessly fits in the traditional Cartesian view, holds that perception enslaves action. That is, action is based upon and
Perception and action in golf putting: Skill differences reflect calibration controlled by perception without necessity of any further transformation. The implication is that any perceptual error due to suboptimal information-perception relations will be reflected in action. By contrast, the parallel view of perception and action posits that perception and action are separate and largely independent functions that exploit different information (e.g., Milner & Goodale, 1995; 2008; see also Michaels, 2000; Van der Kamp et al., 2003, 2008). Significantly, from this parallel view, distortions in perception do not need to become apparent in action.

The current study does not provide unequivocal support for either view. On the one hand, the finding that manipulating head position affects the pattern of directional errors differently in perception and action points to perception and action operating independently. The use of information for the perception of direction and the use of information to control the direction of the swing in putting seem distinct, relatively modularized processes. In fact, the rescaling or calibration of the relationship between information and movement variables (e.g., the orientation of the club head relative to the ball) with increments in skill is also entirely consistent with an autonomous functioning of action. Yet, relative to the novices, the high skilled participants did not only putt more to the left, they also perceived the direction of the hole more to the left. Hence, calibration was not restricted to action, but also comprises the relationship between information and perception. This interaction between perception and action is easier to reconcile with a serial view than with a parallel view of perception and action. From a serial view, the following scenario could be envisioned. Directional errors in putting provide feedback or information to adaptively scale the relationship between information and perception. As a consequence, errors in perceived direction will gradually reduce, which in turn leads to ever-slighter errors in putting. In other words, the serial view anticipates that changes in perception and action would go hand in hand. Nonetheless, it seems to us that at present any verdict on the aptness of the two views is somewhat premature. One possible next step would be to further substantiate our conclusion that observed skill-related differences in
putting skill may reflect a process of calibration. To this end, we need to go beyond comparing differences in performance of novice and high skilled players, and directly investigate the changes that occur in both perception and action in the learning process of the putting skill.

How should golfers preparing to hole a ball, or sports players in other precision-based aiming tasks, deal with the observed non-veridical perception of direction? Before actually executing a putt, it is important for the player to read the green before addressing the ball (i.e., preparing the actual swing). By reading the green, the golfer can gather information over and beyond information used to control the direction of the swing, such as information about the pace and slope of the green (e.g., Van Lier et al., 2010). This will aid to (consciously) set the boundary constraints within which the movement system autonomously picks up and uses information for the execution of the swing. A conventional technique to overcome errors in perceived direction is the logo alignment aid (Farnsworth, 1997). With this technique, the player must stand behind the ball before addressing it. From this point of view, the player can accurately position the ball so that its logo or any other elongated mark on the ball is aligned with the true line between the ball and hole. Finally, while addressing the ball to execute the swing, the player aligns the putter to the logo instead of the hole. To accomplish this, gaze should only be directed to the ball and not to the hole. This way, the player does not fall fool to distortions in perceived direction, and additionally, may benefit from a prolonged final fixation before executing the putting movement (Vickers, 1996). To the extent that biases in putting direction are caused by biases in perceived direction, the logo alignment aid and intermediate aiming strategy seem appropriate. In this regard, the present results suggest that novices would benefit more from this technique than high skilled players. However, we also observed that the errors in the perception of the direction in which the ball must roll to be holed, particularly among the high skilled, does not directly translate into the putting action. Particularly, it was found that although a change in head position annulled errors in perceived direction, it did not affect
biases in putting accuracy. Thus, we found no unambiguous evidence that the use of information to control the swing can be augmented or improved by the golfer maintaining the head directly above the ball, at least as far as it concerns the present errors in perceived direction. Instead, it may be more important for the player to obtain knowledge about the type of putting errors, because this may be used to make adaptive adjustments in aiming. Whether perceptual learning alone will be sufficient to realize these adjustments in aiming is, as yet, not completely clear.

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5

No transfer of calibration between action and perception in learning a golf putting task

Chapter 5

Abstract

We assessed calibration of perception and action in the context of a golf putting task. Previous research has shown that right-handed novice golfers make rightward errors both in the perception of the perfect aimline from the ball to the hole and in the putting action. Right-handed experts, however, produce accurate putting actions, but tend to make leftward errors in perception. In two experiments, we examined whether these skill-related differences in directional error reflect transfer of calibration from action to perception. In the main experiment, three groups of righthanded novice participants underwent a pretest-practice-posttest-retention-test design. During the tests, directional error for the putting action and the perception of the perfect aimline was determined. During practice, participants were only provided with verbal outcome feedback about directional error; one group trained perception, the second trained action, whereas the third group did not practice. Practice led to a relatively permanent annihilation of directional error, but these improvements in accuracy were specific to the trained task. Hence, no transfer of calibration occurred between perception and action. The findings are discussed within the two-visual system model for perception and action, and implications for perceptual learning in action are raised.
Introduction

In putting, right-handed novice golfers who stand to the left side of the ball make systematic directional errors to the right of the hole (Johnston, Benton, & Nishida, 2003; Roberts & Turnbull 2010; Van Lier, Van der Kamp, & Savelsbergh, 2011). These putting errors in novice golfers appear to be predicated on the misperception of the direction of the perfect aimline between the ball and the hole, although the rightward errors in perception are smaller than the rightward putting errors. Intriguingly, although skilled golfers accurately aim when putting, they tend to make leftward errors in the perception of the perfect aimline (see Figure 1). Van Lier et al. (2011) argued that skilled golfers had managed to overcome the rightward errors by a process of calibration, during which they presumably adjusted the relation between directional information and the control of the orientation of the club head relative to ball.

They further proposed that the parallel leftward shift in perception may suggest that this calibration of putting action transferred to the perception of direction. The nature of a learning process, however, cannot be conclusively inferred from performance differences between groups of different skill levels. In addition, it cannot be ruled out that the skilled participants in the study by Van Lier et al. (2011) had first calibrated the perception of direction and subsequently transferred this calibration into the putting action. In order to address these issues, the current study employed a learning experiment during which novice golfers learned to overcome the directional errors in the perception of the perfect aimline or in the putting action by either practicing the perceptual judgments or the putting action.

The first purpose of this study was to verify whether learning to aim a golf putt indeed is consistent with a process of calibration. From an ecological approach, calibration is defined as the scaling or adjustment of an action or perceptual judgment to the information that is used. That is, proponents of the ecological approach argue that for any task, a
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Figure 1: Directional errors in the putting action (i.e., dashed lines) and the perception of the perfect aimline (i.e., plain lines) for novice and skilled golfers.

-1.7°  0.7°  0.9°  1.9°

Figure 1: Directional errors in the putting action (i.e., dashed lines) and the perception of the perfect aimline (i.e., plain lines) for novice and skilled golfers.
lawful relation exists between information (i.e., $I(t)$) and task variables (i.e., $T(t)$) (Warren, 1988; see also Van der Kamp, Oudejans, & Savelsbergh, 2003). In its simplest appearance, this so-called law of control is formally expressed as:

$$T(t) = a + b \cdot I(t) \quad \text{(Eq. 1)}$$

in which $T(t)$ stands for a particular task variable (e.g., in the case of putting the orientation of the club head at impact, or in the case of a perceptual judgment, the perception of the direction of a line), $I(t)$ stands for a particular information variable (e.g., an optic variable specifying the direction towards the hole), and $a$ and $b$ stand for constants that reflect the precise relationship between the task and information variables.

Calibration refers to a change in the relation between the task and optic variables by tuning of the constants $a$ and $b$ (Jacobs & Michaels, 2007; Withagen & Michaels, 2005; for an alternative theoretical account of calibration, see e.g., Ernst & Banks, 2002).

A popular paradigm to examine the process of calibration has been the use of wedge prisms (e.g., Redding & Wallace, 1997). By laterally displacing the field of view, wedge prisms artificially manipulate the relation between informational and task variables. Martin, Keating, Goodkin, Bastian, and Thach (1996), for example, examined participants’ adjustments in throwing direction after donning prisms. Initially, participants made large directional errors in line with the artificial lateral displacement, but they rapidly adapted to the optical distortion. The directional errors had reduced to zero within 10 to 30 throws. After removal of the prisms, negative aftereffects occurred (i.e., throwing errors in the opposite direction), which indicates that the short-term learning involved a realignment of the relationship between the exploited informational variables and the aiming action (e.g., Redding et al., 1997; Willingham, 1998). These findings point to calibration, rather than a shift in the use of informational variables.
A similar process of calibration was proposed by Van Lier et al. (2011) to explain golfers’ improvement in directional putting accuracy with increases in skill level. Yet, the origin of the perceptual distortion in golf putting may be crucially different from that in the prism studies. In the prisms studies, errors in perceived direction are artificially induced and usually short-lived, whereas the directional errors in golf putting (or in the perceived direction of the perfect aimline) occur more generally and are relatively persistent (Cuijpers, Kappers, & Koenderink, 2000). This raises the question whether indeed the directional inaccuracies in putting that emerged from this intrinsic bias or dynamics (see Kelso, 1995) are as easily amendable as the artificially induced errors in the prisms studies.

The second purpose of this study is to scrutinize whether calibration of putting direction generalizes to perceptual judgments of the direction of the perfect aimline and/or vice versa. To test this, we provided two groups of novice golfers that made consistent and systematic directional errors feedback about the direction and magnitude of the error, while they were either practicing golf putting or practicing perceptual judgments. In subsequent post- and retention-tests, we assessed transfer of calibration. Some have argued that transfer of calibration between tasks occurs, if, and only if, the tasks are functionally similar, that is, share the same purpose (e.g., Rieser, Pick, Ashmead & Garing 1995; Withagen & Michaels, 2002). Yet, the empirical evidence is contentious. Martin et al. (1996) found that adaptation to prisms was specific for the throwing limb (i.e., no transfer of calibration occurred from the right to the left hand) and throwing pattern (i.e., no transfer occurred between overhand- and underhand throws), despite these tasks being functionally similar. By contrast, Withagen and Michaels (2002, 2004) provided support for the functional hypothesis for transfer of calibration in both motor tasks and perceptual tasks. For example, it was shown that calibration of walking (i.e., the relation between moving speed and optical flow field was realigned by having participants walk on a treadmill in a virtual environment) transferred to crawling. Although different limbs are involved, walking and
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crawling are locomotor tasks with the same functional goal (i.e., move from one place to another). In a second study, Withagen and Michaels (2004) demonstrated transfer of calibration of rod length perception from the right hand to the left hand. Hence, with respect to the current study the issue is whether the putting action and the perception of direction can be considered as functionally similar tasks (e.g., they both entail obtaining information for directional judgments of the perfect aimline).

In this respect, the influential two-visual systems model of Milner and Goodale (1995, 2008; see also Van der Kamp, Rivas, Van Doorn, & Savelsbergh, 2008; for a contrasting view see Franz, Gegenfurtner, Bülthoff & Fahte, 2000) proposes that the use of information for action (e.g., the control of the orientation of the club head in putting) and perception (e.g., obtaining knowledge on the direction of the perfect aimline) are functionally distinct and supported by separate neuro-anatomical systems. This provides a reason to suspect that transfer of calibration will not occur between the putting action and the perception of direction. The empirical evidence supporting Milner and Goodale’s claim of functionally and neurologically dissociated systems for action and perception, however, is largely confined to observations in real-time, that is, for tasks performed on the time-scales of seconds (but see Gonzalez, Ganel, Whitwell, Morrissey and Goodale 2008). Hence, it remains to be seen whether independence also applies to changes on longer time-scales of learning.

By contrast, others have argued that perception and action are tightly integrated and use similar information (e.g., Hommel, Müsseler, Aschersleben & Prinz, 2001; Prinz, 1997, 2006). Within the common coding theory this is conceptualized as perception and action sharing common codes or representations. The notion of common codes for perception and action is corroborated by neuropsychological evidence that specialized neural pathways exist (i.e., the mirror neuron system), that respond during both action and perception (e.g., Blakemore & Frith, 2005; Rizzolatti & Craighero, 2004). Hence, to the extent that
the putting action and the perception of direction are indeed tasks that exploit common codes or use the same information, a strong argument can be made that improvements in putting direction following a process of calibration would transfer to the perception of direction and vice versa.

We report two experiments. Experiment 1 sets the stage by examining the circumstances in which directional errors are most likely to occur consistently and reliably. Subsequently, in Experiment 2 these circumstances are exploited to examine whether augmented feedback on the direction of putting and perceptual errors induces a process of calibration, and to examine whether transfer of calibration occurs between putting direction and perception of direction of the perfect aimline.

Experiment 1

Obviously, learning can only take place when systematic and consistent errors exist. Previous work showed that systematic rightward error in perceived direction occur at group level (Johnston et al., 2003; Van Lier et al., 2011), but it has also been suggested that inter- and intra-individual differences transpire in the magnitude of the perceptual distortion (e.g., Cuijpers et al., 2000, 2003; Koenderink & Van Doorn, 1998; Koenderink, Van Doorn, & Lappin, 2000, 2003). For example, in golf the exact position of the eyes (i.e., line of sight) relative to the perfect aimline affects the magnitude of the perceived directional error (Van Lier et al., 2011).

The directional errors only occurred when the eyes were positioned next to the ball and above the hands (positions H3 and H4, Figure 2), but not when they were directly above the ball (position P, Figure 2). Van Lier et al. (2011) attributed this increase due to a larger angle between the line of sight and the perpendicular to the plane in which the direction of the perfect aimline was to be judged. However, alternative explanations such as the absolute distance or lateral distance (see Figure 2) between the eyes
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Figure 2: Schematic representation of head positions H1 to H4 as used in Experiment 1. P indicates the point straight above the ball and perpendicular to the plane in which the direction of the perfect aimline was to be judged.
and the ball cannot be ruled out. Hence, in Experiment 1 we assessed what head (and eyes) position resulted in the most consistent and reliable errors in perceived direction for the individual participants by evaluating the effect of varying the angle between the line of sight and the ground plane, and the lateral, vertical and absolute distance between eyes and ball.

**Method**

**Participants**

Ten right-handed novice golfers (mean age = 21.9 ± 2.7 years) with normal or corrected to normal vision volunteered to participate in the experiment. They provided informed consent prior to the experiment and were treated in accordance with the local institution’s ethical guidelines.

**Apparatus**

The experimental apparatus and procedure was based upon earlier work by Van Lier et al. (2011). A triangular shaped level platform was used that was covered with artificial grass from synthetic turf (GreenFields®, Genemuiden, The Netherlands). The green was approximately 4 m long and 2 m wide. The green was cleaned prior to the experiment in order to prevent the presence of any landmarks that might be used as a reference. Additionally, black plastic sheeting, which hung from the ceiling, covered the edges of the green. The sheeting was wrinkled, creating irregular cavities and protrusions so as to minimize any salient reference points for the participants. At a distance of 1.80 m from the hole a pointer was placed 2 cm above the artificial green. The pointer comprised of a golf ball from which a 3 mm thick needle stuck out 15 cm from the ball’s front and 10 cm from its back. The pointer could be rotated in a stepwise fashion using two hand-held switches that fed into a computer. The hand-
held switches controlled a servomotor that was connected to the pointer and placed underneath the green. The rotation speed of the pointer was $6^\circ$/s when the pointer’s front was more than $20^\circ$ off-target at the time the switch was pressed, but reduced to $1^\circ$/s when it was within $20^\circ$ off the target. The precision of the pointer was .06°.

To consistently vary the position of the head and eyes in relation to the pointer an adjustable head support was used, which comprised of an adjustable stand bearing a small wooden ball (i.e., 3 cm in diameter). The participants were instructed to keep the back of their head to the adjustable wooden ball, thereby creating four head and eyes positions that varied in height (i.e., at 75 cm and 150 cm) and lateral distance (i.e., 75 cm and 150 cm) relative to the pointer (Figure 2). Alongside, the angle between the line of sight and the perpendicular to the plane in which the directional judgment was made (i.e., 30°, 45°, 60°) and the absolute distance between the eyes and the pointer (i.e., 106, 168, 212 cm) were varied.

Procedure and design

The participants stood to the left side of the ball, and were instructed, prior to each trial, to contact the head support with the back of their head (i.e., protuberantia occipitalis externa). During the trial, they were allowed to move their head freely (i.e., to look from the pointer to the hole and vice versa), but to keep their head close to the head support. For the two low head positions (i.e., position H1 and H2), participants had to sit on their knees, while for the two high positions (i.e., position H3 and H4) they had to stand like they would do when addressing a ball in order to putt.

At the start of each trial, the pointer was automatically placed in a random orientation between 30° and 60° to either the right or left of the hole. This was changed from trial to trial, and prevented participants from making judgments relative to the initial pointer orientation in the current trial and/or the final pointer orientation in the previous trial. Participants were first instructed on how to rotate the pointer by pressing the two hand-
held switches. Pressing the switch in the left hand resulted in the pointer rotating in a clockwise direction, while pressing the switch in the right hand made the pointer rotate in an anti-clockwise direction. Participants were then instructed to rotate the pointer such that it pointed to the centre of the hole, which was indicated by the foot of a flagpole. The pointer’s exact orientation with respect to the perfect aimline was registered by a computer once the participants verbally indicated that they had positioned the pointer correctly.

The four head position conditions were administered in blocks of twelve trials in a counterbalanced order across participants. Participants did not receive any knowledge of results during the experiment.

Data reduction and statistics

The error in perceived direction served as the dependent variable. It was defined as the angle between the direction of the pointer and the direction of the true line between the ball and the hole (i.e., perfect aimline). A negative angle indicated a counterclockwise error (i.e., leftward error), whereas a positive angle indicated a clockwise error (i.e., rightward error). To test whether the individual participants made consistent and systematic errors in perceived direction, we used one sample t-tests with the Šidák correction for multiple comparisons to assess whether the error in perceived direction was different from zero (i.e., no error) for each participant and head position separately. In addition, individual regression analyses were conducted to examine which factor or combination of factors contributed most to the directional error.

Results and Discussion

Figure 3 shows the pattern of errors in perceived direction for three individual participants. The inter-individual differences immediately stand...
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out. For example, participant P3 shows larger errors for head positions at larger heights (i.e., H3 and H4). This is also the case for Participant P7, but with the errors in the opposite direction (i.e., leftward instead of rightward errors). In Participant P5, however, the error in perceived direction was chiefly affected by lateral distance, with larger rightward errors for head positions H2 and H4.

Notwithstanding these inter-individual differences, t-tests revealed that errors in perceived direction most consistently and reliably occurred for head position H4. That is, eight participants showed a significant error, seven of whom made the anticipated rightward error ($t(11) > 3.2$, $p’s < .01$), while one participant made a significant error to the left of the hole ($t(11) = 15.7$, $p < .01$). The one final participant did not produce a significant error for head position H4 ($t(11) = 1.9$, $p > .05$). Three to five participants made significant errors in perceived direction for the other three head positions. The source of the inter-individual differences remains uncertain; the regression analyses outcomes point to the individual participants’ errors in perceived direction being differently related to angle between the line of sight and the perpendicular to the plane in which the pointer was rotated, and the vertical, lateral and absolute distance between the eyes and the pointer (Table 1).

Previous work pointed to the angle between the line of sight and the perpendicular to the plane in which the judgment is made as the most important determinant for the size of the error in perceived direction (Van Lier et al., 2011). However, none of the individual patterns of error was in line with this suggestion. Finally, we conclude that the largest combined vertical and lateral distance between the eyes and the ball (i.e., head position H4) most reliably resulted in errors in perceived direction (although not completely consistent across participants). We therefore used this head position in Experiment 2 to assess learning.
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Figure 3: Errors in perceived direction as a function of head position H1 to H4 for three individual participants (P2; P7; P3) in Experiment 1. Negative and positive errors indicate leftward and rightward errors, respectively.
Table 1: Outcomes for the regression analysis for the individual participants, displaying the variable that entered the regression equation and the corresponding coefficient.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Variables entered</th>
<th>Beta coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>height</td>
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</tr>
<tr>
<td>P2</td>
<td>absolute distance</td>
<td>0.59</td>
</tr>
<tr>
<td>P3</td>
<td>height</td>
<td>0.51</td>
</tr>
<tr>
<td>P4</td>
<td>none</td>
<td>-</td>
</tr>
<tr>
<td>P5</td>
<td>lateral distance</td>
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</tr>
<tr>
<td>P6</td>
<td>lateral distance</td>
<td>0.73</td>
</tr>
<tr>
<td>P7</td>
<td>height</td>
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</tr>
<tr>
<td>P8</td>
<td>lateral distance</td>
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</tr>
<tr>
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<td>absolute distance</td>
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</tr>
<tr>
<td>P10</td>
<td>none</td>
<td>-</td>
</tr>
</tbody>
</table>

Experiment 2

Experiment 2 investigated whether augmented outcome feedback induces relatively permanent changes in putting and perception. Previous work has shown that outcome feedback (or knowledge of results) on the magnitude and sign of error aids the learner to enhance calibration of an informational variable to a task variable [i.e., \( I_y \) and \( T_y \) in Eq. 1] (e.g., Cabe & Wagman, 2010; Wagman, McBride, & Trefzinger, 2008; Withagen & Michaels, 2005). Wagman et al. (2008; see also Gibson & Bergman, 1954) argued that such calibration is revealed in increases in accuracy and consistency of performance. In a series of length perception studies, it was found that improvements in the accuracy of performance (i.e., indicated by a change in constant error) were conditioned upon the presence of outcome feedback. By contrast, improvements in the consistency or variability of performance (i.e., indicated by a change in variable error) occurred irrespective of the presence of feedback, only a
few repetitions without feedback apparently sufficed. In the present study, two groups of novice golfers received outcome feedback on the magnitude and sign of the directional errors they made while either practicing putting or perception with their head positioned at a large vertical and lateral distance from the ball (i.e., position H4 per Experiment 1). A pre-test, practice, post-test and retention-test design followed. We hypothesized that the outcome feedback induces calibration, which would result in enhanced performance accuracy and increased consistency (i.e., reduced variability) at the post- and retention-tests relative to the pre-test. Our chief interest, however, was in whether calibration induced by putting practice with outcome feedback transferred to perception, and vice versa whether calibration due to perception training with feedback transferred to putting. We expected transfer of calibration to occur to the degree that the tasks have functional characteristics in common [e.g., they crucially depend on accurate information - or codes - about the direction of perfect aimline] (Hommel et al., 2001; Prinz, 1997; see also Van Lier et al., 2011). We expected the transfer to be restricted to performance accuracy and not to comprise consistency, because an increase in consistency requires at least a limited amount of repetitions. Alternatively, however, following Milner and Goodale (1995, 2008; see also Withagen & Michaels, 2004) the putting action and perception task may be considered as functionally separate, which would rule out that transfer of calibration between the tasks would occur.

**Method**

**Participants**

Thirty-nine right-handed novice golfers with normal or corrected to normal vision volunteered to participate. In order to assure that participants were unskilled, eight volunteers were excluded from further participation in the
experiment because they holed more than four out of ten putts during the pretest (for Procedure, see below). Five more participants were excluded after completion of the experiment, because the average constant errors in the putting and/or perception task during the pretest did not exceed zero. Finally, due to technical failure the data for one participant was lost. The remaining participants were randomly assigned to the perception training group \( n = 9; \text{ mean age } = 22.2 \pm 2.8 \text{ years} \), the action training group \( n = 8; \text{ mean age } = 23.4 \pm 3.0 \text{ years} \) and the control group \( n = 8; \text{ mean age } = 25.0 \pm 4.6 \text{ years} \). The volunteers received a small monetary fee, and were treated in accordance with the local institution’s ethical guidelines.

Material and Apparatus

For the perception task the same pointer was used as per Experiment 1. The putting task was performed on the same platform, which was prepared prior to testing to assure that the ball roll was unaffected (i.e., a speed of 14’ Stimp). Using standard golf balls participants had to perform putts using a specially fitted long conventional putter. The length (1.21 m) and lie angle (50°) of the putter allowed to make putts comfortably while standing with the head positioned at 1.50 m above and next to the ball (i.e., position H4 in Experiment 1). The adjustable head support (see Experiment 1) was used to assist participants maintaining this position.

Liquid crystal goggles (Plato Translucent Technologies, Toronto, Canada) were used to remove visual feedback about task outcome. During the perception task, the goggles turned opaque after the participants indicated they had rotated the pointer in the desired position, and in the putting task the goggles turned opaque the moment the ball interrupted a light beam of a photoelectric switch (Omron E3S-R 3OE4), which was positioned perpendicular to the ball path at 40 cm from the initial ball position. The hole was covered with a white artificial grass plug to eliminate auditory feedback from the ball entering the hole.
Two digital video camera’s (Panasonic 25 Hz interlaced PAL) were used. One camera was positioned directly above the ball and allowed to determine the initial direction of the ball roll. The second camera with a transparent visor was placed behind the ball directly in line with the ball-hole direction. Its recordings were displayed on a monitor to provide verbal feedback about the distance the ball passed next to the hole during the putting task (i.e., this reflects the magnitude and sign of the directional error). To this end, a foot-rule was drawn on the monitor in such a manner that it precisely overlapped the line through the center of the hole that was perpendicular to the perfect aimline. The foot-rule indicated intervals corresponding to 5 cm on the platform.

Procedure and design

Participants were randomly assigned to one of three groups based on their pre-test performance. The perception and action training groups followed a pre-test, practice, post-test, retention-test design. The control group, however, did not receive practice. Participants first performed the pre-test, which was followed by three practice sessions that took place at separate days. The post-test was performed on the same day as the third practice session with a fifteen minutes break in-between. Finally, the retention-test was conducted between two and four days after the post-test.

During the pre-, post- and retention-tests, the participants performed a block of twelve perception trials and a block of twelve putting trials, the order of which was counterbalanced across participants. The tests were administered in two bouts of 6 trials. The perception task was similar to that in Experiment 1. That is, the participants rotated the pointer such that it pointed to the centre of the hole. In the putting task, participants attempted to put the ball into the hole. Participants wore the Liquid Crystal goggles to ensure that visual feedback of the task outcome could not be used to improve performance on the subsequent trial. In the perception task, the glasses turned opaque after the participants indicated that they had rotated
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the pointer in the desired position. In the putting task the goggles turned opaque at the moment the ball had traveled 40 cm in the direction of the hole. Participants did not receive augmented feedback during the test trials. Participants were constrained to consistently position the head at a height of 150 cm and a lateral distance of 150 cm relative to the pointer or the ball (i.e., head position H4 in Experiment 1). Although they were allowed to move their head in order to look from the pointer or the ball to the hole and vice versa, they had to keep it as close as possible to the head support. After completion of a trial (i.e., after the glasses were closed), the participant turned his or her back to the hole until the experimenter opened the goggles. This was the sign to prepare for the next trial.

During each of the three practice sessions, the participants in the action training group performed 48 putting trials, while the participants in the perception training group performed 48 perception trials. These sessions were administered in bouts of 6 trials, in between which participants were allowed to take short rests to prevent fatigue and to relax. The procedure was similar to that in the pre-, post and retention-tests, but the participants now received verbal augmented feedback on the magnitude and sign of the directional error after each trial. Feedback was provided in intervals of 5 cm distance to the left or right from the centre of the hole. To this end, the directional error in degrees for the perception task was directly converted into distances from the hole’s centre. Specifically, when the pointer was rotated, or the ball passed, i) within 5 cm of the center of the hole participants were told it pointed or passed “in the hole to the left or right from the centre”; ii) when the pointer pointed, or the ball passed, the hole within 30 cm of its center, participants were told it pointed or passed the corresponding 5 cm interval to the left or right from the centre of the hole; iii) when the pointer pointed, or the ball passed, more than 30 cm of the centre of the hole, the participants were told “more than 30 cm to the left or right from the centre”. Before each practice session, participants were shortly informed on the feedback procedure.
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Data reduction and statistics

The error in perceived direction (in degrees) was defined as the angle between the direction of the pointer and the direction of the true line between the ball and the hole (i.e., perfect aimline). A custom made semi-automatic video-analyzing program, developed with the Matlab® Image Processing Toolbox, was used to digitalize the path of the ball and its direction for the first ten frames (i.e., 400 ms) after contact. The error in putt direction was defined as the angle between the direction of ball roll and the true line between the ball and hole. Negative angles for the errors in perceived and putting direction indicated a leftward or counter-clockwise error, while positive angles indicated a rightward or clockwise error.

Like in Experiment 1, perusal of the pre-test data showed that most participants made reliable and consistent rightward errors in both the perception and putting tasks. Yet, one participant made consistent leftward errors in both tasks, whereas a second participant made leftward errors in the perception task and rightward errors in the putting task. To make sure that these interindividual differences in the sign of the directional error and the changes therein as a function of practice did not cancel each other out, the errors in the pretest were transformed into a rightward error (i.e., positive sign). In addition, the errors during practice, in the post-test and retention-test were adjusted such that the magnitude and the sign of the differences with the pre-test were maintained.

Subsequently, we submitted constant errors (i.e., accuracy) and variable errors (i.e., consistency) in perceived direction and putting direction to separate 3 (group: perception training, action training, control) by 3 (test: pre-test, post-test, retention-test) ANOVAs with repeated measures on the last factor. Huyn-Feldt corrections to the degrees of freedom were applied in the case of any violations of sphericity and partial eta-squared ($\eta^2_p$) values were computed to determine the proportion of total variability attributable to each factor or combination of factors. Posthoc comparisons were conducted using Tukey’s HSD test ($p < .05$). One sample t-tests
with the Šidák correction for multiple comparisons were used to examine whether the constant errors were significantly larger than zero (i.e., no error).

Finally, the accuracy and consistency during perception training and action training were calculated in 12 blocks of 12 trials. This was based on the 5 cm distance interval feedback that was provided to the participants. The constant error (i.e., accuracy) and variable error (i.e., consistency) in perceived direction for the perception training group and the putting direction for action training group were submitted to a 12 (block: 1 to 12) ANOVA with repeated measures. Additionally, two tailed one sample t-tests were used to assess whether the constant directional errors were larger than zero (i.e., no error).

Figures 4 and 5 illustrate the constant and variable errors in the pre-test, post-test and retention-test for the putting task and the pointing task respectively. Figure 4 shows that putting accuracy (i.e., the constant error) only reduced for the action training group, and that this increase in accuracy was maintained during retention. This was confirmed with significant effects for test, \( F(2, 44) = 11.85, p < .001, \eta^2_p = .35 \), and the interaction test by group, \( F(4, 44) = 4.82, p < .05, \eta^2_p = .31 \), for the constant putting error.

The effect of group was not significant, \( F(2, 22) = .52 \). Post-hoc comparisons indicated that the directional errors in the post- and retention-tests were significantly smaller than in the pretest, but this decrease only occurred for the action training group. In addition, t-tests showed that the directional errors were significantly larger than zero, except for the errors of the action training group in the post- and retention-tests, \( t_s < 2.0, p_s > .08 \). A subsequent ANOVA on the variable directional errors revealed no significant increase in consistency of putting, although the effect of test was

Results and Discussion

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The effect of group was not significant, \( F(2, 22) = .52 \). Post-hoc comparisons indicated that the directional errors in the post- and retention-tests were significantly smaller than in the pretest, but this decrease only occurred for the action training group. In addition, t-tests showed that the directional errors were significantly larger than zero, except for the errors of the action training group in the post- and retention-tests, \( t_s < 2.0, p_s > .08 \). A subsequent ANOVA on the variable directional errors revealed no significant increase in consistency of putting, although the effect of test was
nearly significant, \( F(2, 44) = 3.03, p = .07, \eta_p^2 = 0.12 \).

Figure 5 shows a similar pattern of findings for the perception task. Thus, significant effects for test, \( F(2, 44) = 7.00, p < .05, \eta_p^2 = 0.24 \), group, \( F(2, 22) = 7.31, p < .05, \eta_p^2 = 0.40 \), and the interaction test by group, \( F(4, 44) = 3.88, p < .05, \eta_p^2 = 0.26 \), were found for the constant perception error. Post-hoc comparisons indicated that the directional error of the perception training group was significantly smaller in the post- and retention-tests in comparison to the pre-test. In addition, tests showed that perception errors were significantly different from zero, with exception of the errors of the perception training group in the post- and retention-tests, \( ts < .81, p's > .44 \). In sum, with practice only the perception training had reduced the perceptual error to zero. The ANOVA for the variable error revealed that consistency of the directional judgments was significantly affected by test only, \( F(2, 44) = 6.01, p < .01, \eta_p^2 = 0.22 \). Post hoc comparisons indicated that variable error was significantly reduced in the retention-test as compared to the pre-test.

Finally, Figures 6 and 7 depict the changes in accuracy and consistency of the action training and perception training groups, respectively. They show that the largest performance gains were achieved during the initial training blocks, which is suggestive of a typical exponential learning curve. This was confirmed by significant effects of block for putting error, \( F(11, 66) = 3.10, p < .01, \eta_p^2 = 0.34 \), and perception error, \( F(11, 88) = 2.47, p < .05, \eta_p^2 = 0.24 \). Post hoc comparisons indeed indicated that the constant errors were significantly larger in the first two blocks as compared to the two final practice blocks.

In addition, two tailed one sample tests showed that from block 9 putting errors were not significantly different from zero (i.e., no error), whereas for the perception task this occurred from block 2 onward. Finally, Figures 6 and 7 suggest that practice did increase consistency of perception, but perhaps surprisingly did not result in more consistent putting. Accordingly, only for the perception training group a significant effect of block was found for the variable error, \( F(11, 88) = 4.94, p < .01 \).
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Figure 4: Constant errors in putting for the pre-, post-, and retention-tests. Error bars indicate variable error, and asterisks indicate errors that are significantly different from zero (* p < .05).

Figure 5: Constant errors in perceived direction for the pre-, post-, and retention-tests. Error bars indicate variable error, and asterisks indicate errors that are significantly different from zero (* p < .05).
Figure 6: Constant error (i.e., black line) and variable error (i.e., grey line) in putting as a function of blocks of 12 trials during practice. Asterisks indicate errors that are different from zero (* \( p < .05 \)).

Figure 7: Constant error (i.e., black line) and variable error (i.e., grey line) in perceived direction as a function of blocks of 12 trials during practice. Asterisks indicate errors that are different from zero (* \( p < .05 \)).
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.01, $\eta^2 = 0.38$. Post-hoc comparisons indicated that this decrease in variable error occurred from the first to second block.

**General Discussion**

A first purpose of the present study was to examine whether improvements induced by outcome feedback about the size and sign of the directional error in golf putting are driven by calibration. Indeed, the reduction of the initial putting errors to zero after putting practice with feedback strongly points to calibration. This is further underlined by the gradual increase in accuracy (i.e., decrease in constant error) during practice. It must be acknowledged that although the findings are consistent with calibration, the current design does not conclusively demonstrate that calibration occurred. A genuine demonstration of a re-scaling between information and task variables (i.e., presumably, for putting this task variable is the orientation of the club head at impact) requires that the informational variable is varied (e.g., by manipulating distance between the ball and hole and/or the head position relative to the ball). Nevertheless, the results show that this putative calibration was relatively permanent, that is, putting accuracy was maintained on a one-week retention-test. As far as we know, and perhaps somewhat surprisingly, this is the first study framed within an ecological theory of learning to investigate and suggest that calibration can lead to relatively permanent changes between informational and task variables (cf. Withagen & Caljouw, 2011). It is perhaps illustrative to compare the present interpretation with that in a recent report by Cavina-Pratesi, Kuhn, Ietswaart and Milner (2011). These authors investigated real and pantomimed reaching movements of magicians. Unlike non-magicians, for who pronounced kinematic differences were observed between real and pantomime grasping, among magicians the kinematics of the two types of grasping were nearly identical. The authors suggested that with sustained practice the magicians had recalibrated the control of the reaching
movements from information of the real object toward information from a spatially separate location. An analogous interpretation for the current findings would be that the outcome feedback during putting practice would have led the participant to aim for a ‘ghost’ hole next to the real hole, as if the golfer compensates for perceptual distortion. Instead, we argue that the relation between the visual information and the putting action is adjusted, rather than making corrections for a misperception of location of the target (see also Van Lier et al., 2011). This is supported by the observation that improvements in putting accuracy are not contingent upon improvements in perception of the direction of the perfect aimline.

The findings with regard to the perception of the direction of the perfect aimline were similar, although the increase in perceptual accuracy during practice seemed to occur much more rapidly than for putting. A more notable distinction between the putting and perception tasks is related to the consistency or variability of performance. For the perception task, consistency increased very rapidly after 10 to 20 trials only. Also in line with earlier observations for length and distance perception (e.g., Gibson & Bergman 1954, Wagman et al., 2008, Withagen & Michaels 2004), these increases in consistency seem not to depend on feedback, since increases were not restricted to the perception training group, but also became apparent in the retention-test for the action training and control groups. By contrast, for the action task changes in consistency were neither observed from the pre-test to the post- or retention-tests, nor during practice. It is not particularly clear why, but one suggestion may be that standardization of movement occurs relatively late during the learning of action. For example, Koedijk, Poolton, Maxwell, Oudejans, Beek, and Masters (2011) have recently proposed that automatization (i.e., as indicated by reliance of movement execution on working memory) of a table tennis forehand stroke transpired before standardization of the stroke. Irrespective of whether this proposal is correct, the divergent patterns for consistency suggest that calibration for the putting and the perception tasks was not identical.
The main purpose however, was to examine transfer of calibration. Perception training resulted in enhanced perception of direction, but did not reduce the directional errors in putting. Conversely, action training did increase putting accuracy, but did not lead to reliable improvements in the perception of direction of the perfect aimline. In other words, we found no evidence that transfer of calibration between action and perception occurred. Nor was there evidence to support the contention of transfer of calibration with respect to consistency or variability of performance. The action training, however, did result in an increased consistency of the perceptual judgments, but this cannot be attributed to the training since the control group showed a similar increase in consistency. These findings are in line with the proposal of the existence of functionally distinct systems for the use of information in action and perception (Milner & Goodale, 1995, 2008), but are much more difficult to reconcile with ideas of a common informational or representational basis for action and perception (Hommel et al., 2001; Prinz, 1997, 2006). The putting action and the perception of direction are best understood as giving rise to separate couplings between task and informational variables. These couplings may not only entail distinct task variables (i.e., \( T \)), but also distinct informational variables (i.e., \( I \)), even though both tasks critically depend on information about the direction of the perfect aimline. Thus, Van Lier et al. (2011; see also Johnston et al., 2003) demonstrated that the perception of direction of the aimline [see Experiment 1 above] was a function of head-eye position with respect to the ball, while directional error in putting accuracy was immune to differences in head-eye position. This indicates the use of different informational variables in the control of the putting action and the perception of direction. If the calibration or scaling of an informational variable to a task variable is unique to a particular coupling, then transfer of calibration between the two tasks is unlikely.

The absence of transfer is contrary to previous suggestions by Van Lier et al. (2011). They observed that expert golfers relative to novice golfers tended to produce lefthand errors in the perception of the perfect
aimline (see Figure 1). Because the novice players made rightward errors in putting, it was argued that the calibration of the putting action induced by practice would have transferred to the perception of direction of the aimline. The present findings however did not reliably show this parallel leftward shift in perception. Yet, the novice participants’ practice in the current study was limited to only 144 putts over three days. This strongly contrasts to expert golfers who have made thousands of putts over at least 10 years. Clearly, we cannot rule out, that over longer time-scales of months or years, transfer may occur. In this respect, it is noticeable that numerically (but not statistically!) there is a trend for the action training group and not for the control group, to make more accurate perceptual judgments in the post- and retention-tests than in the pre-test.

Visual perception plays an indispensable role in a large variety of sports skills, including aiming skills, such as putting in golf, and interception skills, like hitting a ball in tennis or saving a penalty kick in soccer and so forth. In recent years, a number of studies have attempted to improve these skills through perceptual learning interventions (e.g., Rowe & McKenna, 2001; Savelsbergh et al., 2010; Williams, Ward & Chapman 2003, Smeeton, Williams, Hodges & Ward 2005). Typically, researchers do this by repeatedly displaying video clips that represent the situation of interest (e.g., a penalty kicker in the run-up to the ball). By providing instruction or feedback about the pertinent sources of information in the display (e.g., directing attention to the placement of the non-kicking foot), it is tried to enhance a player’s perception. Yet, these interventions received mixed success. Despite improvements in perception for the training task, transfer to the actual action often remains unclear. One concern that has been raised is the degree to which the information available in the display is impoverished (e.g., Abernethy, Thomas, & Thomas, 1993; Dicks, Davids, & Button, 2009). In the present study, however, the perceptual training environment was not recreated by using 2D-displays but was identical to the real-life performance situation. In all likelihood, a more crucial issue with these practice interventions is therefore that perceptual learning
No transfer of calibration between action and perception in learning a golf putting task takes place independent from action. Whereas the use of information for perception is facilitated, it leaves the intricate coupling between information and movement untouched (Milner & Goodale, 2008; Dicks, Button & Davids, 2010). Perception for action cannot be trained in isolation from action (see also Van der Kamp et al., 2008).

To conclude, we have shown that directional errors in golf putting can be permanently cancelled on basis of outcome feedback, consistent with a process of calibration. Similarly, outcome feedback can also annihilate errors in the perception of the perfect aimline. Yet, the observed increases in accuracy were specific to the trained task. Thus, no transfer of calibration occurred between perception and action.

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Chapter 5


No transfer of calibration between action and perception in learning a golf putting task


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 aimline 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 aimline 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 aimline). Chapter 5 provided additional evidence for this contention. Improvements in the accuracy of the perception of the direction of the perfect aimline 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 aimline 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 aimline 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.
Figure 1: Schematic representation of the relevant properties of the ‘environment-actor system’ in a putting task (Adapted from Karlsen, 2008).

Figure 2: Diagram of candidate optic variables. \( \omega \): the angle subtended between the pointer and the target. \( \omega_e \): the orientation of the line of sight and the perfect aimline. Also shown E: representing the error in perceived direction (Adapted from Cuijpers et al. 2000).
Chapter 6

(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).

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 $\xi$ 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 $\omega$ that specifies the orientation of the pointer-target (i.e., perfect aimline) 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 Karlsten, 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.
Epilogue

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 affects 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).

References


7

Samenvatting

Wim H. van Lier
Dit proefschrift handelt over de rol van de visuele waarneming voor het sturen van de putactie in golf, in het bijzonder de nauwkeurigheid van de richting van de put. Drie aspecten werden bekeken. Allereerst werd onderzocht op welke informatiebronnen (bijv. de hole, de green en/of de bal) de aandacht gericht werd, door onder andere na te gaan wat de visuele zoekpatronen waren en wat de invloed was van het richten van de aandacht op verschillende informatiebronnen, zoals de locatie van de bal en de hole. Vervolgens werd nagegaan hoe golfers omgaan met een vervormde waarneming. Het theoretische model van twee visuele systemen van Milner and Goodale vormde daarbij de theoretische achtergrond voor het antwoord op deze vraag. Ten slotte werd onderzocht hoe golfers de Richting van de put leren verbeteren. Daarvoor werd de bijdrage nagegaan van de processen die Gibson (1966) benoemde als ‘education of attention’ (het leren letten op de juiste informatiebronnen) en ‘calibration’ (het schalen van de informatie zodat een juiste relatie ontstaat tussen de informatie- en bewegingsparameters).

In hoofdstuk 2 wordt nagegaan wat het effect is van het richten van de aandacht op een proximaal externe informatiebron (aandacht gericht op de bal) en een distaal externe informatiebron (aandacht gericht op de hole). Zowel beginners als golfers met een hoog vaardigheidsniveau maakten puts op drie verschillende afstanden van de hole (1,8, 2,7 en 3,6 m) met beide aandachtfoci. De resultaten laten zien dat de golfers met een hoog vaardigheidsniveau significant beter presteren met een distaal externe aandachtfocus, maar alleen op een afstand van 1,8 m. Bij de beginners bleek er geen verschil in het effect van de aandachtfocus. In tegenstelling tot het gebruik van golfers om de aandacht tijdens het putten proximaal te richten, door te kijken naar de bal, lijkt het erop dat een meer distale aandachtfocus, door middel van te kijken naar de hole, beter is om succesvol te putten. Deze bevindingen bevestigen ten dele de ‘constrained action’ hypothese van Wulf (2007).

Hoofdstuk 3 behelst een studie die het effect van taakcomplexiteit op het oppikken van visuele informatie naging, teneinde de richting
van het putten te sturen bij golfers met een hoog vaardigheidsniveau. Taakcomplexiteit werd gevarieerd door te laten putten op een vlakke green en een green met 1% en 2% zijwaartse helling, met een balrol van rechts naar links. Allereerst werden de visuele zoekacties direct voorafgaand en tijdens het putten op de verschillende greens in kaart gebracht. Vervolgens werd nagegaan of er spatiale- en/of temporele aanpassingen in het visuele zoekgedrag werden gemaakt en hoe die afhingen van het putten op greens met een verschillende helling. In het bijzonder werd erop gelet of spelers hun blik op verschillende locaties richtten (zoals de bal, de hole en de green), op welke momenten dat gebeurde en hoe lang de blik achtervolgde op een dergelijke informatiebron gericht werd. Eventuele verschillen werden in verband gebracht met het meer of minder succesvol zijn van de golfers. Daartoe werd de groep hoog vaardige golfers verdeeld in twee groepen op basis van hun overall putpercentage. Vervolgens werd nagegaan of de meer en minder succesvolle golfers herkend konden worden op basis van hun visuele zoekpatronen en de manier van oppikken van informatie. Uit deze studie blijkt dat het introduceren van een helling geen effect had op het aantal puts dat uitgeholed werd, maar vooral effect had op het soort missers. Het aantal missers dat langs de lage (linker) kant van de hole ging was significant hoger dan het aantal missers dat langs de hoge (rechter) kant van de hole ging, waarbij dit effect bij de groep minder succesvolle golfers meer te zien was dan bij de groep succesvolle golfers. Wat betreft het richten van de blik werd vastgesteld dat met het toenemen van de steilte van de helling het aantal fixaties op de hoge (rechter) kant van de hole toenam. Bovendien bleek de deelnemers minder tijd aan het kijken naar de bal bij de steele hellingen. De duur van de laatste fixatie voordat de put gemaakt werd bleek niet afhankelijk te zijn van de steilte van de helling. Al met al kan gesteld worden dat de belangrijkste aanpassingen in het visuele gedrag in het spatiale domein en niet in het temporele domein gezocht moeten worden.

In hoofdstuk 4 wordt de rol van de visuele waarneming zelf
op de putprestatie bekeken. Eerdere studies lieten zien dat de visuele waarneming niet altijd waarheidsgetrouw is en dat golfers systematische fouten maken in het waarnemen van de richting van de perfecte lijn naar het doel. (Johnston, 2003). Daardoor werd het interessant om na te gaan wat nou eigenlijk de rol van de visuele waarneming is voor het putten. Waar komen deze waarnemingsfouten vandaan en beïnvloeden ze ook daadwerkelijk de putactie (vergelijk Milner & Goodale, 2008)? Vandaar dat er in hoofdstuk 3 een serie van drie experimenten beschreven wordt die nagaan wat de rol is van de visuele waarnemingsfouten bij het waarnemen van de richting van de perfecte doellijn bij beginners en golfers met een hoog vaardigheidsniveau op het moment dat zij de bal adresseren en putten. Daarbij rees de vraag wat dit betekent voor de rol van ‘education of attention’ en/of ‘calibration’ in het leerproces om van beginner tot een hoog vaardigheidsniveau te komen bij het putten.

In Experiment 1 en 2 werd de studie van Johnston, 2003 gerepliceerd en onze veronderstelling getest dat de in deze studie waargenomen fouten veroorzaakt werden doordat de zichtlijn van de golfer niet loodrecht op het vlak stond waarin de schatting van de richting gemaakt moest worden (dat wil zeggen niet loodecht op het vlak van de green). De resultaten bevestigden dat de perceptuele fout verdween wanneer de rotatie van het hoofd tijdens het op en neer kijken van de bal naar de hole, dusdanig gemaakt moest worden dat de rotatie van het hoofd voortdurend in het vlak door de doellijn en loodrecht op de green plaats vond. In het derde experiment, werden zowel de visuele waarnemingsfouten als de richtingsfouten in het putten zelf tussen beginners en golfers met een hoog vaardigheidsniveau met elkaar vergeleken. In tegenstelling tot de visuele waarnemingsfouten bleek de nauwkeurigheid van het putten zelf niet beïnvloed te worden door de positie van het hoofd opzichtje van de lijn tussen de bal en de hole. Bovendien deden de resultaten vermoeden dat, de grotere putnauwkeurigheid geconstateerd bij hoog vaardige golfers (waarbij de systematische putfout naar rechts niet gemaakt werd), mogelijk veroorzaakt werd door een proces van kalibratie.
Hoofdstuk 5 gaat vervolgens in op de mogelijke onafhankelijkheid van perceptie en actie bij golfers die putten. In plaats van beginners met hoog vaardige golfers te vergelijken om te kunnen concluderen of in het leerproces om vaardig te worden in putten ‘education of attention’ en/of ‘calibration’ een rol spelen, werden in het hoofdexperiment van deze studie uitgebreide trainingen met uitsluitend toegevoegde feedback gegeven aan beginners ofwel in het verbeteren van de visuele waarneming van de doellijn (perceptuele trainingsgroep) ofwel in het verbeteren van de putrichting (motorische trainingsgroep). De vraag daarbij was of training met dergelijke feedback, het leren door een proces van kalibratie bevordert, en meer in het bijzonder, of er na perceptuele training enige transfer optreedt van perceptie naar actie en omgekeerd na een motorische training van actie naar perceptie. In het eerste experiment werd nagegaan welke hoofdpositie ten opzichte van de doellijn de grootste richtingsfout teweeg brengt in de waarneming van de doellijn. Nadat vastgesteld werd dat de grootste verticale en laterale afstand het meest betrouwbaar de waargenomen richtingsfout voortbracht, werd ervoor gekozen om deze hoofdpositie (1,5 m boven de bal en 1,5 meter naast de bal) als hoofdpositie te kiezen voor het uitvoeren van het tweede en belangrijkste experiment. In dit experiment werd met behulp van een pretest - posttest - retentietest design de gemaakte richtingsfout zowel van de visuele waarneming als van het putten vastgesteld. Tijdens de trainingen kregen de deelnemers van de perceptuele trainingsgroep en de motorische trainingsgroep uitsluitend verbale feedback over de richtingsuitkomst van respectievelijk hun waarneming of putactie. Een derde, controle groep deed in het geheel geen training.

De beide trainingen leidden tot een volkomen verdwijnen van de gemaakte richtingsfouten, maar deze verbeteringen in nauwkeurigheid van richting bleken specifiek te zijn voor de getrainde taak. Er trad dus geen transfer van kalibratie op tussen perceptie en actie en vice versa. Deze resultaten werden in het licht van het theoretische model van twee visuele systemen van Milner and Goodale geduid.
Ten slotte worden in hoofdstuk 6, de epiloog, de theoretische implicaties van de resultaten van de verschillende studies bediscussieerd. Bovendien worden hier suggesties gedaan voor toekomstig onderzoek op het gebied van de visuele waarneming en de motorische actie bij het putten in golf.
Samenvatting
Dankwoord

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Dankwoord
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