

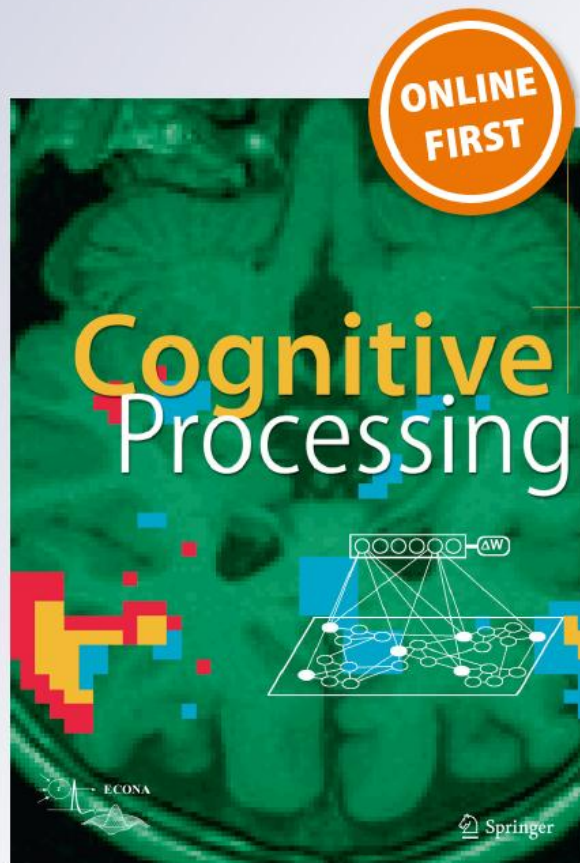
There is more to green reading than meets the eye! Exploring the gaze behaviours of expert golfers on a virtual golf putting task

Mark John Campbell & Aidan P. Moran

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Abstract

4 Gaze patterns and verbal reports of golfers at three skill levels (professional, elite
5 amateur, club) were recorded as they read the slope of a virtual golf green from six
6 different positions. The results showed that the professional golfers used a more
7 economical gaze pattern consisting of fewer fixations of longer duration than the amateur
8 and club players. Gaze pattern were accompanied by verbal reports that were not
9 significantly more accurate in terms of aiming accuracy, although the professionals were
10 accurate on 76.5% of putts compared to 57.1% for the elite and club groups. Two read
11 positions lead to more accurate predictions by the professional golfers only, suggesting
12 distinctive periods of visual perceptual-cognitive attention may underly higher levels of
13 putting skill. Theoretical implications of these results are discussed in relation to the
14 application of visual attention theory to practice, as well as suggestions provided for
15 further research.

16

1 Running Head: EXPERTISE, GREEN-READING, GAZE BEHAVIOUR

2

3 KEYWORDS- Expertise, Slope Perception, Visuo-Motor Planning, Attention, Visual

4 Attention, Eye-tracking

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Introduction

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Expertise in sport, or the growth of specialist athletic knowledge and skills through instruction and experience, has attracted increasing interest from researchers in cognitive science (Bilalic, McLeod & Gobet, 2009; Ross, 2006), cognitive psychology (Kahnemann & Klein, 2009; Rey & Buchald, 2011) and sport psychology (Causser, Holmes, Smith & Williams, 2011; Hodges, Starkes & MacMahon, 2006) in recent years. The upsurge in popularity of this topic is attributable to a combination of theoretical and methodological factors. Theoretically, a significant benefit of studying athletic expertise is that it provides a window on knowledge-based perception. Specifically, studies in this field reveal the role of cognitive processes in mediating the relationship between visual perception and skilled action in dynamic environments characterised by severe time constraints (see the work of Libet, 2004; Müller, Abernethy & Farrow, 2006 for examples).

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Methodologically, the domain of competitive sport (like chess) appeals to expertise researchers because it supplies a wealth of objective rating and ranking systems to facilitate the measurement of skilled performance. In view of these factors, a considerable amount of research evidence has accumulated on expert-novice differences in visual perception in sport (see Hodges et al., 2006; Williams, Davids & Williams, 1999). Typically, studies in this field have employed eye-tracking systems to compare the visual search behaviour of two samples of participants engaged in simulated performance in a given sport (see review by Ward, Williams & Hancock, 2006). These samples comprise “experts” or elite performers and “novices” or relative beginners. Using this

1 group comparison paradigm, investigators have discovered that expert athletes tend to
2 display more efficient search strategies than novices when inspecting sport-specific visual
3 displays in rapid dynamic activities such as soccer (Helsen & Starkes, 1999), tennis
4 (Singer, Cauraugh Chen, Steinberg, & Frehlich, 1996), cycling (Parry, Chinnasamy &
5 Micklewright, 2012), boxing (Ripoll, Kerlirzin, Stein & Reine, 1993) and basketball
6 (Vickers, 1996). Such efficiency is usually evident in characteristic quantitative and
7 qualitative differences between expert and novice groups. Specifically, proficient
8 performers tend to display fewer visual fixations than novices while engaged in their
9 sport skills (e.g., Abernethy, 1990) but these fixations are often of longer duration than
10 those of their less skilled counterparts (Gegenfurtner, Lehtinen & Säljö, 2011)

11 There are also reliable qualitative differences in visual search behaviour between
12 these groups with experts tending to fixate more than novices on “information rich” areas
13 of the visual display in question (Hodges et al., 2006). Taken together, such findings
14 suggest that experts in dynamic sporting domains are capable of extracting more
15 information than novices from a single glance at a pattern relevant to their field even
16 when the dynamic environment is a virtual reality computerised task (Correia, Araujo,
17 Cummins & Craig, 2012). Unfortunately, due to a paucity of relevant research, it is
18 unclear whether this latter finding applies to self-paced skills performed in relatively
19 static environments (e.g., the golf putt) as much as to reactive skills performed in
20 dynamic environments (e.g., the tennis volley). Given this unresolved issue, the purpose
21 of the present paper is to address this gap in the research literature by investigating the
22 visual search patterns of skilled golfers while they perform a crucial but hitherto
23 neglected perceptual skill – namely, “green reading” or trying to determine the slope of

1 the putting surface prior to aiming the ball towards the hole. At this stage, it is important
2 to consider in more detail what this skill of green reading or slope perception involves in
3 the context of golf putting.

4 “Putting”, or attempting to strike the ball along the ground from its resting
5 position into the hole on the green, is one of the most important skills in golf.
6 Specifically, it requires fine motor control, sound technique and precise judgement and
7 accounts for an estimated 41% of all strokes made during an average round of tournament
8 golf (Professional Golfers Association, 2011). But what makes this skill especially
9 difficult to perform successfully is the fact that golf putting greens are never flat surfaces
10 but instead contain built-in slopes and undulations (designed traditionally to facilitate
11 drainage of water off the surface) - many of which are subtle or disguised. Faced with
12 such uncertain terrain, a golfer’s putting performance depends on three skills (MacKenzie
13 & Sprigings, 2005). First, appropriate club-head speed in striking the ball and second, at a
14 biomechanical level, the golfer must ensure that his or her putting stroke will have only
15 horizontal velocity in the chosen target line towards the hole. Finally, and arguably most
16 importantly, accurate perceptual judgement is required when the golfer attempts to
17 predict the proposed path of the putt in relation to the slope of the green. Specifically, the
18 golfer must be able to determine the degree of break or swing in the putt when directing
19 the ball towards the hole across the uneven putting surface.

20 This process of green-reading varies considerably from golfer to golfer but
21 typically takes between 30 and 120 seconds and indeed, golfers themselves highlighted
22 this inspection time as an important pre-requisite to making a good decision on where to
23 aim and subsequent stroke execution (Campbell, 2006). During this period of time,

1 golfers invariably walk around the green and visually inspect the position of the ball in
2 relation to the hole from a number of different angles and positions before making a final
3 decision about the optimal line or aim of the putt and the corresponding force required to
4 execute the shot.

5 Unfortunately, despite its importance in golf, proficiency in green-reading or
6 slope perception has received little or no published scientific attention from researchers.
7 A possible reason for this neglect is that there appears to be little agreement as to the
8 most effective method for assessing the slope of a given golf green (MacKenzie &
9 Sprigings, 2005). Against this background, the purpose of the present paper is to
10 investigate for the first time expertise differences in the gaze behaviour of skilled golfers
11 faced with the task of reading putts.

12 Although golf putting is a complex skill, it can be measured relatively easily in
13 the laboratory. Accordingly, a number of psychological studies have been conducted on
14 various aspects of this skill. For example, research in this field has examined such topics
15 as gaze control and putting (Vickers, 1992; Vine, Moore & Wilson, 2011), the effect of
16 putting grip on eye and head movements (Hung, 2003), mental imagery in putting
17 (Beilock, Afremow, Rabe & Carr, 2001; Short, Bruggeman, Engel, Marback, Wang,
18 Willadsen, & Short, 2002; Kornspan, Overby & Lerner, 2004), vibrotactile sensations in
19 the “feel” of a putt (Roberts, Jones, Mansfield & Rothberg, 2005), attentional processes
20 in putting (Beilock, Carr, MacMahon & Starkes, 2002; Beilock, Wierenga & Carr, 2002,
21 2003; Perkins-Ceccato, Passmore & Lee, 2003), EEG measures of attentional patterns
22 prior to putt execution (Crews & Landers, 1993) and brain imaging of people imagining
23 putting (Ross, Tkach, Ruggieri, Lieber & Lapresto, 2003).

1 Unfortunately, none of these studies has addressed the specific issue of what golfers
2 *actually* look at during their pre-putt routine while they inspect the slope of the putting
3 surface. Faced with such inherent perceptual uncertainties, where golfers have to look
4 and attend to should be a matter of importance and critically has been highlighted as
5 largely ignored but deserving of empirical scrutiny (Craig, Delay, Grealy & Lee, 2000).
6 Indeed, van Lier and colleagues summed it up when they said that "...successful putting
7 entails more than proficient movement control, but requires...skillful perception" (van
8 Lier, van der Kamp & Savelsbergh, 2011, p. 349). Van Lier and colleagues demonstrated
9 that systematic perceptual errors in relation to the direction of a line are made in golf
10 putting and they looked at how golfers overcome this perceptual distortion (2011).
11 Importantly they highlighted the following; 'Before actually executing a putt, it is
12 important for the player to read the green before addressing the ball (i.e. preparing the
13 actual swing'). By reading the green, the golfer can gather information over and beyond
14 information used to control the direction of the swing' (p. 366). Such a strategy they
15 recommend can reduce biases evident in perceived direction of golfers. Finally, they
16 concluded that 'the present results suggest that novices would benefit more ... than high
17 skilled players' (p.366). In a further related study of 407 golfers Pelz (1994) found that
18 'men, women, pros and amateurs, indeed all golfers, consistently and substantially
19 underestimate the amount a putt breaks' (p. 180). This underestimation is realised in
20 golfers missing putts on the 'low' side i.e. the side away from the break or slope.
21 Importantly, Pelz (1994, 2000) posited that golfers have to compensate for this under-
22 read/ underestimation during their preparation of the stroke. The gaze behaviors of

1 golfers may therefore serve an important function of cognitively processing this
2 underestimation with an appropriate compensatory aiming and motor action.

3 Vickers (1992; 2007) has provided some insights into a similar perceptual process
4 – the visual search behaviour of golfers as they stood over the ball, about to strike their
5 putts. Briefly, she explored expert-novice differences in the eye-movements of golfers as
6 they performed a series of golf putts in the laboratory. Results revealed significant
7 differences between these groups in the number and duration of visual fixations displayed
8 during the preparation and executing of the putting action. Specifically, in comparison
9 with the less skilled players, the more expert golfers displayed significantly fewer
10 fixations per putt. Finally, Wilson and Percy (2009) conducted a study examining
11 golfers gaze behaviour in both the preparation (line reading) and execution of putts with
12 different break characteristics as golfers stood over the golf ball ready to address it and
13 execute their putts. They found that the only gaze variable to distinguish between
14 successful and unsuccessful putting outcome was the quiet eye period. This quiet eye
15 period equated to a significantly longer period of gaze fixation immediately prior to onset
16 of putting stroke. Additionally, Wilson and Percy (2009) also found that golfers
17 displayed more aiming fixations on sloped putts than straight putts. This they argued was
18 because of the demands of specifying an abstract target on a sloping putt.

19 Perhaps the most intriguing finding of this study, however, was the discovery that
20 the expert players spent significantly *longer* than their novice counterparts in looking at
21 the target (in this case the golf ball) as the last step before initiating their putting stroke.
22 Vickers (1996) coined the term quiet eye (QE) for this finding and specifically, she used
23 this term to designate a phenomenon whereby sport performers who are aiming at

1 something tend to display a final visual fixation at the target of their aim before executing
2 the relevant motor action (e.g., striking the golf ball towards the hole or throwing the
3 basketball at the hoop). This QE period, which can last from 300 to 2,000 ms depending
4 on the sport, is thought to reflect the performer's attempt to establish cognitive control of
5 relevant visual parameters prior to skill execution. It is also believed to facilitate the
6 "dampening" of unwanted variability in the performer's motor system before task
7 execution (Vickers, 2006; 2007). Perhaps not surprisingly, QE phenomena have been
8 discovered in the performance of aiming skills in other sports such as basketball (Harle &
9 Vickers, 2001; Vickers, 1996), ice hockey (Martell & Vickers, 2004), golf putting
10 (Vickers, 1992), table tennis (Vickers & Adolphe, 1997), billiards (Williams, Singer &
11 Frehlich, 2002), and darts (Vickers, Rodrigues, & Edworthy, 2000).

12 Although Vickers' (1992; 2007) research on golfers gaze behaviours was seminal
13 in the field of expertise and visual perception in athletes, it has at least two key
14 limitations that need to be addressed. First, it was based on data collected from
15 participants while they were executing their skills – not while they were planning them.
16 Indeed, as she noted, we do not "understand ... the manner in which golfers move their
17 eyes about the putting environment" (p. 117). A second limitation of Vickers' (1992)
18 study stems from the number and classification of the participants tested. Specifically,
19 her sample size (n=12) was small and somewhat idiosyncratically defined. To explain,
20 the highly skilled golfers in her study were not "experts" in any conventional sense
21 because their mean handicap (of 6.2) indicated that they played at a proficient rather than
22 excellent competitive level. In an effort to rectify this performer classification problem,
23 *three* groups of golfers will be employed in the present study – two samples of experts

1 (from touring professionals to so called ‘lesser skilled’ experts; elite amateurs) and a
2 group of club-level players. In summary, the purpose of the study was to investigate
3 expertise differences in the visual search behaviour of golfers of different levels of ability
4 as they engaged in a simulated green-reading task.

5

6 Hypotheses

7 Hypothesis 1- With regard to the number of visual fixations per pre-putt position, golf
8 professionals would display least fixations, elite-amateurs would display more, and club
9 players who would display the largest number of fixations.

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11 Hypothesis 2- With regard to the duration of pre-putt fixations, professional golfers
12 would display the longest durations, followed by that of elite-amateurs and finally, by
13 that of club players who would display the shortest fixation durations per position.

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15 Hypothesis 3- With regard to the pre-putt green-reading positions, professional golfers
16 would display longer fixation durations in green-reading positions followed by that of
17 elite-amateurs and finally, by that of club players who display the shortest fixation
18 durations

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20 Hypothesis 4- With regard to accuracy of predicted aim, golf professionals would display
21 greatest accuracy, followed by that of elite-amateurs and finally, by that of club players
22 who would have the least accurate aim predictions.

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Methods

Participants

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The experiment was undertaken with the full voluntary and informed consent of each participant and a full debriefing was given after the testing. No ethical issues were raised by the relevant authorities where the research was conducted. The participants comprised 45 golfers of three different levels of ability and experience: touring golf professionals (most expert), elite amateur golfers (next level of expertise), and club-level amateurs (least expert). The professional group consisted of 17 golfers recruited from the Irish Professional Golfers Association who played full-time on the UK/European professional tours and circuits. They no longer had a handicap as they had earned their playing privileges to compete on a professional tour. These players had a mean age of 24.4 years ($SD=2.91$) with an age range of 18 to 28. The elite amateur group consisted of 14 low handicap golfers recruited from the Golfing Union of Ireland's national training panels. These golfers had a mean age of 23.0 years ($SD=5.53$) and an age range of 16 to 26. Their handicaps ranged from +4 to -2 and their mean handicap was +1.14. The third group consisted of 14 club-level golfers recruited from two local golf clubs. This group had a mean age of 30.78 ($SD=14.34$) and an age range of 15 to 59 years. Their handicaps ranged from 8 to 16 and their mean handicap was 10.29.

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Golf green-reading task

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The aim of this experiment was to measure expert golfers' eye-movements and fixations as they engaged in a dynamic computerised green reading/slope perception task. In the absence of an existing simulation technique to capture expertise in golf green reading, a

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1 virtual three-dimensional, computer generated golf green was designed for this purpose.
2 Based on a series of photographs of a golf putt on a real putting green in a local club, we
3 used 3D Studio Max software (Autodesk, 2006) to create a simulated green and an
4 immersive virtual tour of it. As in real-life, this virtual tour enabled participants to view
5 the golf putt from a number of different angles and positions around the green.
6 Specifically, based on extensive interviews and observational data (Campbell, 2006),
7 participants “toured” the green virtually in a manner similar to the way in which they
8 would inspect a putt in normal field conditions (see Pelz, 2000; Utley & Rudy, 2006 for
9 an elaboration on an optimal green-reading routine and optimal viewing positions). In
10 particular, this virtual tour simulated golfers’ inspection of the putt from six different
11 positions: (i) Crouching down (low) behind the ball looking towards the hole (ii) standing
12 up while looking from the left side halfway between the ball and the hole (iii) crouching
13 down behind the hole while looking towards the ball (iv) standing up behind the hole
14 looking towards the ball (v) standing up looking sideways about half way between the
15 ball and the hole - at the opposite side to the second position and finally, (vi) standing up
16 behind the ball looking towards the hole. For each position, 6 seconds was allowed to
17 facilitate virtual inspection of the ball on the green from each of the six perspectives.
18 However, no time limits were imposed on participants at the decision-making stage at the
19 end of the tour. The participants’ task was to tour the green and make a decision on where
20 they would aim to try to successfully hole the prospective putt. The tour consisted of
21 viewing the putt from six pre-identified positions. In these positions participants had to
22 judge the contours on the green and make a perceptual judgement on how the ball would
23 react over these contours when trying to successfully aim and strike the putt. Prior to the

1 onset of the green-reading task, participants were instructed to view the upcoming putt
2 and make a judgement on *precisely where* they would aim their line - as if they were
3 taking a putt on a golf course. Participants' verbal expressions of their aim were recorded
4 as they viewed the putt from the series of positions. At the end of the final position,
5 participants were asked to indicate their final answer as to where they would aim.
6 Participants were prompted to give an answer that was: "straight"; "left of the hole"; or
7 "right of the hole". They were also required to indicate *how far* right or left their
8 planned aim would be.

9 The optimal line that golfers should have selected was determined to be 15cm
10 right of the hole. This corresponds to an overall slope of 1 degree right to left that was
11 created for the putt. Pelz (1994) calculated that a putt struck at optimal speed with a 0.9
12 degrees of slope needs approximately a break or aim point of 13-cm. Interestingly,
13 gravity has a growing influence during a putt (as the ball slows down on a sloped surface)
14 that there is an accuracy point (in theory) of between 5 and 25 cm that would still be
15 accurate for the putt if golfers can apply the appropriate force. For example, a golfer
16 could still be successful were he to aim only 5 cm to the right of the hole but s/he would
17 need to apply much greater force to keep the ball on this line but not too much for the ball
18 to be going too fast that it would not drop into the hole. Therefore estimates of between 5
19 and 25 cm were deemed as accurate and anything outside of these parameters was
20 deemed as inaccurate (see Figure 3).

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Materials and Apparatus

1 The software program 3 D Studio Max (version 6, autodesk inc, 2006) was used
2 to create a computer simulation of a golf green from digital photographs of a golf green
3 in a well-known golf club in Dublin, Ireland. A Dell Inspiron 5150 Notebook computer
4 was used to present the virtual golf greens to participants using an Avi movie file that
5 consisted of a 1 minute and 20 second video of the computerised virtual tour of the golf
6 putting green. The dynamic tour of the golf green was presented on a 17” colour monitor
7 extending to 28 degrees horizontally and 21 degrees vertically, with resolution set to
8 1280 x 1024. Visual search behaviour was recorded using the EYE-Gaze binocular eye-
9 tracker (LC technologies, 2005).

10 This system has a 120 Hz sampling rate, is accurate to 0.45 degrees and was
11 linked to a PC running at 3.0 GHz with 1 Gb Ram. EYE-GAZE is a video based
12 binocular tracking system that measures the eye line and eye position of gaze. It operates
13 by detecting two features; the pupil and the corneal reflex (reflection of light source from
14 the surface of the cornea) in a video image of the eye. The relative position of these two
15 features is used to compute visual point of gaze. Two infrared eye monitors record
16 displacement data from both pupils and corneas. The data were processed by the PC. The
17 EYE GAZE system is accurate and tolerant to many variations such as pupil drift and
18 head range variation. The typical average bias error is only 0.45 degrees and the gaze
19 point sampling rate is 60-120 Hz. The PC ran a Windows 2000 platform and used
20 “NYAN” software (Interactive Minds, 2005) to analyse eye-movements.

21 The computerised immersive virtual tour was constructed using 3D Studio Max
22 software programme following extensive training to specific co-ordinates. This video file
23 was a computerised re-construction of what was previously identified by golfers and

1 coaches (Campbell, 2006; Pelz, 2000; Utley & Rudy, 2006) as an optimal pre-putt routine
2 on the green as they “read” the putt and tried to judge its slopes.

3 Data were analysed using SPSS v. 16 (SPSS, 2008) running on windows XP.
4

5 Procedure

6 The eye-tracker was calibrated in accordance with standard instructions for the
7 EyeGaze system. This process took about 15 seconds to complete in each case and was
8 necessary to ensure that the eye tracking system was accurately registering the
9 participants’ point of gaze. Specifically, each participant was required to follow a target
10 point (blue dot) in a 9 point grid covering the area of the computer screen. Both eyes
11 were tracked and a pre-determined accuracy level was set with participants having to
12 attain this accuracy level. If they did not do so at the first time of the process, the blue dot
13 simply returned to the area of poor measurement calibration and a re-measurement was
14 done until the accuracy level was achieved and an adequate level of calibration was
15 attained. Calibration itself took about 15 seconds to complete once a satisfactory image of
16 the eye was obtained. Once calibration thresholds were met (within 0.5 degrees on all
17 nine calibration points), presentation of the green reading tour was initiated. In line with
18 previous research (e.g., Moran, Byrne & McGlade, 2002), a visual fixation was defined
19 operationally as a period of time during which the eye remained stationary on a fixed
20 point for 100 milliseconds or longer.

21 Data Analysis

22 Visual search data were collected for each of the 45 participants as they engaged
23 in the green reading simulation task. The first independent variable was the level of

1 expertise of the golfers (i.e., professional, elite amateur and club-level players) and the
2 second independent variable was the green reading position. The dependent variables
3 were two standard indices of visual search behaviour - mean duration of visual fixations
4 and mean number of visual fixations (see Gegenfurtner et al., 2011; Greene, 2006;
5 Williams et al, 1999 for further discussion of these variables). Additionally, a verbal
6 estimate of measurement accuracy, namely, where the golfers indicated where they would
7 aim their prospective putts was recorded and presented in Table 2 below.

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Results

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Hypothesis 1

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A 3x6 repeated measures ANOVA investigated the main effects of expertise status (Independent variable 1; professional, elite amateur and club am golfers) and viewing positions (Independent variable 2; one of six positions, see above) in their effect on the mean number of visual fixations (dependent variable) recorded. Significant

1 differences were observed for position, $F(2, 42)=51.054$; $p < .001$) and status/ expertise
2 level ($F(2, 42)= 7.5$; $p < .002$).

3 Turning to the results observed in Figure 1, significant effects of expertise on the
4 number of visual fixations recorded was evident for three of the six positions used in the
5 virtual tour of the greens. These three positions are position 2 (where the golfer stood up
6 while looking from the left side halfway between the ball and the hole), $F(2, 42)= 4.2$, $p <$
7 $.05$); position 4 (where the golfer stands behind the hole and looks towards the ball), $F(2,$
8 $42)= 4.8$, $p < .05$); and position 6 (where the golfer typically stands behind the ball,
9 looking towards the hole), $F(2, 42)= 3.55$, $p < .05$).

10 A Scheffé post hoc test revealed that the club-level golfers differed significantly
11 from their professional and elite amateur counterparts in mean number of fixations. For
12 example, the club-level golfers displayed significantly more fixations than the
13 professional players in positions 2, 4 and 6 of the virtual tour of the green. More
14 precisely, taking the green reading positions 2, 4 and 6 a trend can be seen in the average
15 number of fixations in the 3 positions. For position 2 there were 20.57 (SD= 3.546),
16 15.64 (SD=3.56) and 16.76 (SD= 3.153) average fixations for the club, elite and pro
17 groups respectively. For position 4 there were 21.21 (SD= 6.63), 15.86 (SD= 4.01) and
18 17.35 (SD= 4.36) for the club, elite and pro groups respectively. For position 6 there were
19 18.7 (SD= 5.07), 15.28 (SD= 2.84) and 14.29 (SD= 3.69) for the club, elite and pro
20 groups respectively.

21 From these data, it seems clear that the less skilled golfers (club-level players)
22 displayed significantly more fixations, on average, than the other two groups in three of

1 the six green reading positions. On average, the club-level players displayed almost 4
2 additional fixations across the green reading positions - lending support to the hypothesis
3 that the club-level group would display a less economical search rate.

4 Hypothesis 2

5 .
6 Again a 3x6 mixed model ANOVA was used to investigate expertise (Independent
7 variable 1; 3 levels - professional, elite amateur and club-level) and viewing position
8 (Independent variable 2; 6 positions – see above) in their effects on mean duration of
9 visual fixations (dependent variable). When looking at the main effects it can be seen that
10 both independent variables had a significant effect on the dependent variable of fixation
11 duration (for expertise status, $F(2,42)= 5.831$, $p< .006$; and for position, $F(2,42)=7.183$,
12 $p< .001$).

13 Following a test of simple effects results observed for the independent variable,
14 expertise status, we see only two positions yielding a significant effect on the dependent
15 variable (fixation duration) out of the six available positions. These effects occurred for
16 position 1 and position 6 (green reading position 1- $F(2, 42)=4.17$, $p< .05$) (green reading
17 position 6- $F(2, 42)=3.9$, $p< .05$). A Scheffé post hoc test was used to find out which of
18 the groups differed significantly from one another and it was found that the club-level
19 players differed significantly from both the professional group and the elite amateur
20 group in terms of overall mean fixation duration. Examining the mean fixation duration
21 in the two significant green reading positions, it is evident that the professional group
22 showed a mean duration of 826.04 m/s, with 969.63 for the elite amateur group and

1 640.57 for the club-level group in position 1. In position 6, the mean duration of
2 fixations for the professional group was 859.63 m/s, with 726.41 for the elite amateur
3 group and 554.98 for the club-level players.

4

5 INSERT FIGURE 2 HERE

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Hypothesis 3

8 Finally, ANOVA was carried out to test for an interaction between area of interest
9 (AOI; where they looked), position and status in terms of the effect on fixation duration.

10 No significant interaction was observed ($F= 1.137$, $p>.05$). Hypothesis 3 was not
11 supported. Of interest perhaps was that the entire sample when looking at their viewing
12 locations spent on average 51.4% of their time fixating in the immediate region of the
13 target area (See Figure 4). 34.8% of the time is spent in the preceding 2 feet leading up to
14 the target and only 13.7% of the time is spent viewing the ball.

15

16 INSERT FIGURE 4 HERE

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Hypothesis 4

19 Verbal estimates of intended aim were categorised as accurate or inaccurate and
20 inferential statistics in the form of a Proportions test were carried out on the data. The
21 hypothesis was not supported with the intended Aim Accuracy between the groups, $\chi^2 =$
22 2.689, $p> 0.05$. Please see Figure 3 for a graph of the accuracy predictions and Figure 5
23 for a graph of mean gaze duration for accurate and inaccurate predictions for positions 1

1 and 6. Proportions test revealed no significant accuracy differences in these two positions
2 in terms of gaze duration $\chi^2 = .594$, $p > 0.05$. Please note that despite not being
3 statistically significant the Pro group were accurate 76.5% of the time compared to 57.1%
4 of the time for both elite am and club am groups.

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6 INSERT FIGURE 3 & 5 HERE

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Discussion

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The present study is the first empirical investigation of expertise and eye-tracking in golf green reading. Extending previous research on expert-novice differences in planning and perception in sport, we suggest that there are significant differences between professional golfers and club-level players in the number and duration of the visual fixations displayed while engaged in the inspection of a golf putt during a virtual tour of a simulated golf green. Specifically, two findings can be highlighted as follows. First, we discovered that the less skilled golfers in our sample displayed significantly *more* fixations than the more expert players in three of the six pre-determined viewing positions on the virtual tour of the golf green. Second, we found that average visual fixation times *increased* among expert players in two of the six pre-determined viewing positions. Taken together, we interpreted these findings to indicate that relative to less skilled performers, expert golfers display distinctive periods of visual cognitive activity while inspecting aspects of the golf putt that they face.

1 In general, these findings are broadly consistent with previous research on expert-
2 novice differences in the perceptual processes of athletes. Specifically, they corroborate
3 Vickers' (1992) speculation that expertise in golf putting is "characterized by economy in
4 the number of gaze shifts" (p. 117) during the stroke planning process. Economical
5 search patterns among expert athletes have also been reported in previous studies with
6 athletes from other sports. For example, Moran and colleagues (2002) found that expert
7 gymnasts and equestrian performers displayed an economical search strategy that was
8 characterised by a relatively low number of short duration fixations and a relatively
9 greater number of longer duration fixations directed at task relevant areas. In relation to
10 planning of skills, Williams et al. (2002) found that skilled billiards players exhibited
11 longer visual fixations on the target during the preparatory phase of their stroke than their
12 less skilled counterparts.

13 In the present study the lesser skilled club level golfers displayed more fixation
14 numbers of shorter duration on average than their more skilled professional counterparts.
15 The expertise and eye-tracking literature has no fixed agreement on whether this is more
16 'expert' like or not. Some authors have reported that experts have more fixations of
17 shorter duration than novices (Konstantanopoulos, 2009; Litchfield, Ball, Donovan,
18 Manning & Crawford, 2008) while others have reported the opposite direction (Bertrand
19 & Thullier, 2009; Vogt & Magnussen, 2007). One ongoing problem with eye-tracking
20 methodology in expertise research is the typically small sample size (Gegenfurtner et al.,
21 2011) and possible sampling error arising from this. The current study with a very large
22 number of participants (N=45) aimed to avoid this traditional problem.

1 The preceding conclusions must be tempered by acknowledgement of certain
2 limitations of our research, however. For example, the green reading task that we used
3 was a computer simulation whose ecological validity is unknown. Perceptual-cognitive
4 judgements can be adversely affected by the demands and/or set-up of the task (Dicks,
5 Button & Davids, 2010). Thus critics may argue that the 3-dimensional software used to
6 create the virtual greens does not mimic adequately the appearance of an actual golf
7 green. The benefits of using a real golf green in a field setting must be balanced against
8 the difficulty and inconvenience of measuring eye-movements in such environments. A
9 second limitation of the present study stems from the fact that we did not address the
10 issue of proprioceptive feedback which walking on a surface can provide about its
11 possible slope. Thirdly, problems arise from the fact that we used a pre-determined
12 sequence of viewing positions in the virtual tour of the green. In reality, considerable
13 individual differences can exist among golfers in pre-putting visual inspection routines.
14 These individual differences are ignored by the use of a standard sequence of viewing
15 positions. In our defence, however, we decided to use a standard 6-step virtual tour for
16 participants because a previous qualitative study (reported in Campbell, 2006) and
17 various coaching instruction books (Pelz, 2000; Utley & Rudy, 2006) had shown that
18 professional golfers tended to favour a consistent pre-putt inspection routine – involving
19 a combination of the six positions that formed the basis of our virtual tour. Turning to
20 suggestions for future research, it is important to explore more precisely the cognitive
21 processes and theoretical mechanisms that underlie the “quiet eye” (QE) effect in target
22 sports. Also it would be very pertinent to examine the gaze behaviour of golfers as they
23 engage in the pre-shot routines and to marry this up with the subsequent skill execution.

1 This way a link can be made between quiet eye findings and earlier visual perceptual-
2 cognitive periods of activity. This could then provide a more robust examination of a
3 complete perception-action cycle in a sensori-motor skill such as golf. Finally,
4 subsequent research may investigate the benefits of a structured visual perceptual training
5 programme or a programme that instructs performers in obtaining knowledge about the
6 type of reading or perceptual errors that they make as this may facilitate adaptive changes
7 in alignment, aiming and shot selection.

8 To summarise, our research provides the first empirical evidence of expertise
9 differences in visual perceptual processes on a simulated green reading task. It also
10 suggests that distinctive periods of visual perceptual-cognitive activity may be evident in
11 athletes' pre-performance routines - as they "toured" the environment in which skill
12 execution was required.

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