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An in-situ examination of cognitive processes in professional and amateur golfers during green reading

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Abstract

Experts consistently display superior performance when compared to less-skilled individuals. This superior performance has been explained using the concept of Long-Term Working Memory that details enhanced recognition and recall processes in expert performers (LTWM; Ericsson & Kintsch, 1995). Research investigating LTWM in sport has often used simplified tasks, such as repeating the same golf putt in a laboratory. Such tasks can fail to capture the entire process of expert performance, often omitting important strategic elements that occur prior to executing a movement. We aimed to capture cognitions of professional and amateur golfers and test predictions based on LTWM using a representative task. We incorporated the entire process of reading a putt, including the walk to the green, which has not previously been investigated. Professional ($n = 12$) and amateur ($n = 12$) golfers walked from the tee box to the green and completed nine ‘holes’ comprising of short, medium, and long putts whilst verbalising their thoughts. Professional golfers performed better than amateurs on all putt lengths. Professional and amateur golfers verbalised similar statements when walking to the green. However, when on the green, professional golfers verbalised more outcome focused planning statements in comparison to the amateur golfers, who focused more on technical execution. Findings enhance our understanding of cognitive expertise in green reading and have implications for the development of green reading skill in golf.

Keywords: cognitive expertise, verbal reports, think aloud.
Introduction

Expertise can be defined as the characteristics, skills, and knowledge that differentiate experts from less-skilled individuals in that specific domain or endeavour (Ericsson et al., 2018). Expert performers have shown superior abilities to attend to domain relevant information, make judgements, and take actions across a variety of domains including, chess (Chase & Simon, 1973; Gobet & Charness, 2006), medicine (Norman et al., 2012; Patel et al., 1997), the military (Janelle & Hatfield, 2008), and sport (Mann et al., 2007; Williams & Jackson, 2019). In the sporting domain there has been considerable focus on perceptual and motor expertise, particularly in time constrained tasks (Runswick et al., 2018; Simonet et al., 2019). However, in self-paced skills that are commonplace in some of the world’s biggest and richest sports, such as golf, key decisions are made in the time prior to movement execution. Golf putting in laboratory environments has been a popular task used to investigate motor control processes involved in executing the putt (Arsal et al., 2016; Beilock & Carr, 2001). However, there is currently a lack of understanding of the cognitive processes at work when both planning (i.e., green reading) and executing a putt on the course.

Previous work investigating golf putting has often tested theories that focus on the automaticity of skilled motor performance (e.g., Fitts & Posner, 1967; Dreyfus & Dreyfus, 1986). These approaches predict that, while learning a skill may require some cognitive control, highly skilled performance involves executing actions retrieved directly from long-term memory without need for conscious control. Consequently, if a skilled performer engages in cognitive control of an action, execution will be less efficient and performance negatively affected (Beilock & Carr, 2001; Masters, 1992). However, the automaticity based account of skilled motor performance focuses on the motor control aspects of the putt itself and does not necessarily consider the other elements that precede the execution of skilled movement. Christensen and colleagues (2016) theorised that more cognitive control is
required for high level aspects of performance. For example, strategic elements such as the process of green reading, compared to lower-level aspects such as controlling mechanisms underlying the execution of the movement. When investigating the process of putting there is a need to consider the strategic elements (e.g., green reading), which could begin on the walk from the previous shot (Colgan, 2020), as well as the motor control elements of the putt itself.

Ericsson and Kintsch's (1995) Long-Term Working Memory (LTWM) proposes that individuals driven to produce skilled performance aim to maintain cognitive control to monitor and improve performance. Through cognitive awareness of a task, performers can engage in deliberate practice activities (Ericsson et al., 2005), and learn to perform skills that use complex cognitive process and an extended working memory known as LTWM. Specifically, LTWM affords highly efficient encoding of information in long-term memory (LTM) and rapid selective retrieval of this information (Ericsson et al., 2000). LTWM facilitates monitoring of cues, the formulation of planning actions, continual evaluation of the present situation, and prediction of future outcomes (Williams et al., 2011). In turn, this allows experts to create enhanced representations of the current situation by facilitating the integration of environmental information with existing representations in LTM.

In sport specifically, an athlete’s ability to perceive critical information in complex environments is crucial for performance (North et al., 2009). Sport performers must be able to identify salient information presented in the environment, focus their attention appropriately, and proficiently extract meaning from these areas (Mann et al., 2019; Williams & Davids, 1998). A considerable amount of research evidence has accumulated on how cognitive processes mediate the relationship between perception and skilled action in dynamic environments. Typically, researchers have adopted some form of the expert performance approach (Williams & Ericsson, 2005) that provides a framework for the systematic study of expert performance. The approach outlines three key stages; capturing
expert performance, identifying underlying mechanisms, and the need to examine how expertise is developed.

The challenge facing researchers examining perceptual-cognitive expertise is to effectively capture performance (stage one) and the underlying mechanisms (stage two) using representative tasks (Harris et al., 2020; Müller et al., 2015). Although performance measures may be straightforward in relatively simple tasks such as race times in running or swimming, the nature of decision-making is difficult to measure in ecologically valid settings. The tendency in the motor behaviour literature has been to design simple and often novel tasks to examine the tenets of the model (e.g., Runswick et al., 2020; Ward et al., 2013). The lack of representative designs has been a key issue in golf green reading literature to date (Carey et al., 2017). For example, researchers have aimed to enhance experimental control by requiring participants to take numerous putts from the same location on an artificial green in a laboratory setting (Beilock & Carr, 2001). This is a situation that cannot occur in a performance environment and encourages unrealistic automaticity in skilled motor performance where golfers may think less about a putt after the first attempt (Arsal et al., 2016). Whilst simple research designs are likely to enhance experimental control, they are unlikely to reveal the complex mechanisms underpinning expert performance (Pinder et al., 2011). To shed light on the complex mechanisms underpinning expert performance, more representative tasks or in-situ designs are needed so that findings can be applied to the real world. Research examining LTWM in green reading should incorporate the second stage of the expert performance approach to measure cognitive processes in a representative task, which incorporates the walk to the green and only a single putt from each location (Arsal et al., 2016).

Research using representative designs may enhance measurement validity, increasing the possibility of detecting meaningful differences between experts and novices (Mann et al.,
However, much of the work investigating cognitive expertise is criticised for the true lack of ‘expert’ samples (Swann et al., 2015) and the low sample sizes used in expert groups (Schweizer & Furley, 2016). Stronger samples of ‘competitive’, ‘successful’, and ‘world-class’ elites are required. In golf, while handicaps can vary based on the difficulty of the players home course, they do offer a clear insight into the quality of samples. Previous ‘expert’ or ‘more-skilled’ groups have regularly been populated by low-handicap (e.g., 0-5) club golfers who would likely not be classed above semi-elite (Swann et al., 2015).

Work attempting to access key mechanisms that underpin performance in skilled samples has regularly utilised think aloud protocols and verbal reports (see Eccles, 2012; Eccles & Arsal, 2017) to compare the cognitions of expert and novice performers in virtual (Calmeiro & Tenenbaum, 2011; Ericsson, 2006) and occasionally in-situ environments (Whitehead et al., 2018). Studies employing verbal reports to investigate anticipation and decision-making, have shown that experts tend to use more statements linked to higher order cognitive processes such as planning, prediction and evaluation (McRobert et al., 2011; North et al., 2009; Runswick et al., 2018; Williams, 2011). Research in golf has suggested that skilled golfers verbalise more about pre-shot planning (e.g., the type of shot most appropriate for a situation), whereas less-skilled golfers focus more on the technical elements of playing a shot (e.g., how to move the club to play the shot; Calmeiro & Tenenbaum, 2011; Whitehead et al., 2015).

This ability of skilled performers to engage in planning and prediction is particularly important in putting, which is itself one of the most important aspects of golf performance (Pelz, 2000). During putting, the ball remains on the ground, meaning there is significantly more complexity in understanding the impact of the course on the ball compared to other shots where the ball travels through the air. This creates a complex task to predict where the ball will roll due to slopes on the green and planning how to execute the shot to account for
This process is known as ‘green reading’\(^1\). In a study that aimed to test predictions of automaticity and cognitive control accounts (LTWM) of expert performance, Arsal et al. (2016) explored thoughts verbalised from more and less-skilled golfers from the time a participant began to consider making a putt through to putter-ball contact. Findings showed that not only did the more skilled players verbalise more for longer (i.e., more complex putts), they also verbalised more strategy related thoughts when taking the first putt from a new location, suggesting that they were engaging in green reading despite being in a lab environment.

Despite its complexity and importance, and the processes that have been identified in previous empirical work (e.g., Arsal et al., 2016), relatively little literature has focused on green reading specifically. Campbell and Moran (2014) tested 45 golfers (tour professionals, elite amateurs, and club amateurs) in a virtual environment and recorded gaze behaviour as they read the slope of a virtual green. Results supported the tenets of LTWM. In comparison with amateurs, professional golfers displayed more guided search with fewer fixations of higher duration and were more accurate at hitting the line they reported to be aiming for. While this study recorded some basic verbal reports, these only included a statement of the line the players had chosen to aim for and did not elicit detailed cognitive processes. Furthermore, this study employed a virtual green that does not allow the performer to approach the hole from a distance (e.g., walking to the green) nor move around the hole and interact with the environment; processes that have been identified as important anecdotally by elite players (Colgan, 2020), and vital to inducing realistic cognitions in this context (Araújo et al., 2019).

\(^1\) Green reading has been defined as “trying to determine the slope of the putting surface prior to aiming the ball towards the hole” (Campbell & Moran, 2014, p. 364).
Despite the significant body of literature that has investigated cognitive control using verbal reports in sport, direct comparison of findings across this work is often challenging due to the difference in schemes used to code the data. For example, Arsal et al. (2016) produced an eight category scheme when investigating golf putting that differed from the eight category scheme used by Calmeiro and Tenenbaum (2011) and subsequently applied in golf research by Whitehead et al. (2016) and Birch and Whitehead (2019). Analysing verbal report data inductively can produce categories for a specific data set but dilute the ability to gain an overall understanding of the cognitive processes at work in the given task. Other work investigating LTWM in sport has employed the four coding categories proposed by Ericsson and Simon (1993) and this has allowed for simple comparison of LTWM in action across different sports (e.g., McRobert et al., 2011; North et al., 2009; Runswick et al., 2018). However, this approach can dilute the practical utility of findings for those involved in the sport. More recently, Runswick et al. (2018) employed an approach when analysing verbal reports in cricket where the data were coded twice. Once using Ericsson and Simon’s (1993) framework to allow for clear comparison with other LTWM findings regardless of the skill being tested, and once with a sport specific framework that enhances utility and understanding within the sport and skill. This approach allows for clearer comparison to other work investigating LTWM, other research in the specific sport, and provides more practical utility for practitioners in the sport.

In this study we aimed to investigate cognitions during green reading in golf using a representative task by capturing cognitions of both professional and amateur golfers walking to the green and reading different lengths of putt on a real golf hole. Using the expert-performance approach as a guiding framework, we validated the task to capture expertise through measuring putting performance and recorded verbal reports to capture a mechanism underpinning performance. We analysed the verbal reports using two different coding...
schemes to test predictions of both LTWM theory (Ericsson & Kintsch, 1995) and the sport specific literature. Based on the predictions of LTWM that expert performers will maintain cognitive control over differing task conditions, and the empirical findings of Arsal et al. (2016) where verbalisations increased with the complexity of the task, we predicted that professional golfers would display superior performance by taking fewer putts than amateurs at all lengths and the number of putts and verbalisations would increase with putt length. As LTWM allows experts to create enhanced representations of the current situation by facilitating the integration of environmental information with existing representations in LTM, it also offers less explicit predictions on the nature as well as the number of verbalisations. The amateur performer could verbalise an equal number of thoughts related to the slopes on the green because monitoring statements do not require the enhanced link with LTM. However, integrating this information with existing mental representations in LTM does. Therefore, we predicted that, in comparison to the amateur golfers, professional golfers would make more higher order statements relating to i) predictions of putt break (i.e., how the slope of the green impacts the path of the ball), ii) plans for the upcoming shot and, iii) evaluation of executed putts (e.g., McRobert et al., 2011). Based on the findings from golf specific literature (Calmeiro & Tenenbaum, 2011; Whitehead et al., 2015) and predictions of Christensen et al. (2016), we also predicted that professional golfers would elicit i) more verbalisations relating to planning the putt, and, ii) fewer verbalisations relating to the technical execution of the putt in comparison to amateurs. Given the need to examine higher-level aspects of controlling mechanisms that occur prior to movement execution (Christensen et al., 2016) and anecdotal reports that the putting process can begin on the walk to the green (Colgan, 2020), we also captured verbal reports of golfers walking to the green to establish if this should also be considered as part of the overall putting process.
Method

Participants

The professional group were 12 male tour professional golfers (age: $M = 27.3$, $SD = 6.99$; years professional experience: $M = 4.5$, $SD = 2.71$; scoring average: $M = 70.88$, $SD = 1.58$) who actively competed within the previous month on their respective golf tours (European Challenge Tour, Euro Pro Tour, MENA Tour, Jamega Golf Tour). According to Swann et al.’s (2015) expertise calculation, the professional group can be defined as ‘successful elite’. The amateur group were 12 amateur golfers (age: $M = 23.08$, $SD = 4.25$; male = 10, female = 2; handicap: $M = 12.08$, $SD = 4.11$) who regularly competed in club competitions. A priori power analysis was conducted using G*power (Faul et al., 2007). Due to our interest in the interaction between expertise and cognitive control, we targeted the within-between interaction in a repeated-measures ANOVA and based our calculations on the group by statement type interaction effect size ($\eta_p^2 = 0.24$) reported by Runswick et al. (2018) who elicited verbal reports from skilled and less-skilled performers in a cricket task and used a moderate correlation amongst repeated measures ($r = 0.3$). Due to issues cited in the literature relating to underpowered samples due to difficulty in recruitment (Schweizer & Furley, 2016), we used a power of 0.95. The total sample size required across two groups was $n = 24$. The research was conducted in accordance with the ethical guidelines of the lead institution and written informed consent was obtained from all participants at the outset.
Golf green-reading task

Data were collected on a 91.44 m par three golf hole on an 18-hole championship golf course in Southern England. The green used was 28.35 m long and 20.12 m wide, equating to 570.40 m². The pace of the green was measured at 9 on the Stimpmeter (4 uphill and 14 downhill; this is a severe slope, making this a challenging green). The total amount of feet the ball rolls from the Stimpmeter gives an approximation as to the pace of the green. The green had three holes which afforded three putt lengths at each hole; short (1.52 m), medium (3.05 m) and long (4.57 m; Campbell & Moran, 2014; Figure 1). Hole 1 was positioned 9.14 m from the top edge of the green and 5.49 m from the right edge. The short putt moved right to left across the slope, the medium putt was straight uphill, and the long putt was downhill and moved left to right across the slope. Hole 2 was positioned 10.06 m from the top edge of the green and 5.49 m from the left edge. The short putt moved left to right across the slope, the medium putt
was uphill and moved right to left across the slope, and the long putt was downhill and moved right to left across the slope. Hole 3 was positioned 7.32 m from the bottom edge of the green and 10.06 m from the right edge. The short putt was uphill and moved right to left across the slope, the medium putt moved left to right across the slope, and the long putt was downhill and moved left to right across the slope. Participants used their own putter and golf balls and regulation size golf holes were used (0.11 m in diameter). In line with the recommendations of Carey et al. (2017), the task was designed specifically to resemble putts during a round of golf, including uphill, downhill, right to left and left to right sloping putts.

**Procedure**

Participants were instructed to verbalise their thoughts for all trials of the green reading task, including the walk from the tee to the green. To capture level 1 and/or 2 verbalisations, participants were instructed to report on their cognitive processes as they experienced them (Ericsson & Simon, 1980). Participants were instructed on how to verbalise their thoughts using a training video\(^2\). In line with Ericsson and Simon's (1993) guidelines, a number of exercises were used to guide the process of verbal reporting, including: a) counting the number of dots on a page; b) arithmetic exercises; and c) an anagram problem-solving task. Task-specific training exercises adapted from Birch and Whitehead (2019) were also used to familiarise participants with verbalising their thoughts in a golf context, including three different hypothetical golf scenarios (tee shot on a par 5, fairway shot on a par 5, greenside approach shot over a bunker). Participants then completed three practice putts to familiarise themselves with verbalising their thoughts whilst putting. The putts were different to those used in testing. During this time, the researcher ensured the participant was competently verbalising their thoughts in line with the instructions given in the training video. Failure to competently verbalise one’s thoughts, explaining or justifying decision making (i.e., level 3 reports), or

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\(^2\) The training video can be accessed upon request.
making verbalisations that were not part of the task at hand (e.g., asking questions about the protocol) resulted in the researcher providing feedback and the participant repeating the training scenarios. Data collection did not take place until the researcher was satisfied with the quality of verbalisation. The verbal report training lasted approximately 20 minutes.

After completing the training video and the three practice putts, participants were directed to the tee box. Once on the tee box, participants were instructed that there were nine locations on the green to putt from, all of which were marked by a tee peg, and were then told which putt they would complete first. When the participant was clear on their starting putt, they were asked to walk from the tee box to the green (approximately 91.44 m) as if they had hit that shot when playing a round of golf. Participants were allowed to start reading the green and verbalising as soon as they started walking towards the green. No time constraints were implemented and participants could move freely around the green. Thus, some participants elected to walk straight onto the green and to the first putt location whilst others elected to survey the green more generally before approaching the first putt location.

Participants were instructed to include any normal routines they may have and not to change or add to any processes that they typically adopt. Participants verbalised their thoughts throughout all trials, apart from when they were executing a putting stroke (moving the putter in the putting stance in an attempt to strike the ball), to reduce possible interference with motor control (Schmidt & Wrisberg, 2000). To capture reactive or evaluative comments about the putt, verbalisation started again immediately after the movement was complete (often while the ball was rolling to the hole). Each putt location was completed when the ball was holed and any reactive or evaluative comments relating to the previous putt had stopped. At this point, participants ceased verbalising their thoughts while the researcher indicated the next putting location. Once participants had verbally acknowledged they were clear on the next putting location they were asked to continue to verbalise their thoughts for the next putt.
Participants were required to complete a total of nine holes in as few strokes as possible, one from each of the putting locations in a random order (Figure 1). This represents the amount of putting a player would complete in half a round of golf and utilising one putt per location enhances the representative nature of the task that has been missing in previous work (see Arsal et al., 2016). This was repeated in a random order for all nine putts. Participants were not told how to approach the putt or how to start their pre-putting routine. However, to uphold ecological validity, participants were required to follow regulations when on the green (i.e., marking their ball). In line with our efforts to make the testing environment as representative as possible (e.g., single putts on a real green), we also acknowledged the fact that no putt in competition is ever taken in the absence of context or of a playing partner who is required to mark their score. Therefore, to represent scenarios players would be familiar with on the course, the professional group were told each putt was for a birdie and the amateur group were told each putt was for a par and all participants were told that their scores would be shown to their respective skill group. If participants were silent for longer than 10 s they would be reminded to verbalise all of their thoughts (Whitehead et al., 2016). Verbalisations were captured using an iPhone and iPhone headphones.

Pilot Study

The pilot study consisted of one moderately skilled golfer (8 handicap, 12 years competitive experience) who completed the full procedure. The participant was confident that the training enabled him to understand how to competently verbalise his thoughts and stated that the equipment did not hinder his performance.

Dependent Measures and Data Coding

Performance.
Putting performance was measured by strokes to complete each hole location. Mean scores were then calculated for each player for each of the three putt lengths (short, medium and long; Figure 1).

**Verbal Reports.**

Verbal reports were transcribed verbatim. During data collection participants verbalised continuously and ranged from a total of 8.13 minutes to 26.11 minutes with an average verbalisation time of 16.09 minutes (including breaks when being explained the next putt location). This produced 85 pages of participant transcripts. Verbalisations were coded from the moment the participant was clear on the next hole position through to the point at which the researcher instructed them on the location of the next putt. However, in order to control for the number of putts taken to complete each hole and to ensure we were able to compare verbalisation for the different length putts, only verbalisations from the first putt for each hole were included in the analysis. The end of the first putt was identified as the point between any reactive comments from the first putt and the first comment relating to the next putt. Verbal reports were coded using two different schemes to investigate both general cognitive processes seen in expertise research more broadly and processes specific to sport (see Runswick et al., 2018). Firstly, Ericsson and Simon’s (1993) four category framework focussing on general cognitive processes was adopted. We have termed these *cognitive verbalisations* (Table 1).
Secondly, verbalisations were coded according to the *sport specific verbalisations* coding scheme consisting of eight categories developed by Calmeiro and Tenenbaum (2011), subsequently applied in golf research by Whitehead et al. (2016) and Birch and Whitehead (2019), as well as other sports such as Australian Rules Football (Elliot et al., 2020; Table 2).

**Table 1. Cognitive verbalisations coding framework (Ericsson & Simon, 1993)**

<table>
<thead>
<tr>
<th>Theme</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monitoring</td>
<td>Recalling descriptions of current events and current actions</td>
</tr>
<tr>
<td></td>
<td>‘All sloping down to the gate’</td>
</tr>
<tr>
<td>Planning</td>
<td>Potential decisions on a course of action to anticipate an outcome event</td>
</tr>
<tr>
<td></td>
<td>‘Needing to aim left here’</td>
</tr>
<tr>
<td>Prediction</td>
<td>Anticipating or highlighting possible future events</td>
</tr>
<tr>
<td></td>
<td>‘It’s going to turn downhill’</td>
</tr>
<tr>
<td>Evaluation</td>
<td>Making some form of comparison, assessment or appraisal of events that</td>
</tr>
<tr>
<td></td>
<td>are situation-, task-, or context-relevant</td>
</tr>
<tr>
<td></td>
<td>‘Ah that’s too much’</td>
</tr>
</tbody>
</table>
Inter-rater reliability (IRR). Each transcript was read through for familiarisation and assessed for relevance and consistency before line-by-line deductive content analysis (Maykut & Morehouse, 2002) as employed by Whitehead et al. (2015). Verbalisations from the participants were broken into separate statements (i.e., ‘this will move right to left’). The first author and an independent researcher analysed a 50% sample of the data independently. IRR agreements of 83.07% and 83.25% were found for cognitive verbalisations and sport specific verbalisations, respectively. As IRR agreements were above 80% data were deemed reliable (Hallgren, 2012). The remaining statements were discussed between raters and both raters came to an agreement. For example, ‘planning’ and ‘technical instruction’ in Calmeiro and Tenenbaum’s (2011) scheme could be hard to distinguish between as one researcher may think that the participant is verbalising about technique where the other researcher perceived

<table>
<thead>
<tr>
<th>Theme</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gathering information</td>
<td>Participants’ search for relevant characteristics of the environment</td>
</tr>
<tr>
<td></td>
<td>‘A lot steeper than I thought’</td>
</tr>
<tr>
<td>Planning</td>
<td>Actions or strategies to reach a goal</td>
</tr>
<tr>
<td></td>
<td>‘Maybe a putter head above’</td>
</tr>
<tr>
<td>Mental readiness</td>
<td>Psychological preparation for the task</td>
</tr>
<tr>
<td></td>
<td>‘Let’s nail this’</td>
</tr>
<tr>
<td>Technical instruction</td>
<td>Technical aspects of the motor performance</td>
</tr>
<tr>
<td></td>
<td>‘About half a swing’</td>
</tr>
<tr>
<td>Description of outcome</td>
<td>What had happened as a result of the action</td>
</tr>
<tr>
<td></td>
<td>‘Left it halfway’</td>
</tr>
<tr>
<td>Diagnosis of outcome</td>
<td>Reasons for the observed outcome</td>
</tr>
<tr>
<td></td>
<td>‘Rammed that one’</td>
</tr>
<tr>
<td>Reactive comments</td>
<td>Reactive comments to performance</td>
</tr>
<tr>
<td></td>
<td>‘You are crap, mate’</td>
</tr>
<tr>
<td>Other</td>
<td>Does not fit in other themes</td>
</tr>
<tr>
<td></td>
<td>‘Get in the hole’</td>
</tr>
</tbody>
</table>
verbalisations to be about a course of action. When researchers had coded the same statement in different categories, such issues were described in the context of the rest of the verbalisation and a final code was agreed.

**Statistical Analysis**

In line with the body of literature using TA in sport (e.g., Arsal et al., 2016; Calmerio & Tenenbaum, 2011; Nicholls & Polman, 2008; Whitehead, et al., 2016) a post-positivist epistemology informed this study. A two-way mixed design analysis of variance (ANOVA) was used to analyse the effects of group (professional, amateur) and putt length (short, medium, and long) on performance. Separate two-way mixed design ANOVA was used to analyse the effects of group (professional, amateur) and statement type on verbalisations when walking to the green. Given that participants only walked to the green once (i.e., before the first putt), it is important to note that only one data point was captured per participant for the walking to the green analyses. Separate three-way mixed design ANOVA was used to analyse the effect of group, putt-length, and statement type for verbal reports. A Bonferroni adjustment was used for multiple comparisons to analyse where differences were between groups; it also lowered the likelihood of getting a significant result due to many comparisons (McLaughlin & Sainani, 2014). The assumption of Sphericity was checked for each analysis. Partial eta squared ($\eta^2_p$) was used to measure effect sizes for all ANOVA analyses with Cohen’s d used for pairwise comparisons. We set an alpha level ($\alpha$) of 0.05. As a result of recent discussions surrounding the use of significance testing broadly (Wasserstein et al., 2019) and specifically in expertise research (Campitelli, 2019), we avoid the term ‘significant’ in the description of the data. Raw data for this study is available via the link in the open practices statement.

**Results**
Putting performance

**Main Effects.** There was a main effect of group on putting performance ($F_{1, 22} = 4.484$, $p = 0.046$, $\eta_{p}^{2} = 0.169$; Figure 2). The professional group ($M = 2.02$, $SD = 0.42$) took fewer puts per hole than their amateur counterparts ($M = 2.22$, $SD = 0.37$). There was also a main effect of length on putting performance ($F_{2, 21} = 21.981$, $p < 0.001$, $\eta_{p}^{2} = 0.500$). Participants took fewer puts in short length ($M = 1.74$, $SD = 0.52$) compared to both the medium ($M = 2.11$, $SD = 0.32$, $p = 0.049$, $d = 0.86$) and long ($M = 2.51$, $SD = 0.38$, $p < 0.001$, $d = 1.69$) putts. Participants also took fewer puts from the medium compared to the long length ($p < 0.001$, $d = 1.14$).

**Interactions.** There was no group × length interaction ($F_{2, 21} = 0.747$, $p = 0.480$, $\eta_{p}^{2} = 0.033$; Figure 2). Professional players did take fewer strokes at short ($M = 1.69$, $SD = 0.62$ vs $M = 1.78$, $SD = 0.41$; $d = 0.17$) and particularly medium ($M = 2.03$, $SD = 0.33$ vs $M = 2.19$, $SD = 0.30$, $d = 0.51$) and long putts ($M = 2.33$, $SD = 0.28$ vs $M = 2.69$, $SD = 0.38$, $d = 1.10$).
**Figure 2.** Mean putts per hole for short, medium, and long putts for professional (Pro) and amateur (Am) golfers with individual data points and standard error bars.

**Cognitive Verbalisations**

**Walk to the Green.**

*Main Effects.* There was no main effect of group on the number of statements verbalised on the walk to the green ($F_{1, 22} = 0.007, p = 1.000, \eta_p^2 = 0.001$). There was an effect of statement type ($F_{3, 20} = 64.628, p < 0.001, \eta_p^2 = 0.746$). Post hoc comparisons revealed that participants verbalised more statements relating to monitoring ($M = 4.08, SD = 2.06$) compared to planning ($M = 0.67, SD = 0.92, p < 0.001, d = 2.14$), prediction ($M = 0.54, SD = 0.83, p < 0.001, d = 2.25$), and evaluation ($M = 0.04, SD = 0.20, p < 0.001, d = 2.76$). There were also fewer evaluation statements compared to planning ($p = 0.018, d = 0.95$) and prediction ($p < 0.05, d = 0.83$) with no difference between planning and prediction ($p = 0.015, d = 0.15$).
Figure 3. Total number of statements from cognitive verbalisation analysis for professional (Pro) and amateur (Am) golfers when, a) walking from the tee box to the green, b) reading short putts, c) medium putts, and d) long putts. Individual data points and standard deviation bars are displayed.

Interactions. There was a group × statement type interaction ($F_{3, 20} = 4.073, p = 0.010$, $\eta_p^2 = 0.156$; Figure 3A). The professional group verbalised more statements relating to monitoring ($M = 4.7, SD = 1.86$) compared to the amateurs ($M = 3.42, SD = 2.11, d = 0.67$), who themselves verbalised more planning ($M = 0.92, SD = 0.90$ vs $M = 0.42, SD = 0.90, d = 0.56$) and prediction ($M = 0.92, SD = 0.99$ vs $M = 0.17, SD = 0.39, d = 1.08$).
On the Green.

**Main Effects.** There was no main effect of group on the number of statements made per putt ($F_{1, 22} = 1.004, p = 0.327, \eta_{p}^2 = 0.044$). There was a main effect of putt length on the total number of statements made ($F_{2, 21} = 11.575, p < 0.001, \eta_{p}^2 = 0.345$) whereby participants made more statements when reading long putts ($M = 8.17, SD = 4.26$) compared to short ($M = 5.96, SD = 3.20, p < 0.001, d = 0.59$) and medium ($M = 6.74, SD = 3.59, p = 0.008, d = 0.36$) putts. There was a main effect of statement type ($F_{3, 20} = 35.553, p < 0.001, \eta_{p}^2 = 0.618$) with participants making more statements relating to monitoring ($M = 10.25, SD = 4.88$) compared to prediction ($M = 3.15, SD = 2.35, p < 0.001, d = 1.85$) and evaluation ($M = 5.72, SD = 3.06, p < 0.001, d = 1.11$). More statements relating to planning ($M = 8.69, SD = 4.64$) compared to prediction ($p < 0.001, d = 1.51$) and more statements relating to evaluation than prediction ($p = 0.001, d = 0.94$) were observed.

**Interactions.** Interaction effects are displayed in Figure 3, showing individual data points, means, and standard deviations for each group and verbalisation type across the putt lengths. There was no statement type × group interaction ($F_{3, 20} = 2.206, p = 0.096, \eta_{p}^2 = 0.295$). Professional players made a similar number of monitoring statements ($M = 10.58 \pm 5.21$) compared to amateurs ($M = 9.92, SD = 4.48, d = 0.16$) but made more relating to prediction ($M = 3.39, SD = 2.26$ vs $M = 2.92, SD = 1.98, d = 0.22$) and particularly planning ($M = 10.25, SD = 4.87$ vs $M = 7.14, SD = 3.95, d = 0.70$). There was a putt length × statement type interaction ($F_{6, 17} = 2.545, p = 0.023, \eta_{p}^2 = 0.104$) where the number of all statement types increased with longer putts. There was no putt length × group interaction for the number of statements ($F_{2, 21} = 1.417, p = 0.253, \eta_{p}^2 = 0.060$). Finally, there was no three-way putt length × statement type × group interaction ($F_{6, 17} = 0.408, p = 0.873, \eta_{p}^2 = 0.018$).

**Sport Specific Verbalisations**
Walk to the Green.

**Main Effects.** There was no main effect of group on the number of statements verbalised on the walk to the green ($F_{1, 22} = 0.007, p = 0.936, \eta_p^2 < 0.001$). There was an effect of statement type ($F_{7, 16} = 85.167, p < 0.001, \eta_p^2 = 0.795$). Post hoc comparisons revealed that participants verbalised more statements relating to gathering information than all other categories (all $p$’s < 0.001; Figure 4A). There were also more statements related to planning ($M = 0.88, SD = 0.94$) than description ($p = 0.047$) or diagnosis ($p = 0.047$) of outcome which had no statements made.

**Interactions.** There was a group × statement type interaction ($F_{7, 16} = 9.489, p < 0.001, \eta_p^2 = 0.301$; Figure 4A). The professional group verbalised more statements relating to gathering of information ($M = 4.67, SD = 1.25$) compared to the amateurs ($M = 3.00, SD = 1.22, d = 1.35$), who themselves verbalised more planning statements ($M = 1.67, SD = 1.60$ vs $M = 0.88, SD = 0.28, d = 1.38$).

On the Green.

**Main Effects.** There was no main effect of group on the number of statements made per putt ($F_{1, 22} = 1.555, p = 0.225, \eta_p^2 = 0.066$). There was a main effect of putt length on the total number of statements made ($F_{2, 21} = 6.490, p = 0.003, \eta_p^2 = 0.228$) whereby participants made slightly more statements when reading long putts ($M = 3.83, SD = 2.30$) compared to short ($M = 2.98, SD = 1.88, d = 0.40$). There was a main effect of statement type ($F_{7, 16} = 68.760, p < 0.001, \eta_p^2 = 0.758$) with participants making more statements relating to gathering information and planning compared to all other statement types (all $p$’s < 0.001; Figure 4) and more technical statements compared to description, diagnosis, mental preparation, and other (all $p$’s < 0.05).

**Interactions.** Interaction effects are displayed in Figure 4, showing individual data points, means, and standard deviations for each group and verbalisation type across the putt
lengths. There was a statement type × group interaction ($F_{7, 16} = 5.325, p < 0.001, \eta^2_p = 0.195$). Professional players made more planning statements ($M = 8.81, SD = 4.30$) compared to amateurs ($M = 5.36, SD = 2.57, d = 0.97$) who in turn made more statements relating to technical instruction ($M = 4.53, SD = 2.73$ vs $M = 2.64, SD = 2.28, d = 0.75$). There was no putt length × statement type interaction ($F_{14, 9} = 1.538, p = 0.096, \eta^2_p = 0.065$). There was no putt length × group interaction for the number of statements ($F_{2, 21} = 0.666, p = 0.519, \eta^2_p = 0.029$). Finally, there was no three-way putt length × statement type × group interaction ($F_{14, 9} = 1.538, p = 0.143, \eta^2_p = 0.061$).
Figure 4. Total number of statements from golf specific verbalisation analysis for professional (Pro) and amateur (Am) golfers when, a) walking from the tee box to the green, b) reading short putts, c) medium putts, and d) long putts. Individual data points and standard deviation bars are displayed.
Discussion

One of the key issues in investigating cognitive expertise in domains such as golf has been the lack of research in representative environments (Carey et al., 2017; Müller et al., 2015). In this study we investigated expert cognitions during green reading in golf using a representative task. We applied the expert-performance approach as a guiding framework and tested predictions of LTWM theory (Ericsson & Kintsch, 1995). Consistent with our hypotheses, this task was able to capture expert putting performance. Professional golfers took fewer putts than amateurs on short, medium, and long putts, while accuracy decreased with distance from the hole. Furthermore, participants verbalised more statements as putt length, and therefore complexity, increased. These findings serve to validate the representative nature of the task and build on previous work examining cognitive processes in green reading by including real world performance of the task in question (Campbell & Moran, 2014). It should be noted this putting performance score does not directly assess green reading, but instead measures performance of a task where green reading is required to be successful, without adding additional elements that take away from what would happen in normal play.

Once expert performance has been captured, stage two of the expert performance approach is to gather information on the mechanisms that underpin the superior performance. Here, we utilised concurrent verbal reports to capture such mechanisms and used two different coding frameworks to both maintain practical utility for golf and allow direct comparison with previous work investigating LTWM. In partial support of our hypothesis (using the cognitive verbalisations coding framework), professional players verbalised more statements relating to prediction and planning compared to amateurs when reading on the green but did not make more evaluative statements. This finding supports the predictions of
LTWM regarding superior recognition of pertinent information leading to recall of memory structures that allow for planning and prediction based on experience. These findings are also consistent with previous empirical work that has coded verbal reports in this fashion when investigating expertise in other sports (McRobert et al., 2011; North et al., 2009; Runswick et al., 2018). However, rather than professionals producing more evaluations, here the amateur players also verbalised a large number of evaluation statements. This is perhaps a function of the task and nature of the coding system where golfers often responded to the outcome of the putt but not always in a functional way (see Table 1). It is possible that previous work using only the simplified coding scheme can miss out on this kind of sport specific nuance in the data and in fact evaluations may not always be higher-order cognitions.

The findings are also directly comparable to those of Arsal et al. (2016) who tested predictions of LTWM in more and less-skilled putting from different lengths on an artificial putting green. The skilled group in the present study were professional players, so were more skilled than those in Arsal et al. who recruited low handicap amateurs ($M$ handicap = 4). Similarly, the less-skilled group in the current study were slightly more skilled ($M$ handicap = 12) than Arsal et al. ($M$ handicap = 23). The putt lengths here were 1.52 m, 3.05 m, and 4.57 m, whereas Arsal et al. used 1 m and 2 m putts. Both studies supported the predictions of LTWM in that more cognitive control was evident in longer and therefore more complex putts. In line with LTWM predictions, the more skilled sample in the current study produced slightly more verbalisations ($M = 5.96$) in the 1.52 m putt than Arsal et al. did in the 2 m putt ($M = 5.30$). Furthermore, in the current study, using a real green, golfers verbalised more statements on average across the different putt lengths, suggesting the increase in complexity from using a real (and challenging in this case) green may cause an increase in cognitive control. While Arsal et al. found both a main effect of putt length and a putt length by group interaction for the number of verbalisations, the present study found only a main effect of
length and no interaction. However, in this present study, professional players did report more statements relating to planning and prediction. Clear replications are often lacking in expertise research; it is promising to see similar findings across these two studies. Future replication would facilitate the pooling of findings across studies and begin to predict the number of cognitions that will be made for certain types of putt by certain types of player.

When using the sport specific framework, the data also supported our hypothesis that professional players would verbalise more statements relating to planning (e.g., where to hit the putt) whereas the amateurs verbalised more statements relating to planning technical aspects (e.g., how to hit the putt). These findings show the value in producing sport specific coding frameworks to elicit more specific detail and suggest that when planning statements are further broken down to differentiate between strategic planning and technical instruction, we see changes in how expertise underpins specific planning orientated cognitions of golfers. Like Arsal et al. (2016), these findings also clearly replicate those found previously in other golfing scenarios (Calmeiro & Tenenbaum, 2011; Whitehead et al., 2015), and extend this understanding using higher skilled participants in a more representative task. We also offer support for Christensen et al.’s (2016) proposal that more cognitive control is required in strategic elements of performance compared to lower-level aspects of controlling execution of the movement.

We sought to further examine anecdotal reports by players (Colgan, 2020), which have suggested that the green reading process begins when the walking to the green. In both types of analysis, professional and amateur players verbalised a similar number of statements relating to monitoring and gathering information when walking to the green. These findings support previous work that has suggested skilled golfers go through substantial information gathering prior to shot execution (Calmeiro & Tenenbaum, 2011). However, contrary to much of the literature that used verbal reports in different contexts (e.g., McRobert et al.,
2011; Whitehead et al., 2015), we found that amateurs verbalised more statements relating to planning when walking to the green compared to the professionals. This finding suggests that amateurs may initiate the process of planning their putts before they even reach the green, whereas professionals are less reliant on such information. According to LTWM theory (Ericsson & Kintsch, 1995), experts would be expected to produce a more systematic search for cues that relate more efficiently with information stored in long-term memory to recognise and anticipate events better than their less skilled counterparts (Ericsson et al., 2000). Professionals may therefore deem environmental cues available during the walk as less reliable, and therefore do not link them to possible outcomes until they are closer to the green where they can gather more meaningful information. The walking element of this study is an original contribution to the literature as it provides the first insight into aspects of the putting process that have not been captured in previous tasks. Future research is warranted to focus more on the time points at which key information is gathered when out on the course.

The differences in statements displayed between the walk to the green and on the green itself appear to be consistent with previous work that has investigated the variability of perceptual-cognitive processes based on factors such as viewing distance and context (Mann et al., 2019). In the present study, the professional players monitored and gathered information before they reached the green and then focused on planning and predictions when they were reading putts on the green. Previous research has displayed similar findings when investigating anticipation and decision-making in soccer defending as a function of ‘near’ and ‘far’ viewing conditions (Roca et al., 2013; Vaeyens et al., 2007). This work displayed changes in skilled visual search behaviour as a function of distance from the ball. Skilled football defenders made more fixations of shorter duration than less-skilled counterparts when the ball was further away, suggesting lower information processing demands. When the ball was close, the skilled players made fewer fixations of longer
duration to detect key cues from the opponent’s body. Overall, these differences display the importance of investigating such processes in real world environments where these subtle differences in perceptual-cognitive processes can be detected (Araújo et al., 2019).

By addressing the need to use representative designs, the findings of this present study serve to shed light on the complex mechanisms underpinning perceptual-cognitive expertise in green reading. This study successfully implemented the expert performance approach to offer tentative behavioural support for the predictions of LTWM in relation to the development of superior recognition and recall in a real-world environment. Despite reducing the possible sample size, the use of a highly skilled sample allowed clearer conclusion on the processes used by ‘successful elites’. From a practical perspective, focusing on predicting potential outcomes of the putt rather than features of the green and technical elements of putting may be beneficial in producing more accurate green reads and linking these to the actual performance of the putt. This has implications for developing perceptual-cognitive skills in that experts appear to be interacting with the complex environment of the green through an early onset of assessment but ensuring they have reliable information before planning the putt. The findings of this study offer valuable insight for practitioners working with golfers. Green reading may be enhanced by more proficient planning strategies and encouraging golfers to explicitly interact with the putting green as they approach it and, when on the green, make specific plans relating to the behaviour of the ball, rather than putting technique.

The use of two different coding schemes in the present study enabled us to test predictions of LTWM theory (Ericsson & Kintsch, 1995) while also identifying sport specific verbalisation relating to cognitive expertise in green reading. However, this approach is not without limitations. Calmeiro and Tenenbaum (2011) suggested that there is a need to refine and improve coding schemes to analyse expert cognitions. The deductive approach used here can constrain the analysis to predetermined categories and may not gather the full picture of
the expert cognitions. Furthermore, while our study included the novel element of analysing verbalisations while walking to the green, each player only completed this walk once to a single green. While practically challenging, future work on green reading, and cognitions in golf more broadly, should attempt to use multiple holes on a course to include representative levels of variability between greens and further investigate the cognitive processes that occur between shots. This, combined with the application of improved coding schemes or inductive qualitative analysis methods, may prove valuable in furthering our understanding of task specific nuances of expert cognitions in future work (Eccles & Arsal, 2017; McGreary et al., 2020).

In summary, we implemented a representative task to elicit cognitions during green reading in professional and amateur golfers. We have shown that professional players verbalised statements relating to the intake of environmental information on the walk to and once reaching the green but more statements relating to planning and predicting putt outcomes when reading putts on the green. Findings suggest that it is important, where possible, to include strategic elements of a skill (e.g., the walk to the green and green reading) that occur prior to movement execution (Christensen et al., 2016) in a representative environment and utilise domain-specific analyses when investigating expertise. Furthermore, during performance, expert golfers could benefit from focusing their green reading processes on outcomes rather than technical execution.

Open Practices Statement

This study was not pre-registered. The data for this study are available at

https://osf.io/z8fwr/?view_only=832402816a6d4b6a87563d5c89b2bf8b

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References


https://doi.org/10.1111/j.2044-8295.2010.02013.x


https://doi.org/10.1080/10615800701609207


https://doi.org/10.1002/acp.1581


Williams, A. M., & Jackson, R. C. (2019). Anticipation in sport: Fifty years on, what have we
learned and what research still needs to be undertaken? Psychology of Sport and Exercise, 42, 16–24. https://doi.org/10.1016/j.psychsport.2018.11.014