Guler Arsal, David W. Eccles, and K. Anders Ericsson

Cognitive Mediation of Putting: Use of a Think-aloud Measure and Implications for Studies of Golf-putting in the Laboratory

Abstract

Objectives: Whereas accounts of skilled performance based on automaticity (Beilock & Carr, 2001; Fitts & Posner, 1967) emphasize reduced cognitive involvement in advanced skill, other accounts propose that skilled performance relies on increased cognitive control (Ericsson & Kintsch, 1995). The objective of this study was to test predictions differentiating the automaticity and cognitive control accounts by assessing thinking during golf putting.

Design: The cognitive processes of less-skilled and more-skilled golfers were examined during putting using concurrent, think-aloud verbal reports. The design included putting conditions that differed in complexity and thus the need to adapt the putt to the particular conditions.

Method: Putting complexity was manipulated via changes to putt length and perceived stress during putting. Putts were executed from two starting locations (i.e., the same starting location as the previous putt or a new starting location).

Results: The analysis showed that, during putting: more thoughts were verbalized overall by more-skilled golfers than less-skilled golfers; both groups verbalized more thoughts overall during higher-complexity putts (i.e., longer distance putts, and putts under higher stress when executed from a new starting location) than lower-complexity putts; and the two groups did not differ significantly in the number of thoughts related to motor mechanics.

Conclusions: The results of this study provide support for a cognitive control account of skilled performance and suggest that the path to skilled performance involves the acquisition of more refined higher-level cognitive representations mediating planning and analysis.

Keywords: Cognitive control; concurrent verbalizations; conscious control; expert performance; think-aloud; verbal reports

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Many theories of skill acquisition, such as Fitts and Posner's (1967) three-stage model and Dreyfus and Dreyfus's (1986) skill acquisition theory, characterize skill learning as transitions from cognitive control to eventual automatic execution. These theories assert that, early in learning, successful performance requires the execution of a sequence of cognitive steps. With extended practice, components of a skill gradually become encoded together as integrated units in long-term memory (LTM). The skill is then performed by recognition of patterns and direct retrieval of integrated actions from LTM, requiring less attention and eventually becoming automatic, where proficient processing cannot be changed in response to cognitive control (Shiffrin & Schneider, 1977). In contrast to these theories, Ericsson and Kintsch's (1995) long-term working memory (LTWM) theory proposes that, while automaticity-based theories of skill acquisition apply to the performance of many "everyday" tasks, they do not apply to the performance of tasks for which individuals are motivated to attain or maintain expert performance. According to LTWM theory, experts intentionally resist the normal tendency toward automaticity in order to maintain cognitive awareness and control of performance so they can monitor, evaluate and change performance to improve it during practice. In this paper, we will explore these competing accounts of skilled performance, which we refer to as the "automaticity" and "cognitive control" accounts, respectively. In the next section, we will review the evidence supporting the automaticity account in relation to the performance of motor tasks.

Skill Acquisition Accounts Based on Automaticity

Skill acquisition theories based on automaticity (Dreyfus & Dreyfus, 1986; Fitts & Posner, 1967) offer two key testable predictions. First, these theories propose that expert performance is controlled by integrated actions retrieved directly from LTM that do not require explicit conscious processes for their execution. Consequently, experts' retrieval of the details of cognitive processes mediating their performance is predicted to decrease as a function of skill (Beilock & Carr, 2001). Second, if experts are instructed to try to attend to the individual steps originally involved in executing a task, they are assumed to retrieve the integrated units from LTM into working memory and then have to decompose them into slower and less proficient control structures (Masters, 1992). This additional cognitive activity is predicted to interfere with normal execution and thus degrade performance. Empirical support for these two claims is reviewed below. Space limits constraint our review to a small but representative set of studies. We first examine whether verbal report procedures used in studies of experts' thoughts during performance elicit data that accurately reflect their thoughts, and then whether disruptions to performance caused by instructions to participants to monitor their performance actually provide evidence of the absence of cognitive control.

Beilock and Carr (2001, Experiments 1 & 2) asked novice and expert golfers to provide written responses concerning their episodic memory for the last putt in a putt series. On average, novices reported around two more steps than experts concerning motor mechanics (e.g., hand positions on putter, swing action), which is consistent with the automaticity account that experts have poorer recall than novices of the detailed steps of their performance. However, the episodic recall instructions used by Beilock and Carr (2001, Experiments 1 & 2) differ from the standard procedures for eliciting "think-aloud" verbalizations (Eccles, 2012; Fox, Ericsson, & Best, 2011). Beilock and Carr's (2001) instructions asked participants to: "Pretend that your friend just walked into the room. Describe the last putt you took, in enough detail so that your friend could perform the same putt you just took" (p. 725). Thus, participants were asked to describe and explain what they did rather than merely report on their thoughts. In a review, Fox et al. (2011) found that generating explanations of one's task performance changed the performance and thus did not reflect thoughts generated during a normal task performance. Also, when Beilock and Carr's participants provided their written descriptions, they may have been selective in their recall and made inferences based on their extensive knowledge of golf obtained, for example, by interactions with instructors. Furthermore, written descriptions often differ in accuracy from descriptions given orally (Kellogg, 2007). Finally, Beilock and Carr's participants may have experienced difficulties in recalling details of their last putt, due to the delay between their last putt and when they began their written putt description. In summary, Beilock and Carr's recall method is unlikely to have yielded valid and accurate data reflecting golfers' actual thoughts during a single, specific putt.

Toner and Moran (2011) published a more recent study supporting the automaticity account. In one condition, expert golfers performed 10 putts under normal, silent conditions and then, immediately after the 10th putt, were asked "to state aloud any thoughts relating to the task of which they were consciously aware" (p. 678). Their procedure for eliciting "think-aloud" verbalizations differs from the standard methods (Fox et al., 2011) and they recorded only 39 thoughts in total for all 18 golfers (Table IV, p. 680). The most frequent verbalized thought was "just look at the target" (p. 680). Toner and Moran concluded that their findings support Beilock and Carr's (2001) view that "a lack of 'on-line' attentional control" (p. 681) facilitates expert performance.

In a subsequent study, Beilock, Carr, MacMahon, and Starkes (2002, Experiment 1) required experienced golfers to consciously monitor a component of their stroke while putting and found this activity interfered with their putting performance, supporting the view that attention to individual task steps interferes with normal task execution. Wulf and colleagues (Wulf, 2013; Wulf, McNevin, & Shea, 2001) identified attentional conditions leading to decrements in performance. In the 2013 review, Wulf showed that directing attention to movement effects (i.e., external focus) benefits performance and learning more than directing attention to the movements themselves (i.e., internal focus). According to Wulf et al.'s constrained action hypothesis, adopting an external focus allows individuals to utilize faster reflex loops that operate automatically, whereas an internal focus constrains the motor system and disrupts these automatic processes. These studies imply that imposing the requirement of conscious control degrades performance by disrupting automatic processes that normally regulate movement. Since Wulf et al.'s and Beilock et al.'s (2002) studies, there have been many demonstrations that requiring skilled individuals to attend to particular performance components results in performance decrements (for a review, see Winter, MacPherson, & Collins, 2014).

However, Toner and Moran (2011) found that conscious attention can be deployed to control and foster performance improvements without negatively affecting performance. When the expert golfers in their study made a conscious adjustment to "their technique in a manner that improved or 'fixed' a flawed aspect of their movement" (p. 681), putting performance was unaffected. An important difference between Toner and Moran's study and the studies showing interference (e.g., Beilock et al., 2002) is that Toner and Moran allowed their experts freedom to select which aspect to focus attention on but, in the studies showing interference (e.g., Beilock et al., 2002), the experimenters decided which particular performance component should be monitored. No interference study has collected participants' thought data in the experimental conditions to compare them with their thoughts while putting normally. A first step towards better understanding the effects of conscious control on performance would involve collecting verbal reports of thinking during normal putting performance (Kearney, 2015). In summary, our review of studies supporting the automaticity account shows that the methods in these studies have important shortcomings that cast doubt on the validity of the data in these studies for making inferences about the nature and frequency of experts' thought processes. We now outline the cognitive control account of skilled performance.

Skill Acquisition Accounts Based on Cognitive Control and LTWM

The cognitive control account of skilled performance (Ericsson, 2006a, 2006b; Ericsson & Kintsch, 1995) involves a contrast between the acquisition of expert performance in a specific domain and skill acquisition in everyday life. For "everyday" tasks such as tying shoelaces or a daily bicycle ride to work, individuals are motivated to achieve only a satisfactory level of performance, which, once reached, there is no motivation to improve. Thus, decreases in cognitive control that follow extensive engagement in everyday tasks are acceptable and in many cases desirable because they lead to reductions in physical and mental effort required to complete these tasks. In contrast, during the acquisition of expert performance, performers cannot settle for a satisfactory performance and instead continually strive to enhance their performance. To this end, they seek to increase their cognitive control over performance by engaging in deliberate practice activities that change and improve current performance (Ericsson, Krampe, & Tesch-Römer, 1993).

Research on expert performers has been undertaken in many different domains of expertise such as chess, medicine, music, and sports (e.g., McRobert, Ward, Eccles, & Williams, 2011). Reviews of this research (Ericsson, 2006a, 2006b) have shown that when experts are instructed by researchers to perform challenging tasks while thinking aloud, verbalizations of their thoughts reveal that expert performance is underpinned by complex cognitive processes and an extended working memory, which is known as long-term working memory (LTWM). LTWM affords rapid and efficient storage of, and access to task-relevant information in LTM, and effectively functions to enhance the otherwise acutely limited storage and processing capacities of working memory during ongoing task performance (Ericsson & Kintsch, 1995). During training, expert performers attempt to change aspects of their performance and rely on their working memory to be able to plan, evaluate, and modify their performance. This framework argues that the refined mental representations acquired by experts as they engage in deliberate practice provide more specific input to the motor system, which increases their control over the outcomes of their performance (Ericsson, 2006a, 2006b). The central claim is that performance can be improved by cognitively controlling motor system activity without breaking the action into its original sequence of steps.

In line with this theorizing, Christensen, Sutton, and McIlwain (2016) proposed that more cognitive control is required at "higher levels" of performance concerned with strategic features of a task. By comparison, less direct cognitive control is required at "lower levels" of performance concerned with the mechanisms underlying movement production because mechanical control "involves relatively stable relations" (p. 49). For example, some component skills involved in the task of driving such as braking may remain relatively invariant, whereas higher-level features of driving, such as anticipating and adapting to changing and challenging traffic situations, are more complex and require ongoing cognitive control. It is important to note that both the automaticity and the cognitive control accounts propose that increases in skill are accompanied by the development of higher-level representations for planning actions (i.e., strategic features of a task). However, only the cognitive control account proposes that, as skill increases, individuals retain the ability to control those lower-level aspects (i.e., mechanical features) of a task that can allow improved adaptation to the encountered situations.

In summarizing the two accounts of skilled performance, the automaticity account proposes that skilled performance is controlled by integrated actions that do not require explicit conscious processes for their execution. In contrast, the cognitive control account proposes that "cognitive processes make an important contribution to almost all skilled action" (Christensen et al., 2016, p. 37). Although less cognitive control might be required at lower-level aspects of performance under stable conditions, skilled individuals retain the ability to cognitively control those aspects to adapt in the face of complex situations.

The Current Study

The goal of this study was to test predictions differentiating the automaticity and cognitive control accounts by assessing thinking during the task of golf putting. To this end, the study was designed to include putting conditions that differed in complexity and thus the need for control. Specifically, putting complexity was manipulated via changes to putt length and perceived stress during putting. To assess the effect of golf skill on verbalized thoughts during putting, the study involved two groups of golfers at different levels of skill, which is similar to earlier studies (e.g., Beilock and Carr, 2001). However, there were also key differences between our study and earlier studies that allowed us to address limitations of the methods used in these earlier studies. First, our study used the most direct method of eliciting thought data, which involves thinking aloud concurrent with task performance (Ericsson & Simon, 1993). A recent meta-analysis (Fox et al., 2011) found that this method is not significantly reactive (i.e., does not change performance accuracy), yet provides valid data on thinking processes when generating verbalizations of thoughts is possible and time is available to increase the duration of task completion.

Second, participants in our study putted twice from the same location before the location was changed so we could assess the effects on thinking of putting from the same as well as different locations. Our interest in this assessment was based on Winter et al.’s (2014) concerns that laboratory studies of putting using artificial greens might not capture the complexities of putting in competition, where every putt must be made from a new location. Many studies have required participants to putt from the same location. Beilock and Carr’s (2001, Experiment 1) participants putted from the same location (“neither the green nor the lie of the ball changed during the experiment”, p. 706), and Beilock, Bertenthal, McCoy, and

Carr (2004, Experiment 2) used the same location for all 260 putts made in their study. However, Beilock and Carr's (2001, Experiment 2) participants putted from nine different locations. Toner and Moran's (2011) participants made multiple (i.e., at least 15) putts from the same location prior to the collection of think-aloud data.

Third, our study included only two practice putts, during which the participant thought aloud, prior to the main testing phase; the putt location and distance was the same for the 2 practice putts but the putt distance was different between the practice putts and the putts used in the main testing phase. The rationale for this aspect of our study design was that a golfer has only one opportunity to putt from a given location during competition on a golf course, yet many studies have not analysed the first putts from a given location and, in fact, have discarded the first putts as practice. For example, Beilock et al.'s (2002, Experiment 1; 2004, Experiment 2) participants made 20 practice putts prior to the testing phase; Beilock et al.'s (2004, Experiment 1) participants made 55 putts prior to the putts that were included in the analysis; and Beilock and Carr's (2001, Experiments 1 & 2) participants made at least 70 putts before information was collected on the execution of their final putt.

Finally, in the current study, two putt distances (101 cm [3.3 feet] & 203 cm [6.7 feet]) were used that differed markedly in difficulty and thus, we hypothesized, the need for control. By contrast, in studies by Beilock and colleagues (Beilock & Carr, 2001, Experiment 2; Beilock et al., 2002, Experiment 1; Beilock et al., 2004, Experiment 1), putt distances varied only from 1.2 - 1.5 m (3.9 - 4.9 feet), and Toner and Moran (2011) used a uniform putt distance of 2.5 m (8.2 feet).

According to the automaticity account, skilled performers would be predicted to recognize the patterns associated with complex putting conditions and directly retrieve from LTM an appropriate integrated response, as long as these conditions are within the range of their golf experience. Consequently, for the different conditions of putting in our study, the thoughts generated and verbalized by more-skilled golfers should be uniformly few in number and unaffected by experimental manipulations. In contrast, the cognitive control account predicts that skilled performers are motivated to develop and maintain cognitive control over the task conditions, which implies that more thoughts, on the average, would be generated as the complexity of the putting conditions increases. Therefore, in this study, more-skilled golfers should verbalize more thoughts as putt complexity increases. With respect to less-skilled performers, both competing accounts predict that more cognitive control is necessary and thus more thoughts would be predicted to be verbalized as the complexity of the putting conditions increases. Less-skilled performers would be predicted to verbalize more thoughts than more-skilled performers according to the automaticity account and the reverse pattern would be predicted by the cognitive control account.

Method

Participants

The study involved 52 participants, who formed two groups. The less-skilled group (M_{age} = 21.65 years, *SD* = 2.87) comprising 19 males and 7 females had an average handicap of 23.19 (*SD* = 8.18), an average of 5.84 years (*SD* = 3.32) of golfing experience, and on average played golf for 2.15 hours (*SD* = 1.95) per week. The more-skilled group (M_{age} = 21.85 years, *SD* = 3.90) comprising 26 males[1] had an average handicap of 4.42 (*SD* = 3.34), an average of 11.05 years (*SD* = 4.27) of golfing experience, and on average played golf for 12.42 hours (*SD* = 7.20) per week. Groups differed significantly by handicap (*p* < .001) but not age (*p* = .840). Participants were students at a large public university in the US and were recruited via the university's central research participant pool or advertisements posted at various campus locations including the university's golf course clubhouse. Institutional approval of the testing protocol was obtained and all participants provided informed consent.

Task

Participants putted a standard golf ball using a handedness-appropriate putter on an artificial green over short (101 cm or about 3.3 feet) and long (203 cm or about 6.7 feet) distances. A trial involved two consecutive putts taken from the same starting location (and is described in detail in the procedure section). To begin each putt within a trial, participants had to retrieve a ball from a stand placed alongside the green.

Task performance and duration. A missed putt was scored 0 and a holed putt was scored 1. Task duration for the first putt within a trial was measured from the time when the ball was retrieved from the stand to when contact between the putter and ball was made. Task duration for the second putt within a trial was measured as the time elapsed from the putter-ball contact of the first putt to the putter-ball contact of the second putt[2]. Task performance and duration on each trial were recorded by a video camera.

Concurrent verbal reports of thinking. Concurrent think-aloud verbal reports were obtained using Ericsson and Simon’s (1993, p. 375–379) procedures. Prior to starting the putting trials, participants received standardized instructions to concurrently think-aloud and then completed two “warm-up” exercises. In the first warm-up exercise, participants thought aloud while solving simple problems and received feedback until their verbal reports provided no evidence of explanations and descriptions (i.e., level 3 reports, Ericsson & Simon, 1993). In the second warm-up exercise, participants practiced thinking aloud while putting twice over 89 cm (about 2.9 feet). Participants were asked to think aloud from when they retrieved a ball to begin the first putt of the trial to club-ball contact at the end of the second putt of that trial. Participants were reminded to “think out loud” if there was a period of more than 20 s of silence. The reports from the experimental trials were transcribed and the transcriptions broken into separate statements such as “this putt is longer”. Each statement was coded on the basis of the function of the verbalized thought the statement contained. A complete set of categories was developed so each statement could be coded (Ericsson &

Simon, 1993). In our procedure, the coder would make the decisions about the coding of each statement in the presented protocol.

A coding scheme with eight categories was developed during a pilot study. The *Assessment* code concerned identification of the putt properties (“this is about 6 feet”). *Response identification* concerned identification, selection, and planning of the intended ball path and required putt parameters (“more strength into my swing”). *Mechanics* concerned the preparation and production of the putt movement (i.e., body positioning and movement; “elbow inward”). *Psychological preparation* concerned psychological preparation to putt (“concentrate”). *Evaluation of previous putt* concerned evaluation of the quality of the previous putt (“that one rolled well”). *Goal statement* concerned the simple momentary mediation of attention (“now, I will putt”). *Ambiguous* concerned task-relevant statements with an ambiguous function (“that’s kind of hmm”). *Task-irrelevant* concerned thoughts unrelated to the task (“I have a test tomorrow”). Coding was mutually exclusive and exhaustive. Based on these encodings, three categories were formed. First, *mechanics thoughts* contained the number of statements per putt coded as mechanics statements. Second, *strategy thoughts* consisted of the number of statements per putt coded either as assessment statements or response identification statements. Finally, *task-relevant thoughts* contained the total number of statements per putt coded as task-relevant; that is, mechanics; assessment; response identification; psychological preparation; evaluation of previous putt; goal statement; and ambiguous statements[3]. Coding reliability was assessed by asking a second trained coder to code the statements (n = 166) for 16 (~2%) randomly selected trials on which think-aloud data were collected. When data were aggregated into the three categories Cohen’s kappa was .78 ($p < .001$), indicating “substantial” agreement (Landis & Koch, 1977).

Task complexity manipulations. The complexity of the putting task was manipulated in two ways. First, the study featured two putt length conditions (i.e., short & long), as detailed above. To check that the long putt was more complex than the short putt, task self-efficacy was measured by asking “To what extent are you confident in your ability to hole the putt over this distance?” Responses were provided on a scale ranging from 0% *(not at all confident)* to 100% *(completely confident)* with marking at each decile.

Second, the study featured two stress conditions (low & high), which were created using instructions adapted from Wilson, Smith, and Holmes (2007). In the low-stress condition, participants were asked to hole as many putts as possible. In the high-stress condition, participants were informed that: the recorded videos of their putting would be analysed by a golf professional, who would check for swing faults and score their putts relative to an expert’s putting stroke; and their overall putting score would be compared with other participants’ scores and monetary prizes of up to $100 would be awarded for the best scores. To check that stress was higher in the high-stress condition than the low-stress condition, participants’ competitive state anxiety was measured using the Mental Readiness Form-3 (MRF-3; Krane, 1994). The MRF-3 is a short version of the Competitive State Anxiety Inventory 2 (CSAI-2; Martens, Burton, Vealey, Bump, & Smith, 1990), which is convenient for rapid measurements of anxiety during task performance. The inventory has separate 11-point items for cognitive anxiety (1 = *not worried,* 11 = *worried*); somatic anxiety (1 = *not tense,* 11 = *tense*); and self-confidence (1 = *not confident,* 11 = *confident*). Correlations between the MRF-3 items and the associated CSAI-2 subscales range from .68 to .76 (Krane, 1994).

Procedure

Participants first completed the think-aloud training. Next, for each putt distance (short & long), participants examined the putt distance and rated their task self-efficacy.

Participants then putted under each stress condition (low & high). The order of the stress conditions was counterbalanced. Within each condition, they received condition-specific instructions, filled out the MRF-3, and completed a block of five putt trials over each putt distance. The order of the block types (short putt & long putt) was counterbalanced. Each trial involved two consecutive putts from the same starting location. Participants retrieved one ball from a stand located by the green to complete the first putt and then returned to the stand to retrieve the ball for the second putt. Within each block of trials with the same putting distance there was a new and different assigned starting location position at the start of each trial. Thus, the first putt within a trial was always taken from a location different from the previous putt (i.e., the second putt taken in the previous trial), whereas the second putt within that trial was always taken from the same location as the previous putt (i.e., the first putt taken in that trial). In total, participants completed 20 trials (40 putts): 5 trials in each of the four (i.e., 2 putt lengths crossed with 2 stress conditions) blocks.

Participants were asked to think-aloud during four of the five trials in each block. The fifth trial without thinking aloud afforded a reactivity test for thinking aloud. Based on prior research (Fox et al., 2011), task duration for the think-aloud trials was expected to be longer than for the no-think-aloud trials, whereas task performance was expected to be similar for both types of trials. The serial position of the single silent no-think-aloud trial was randomized within the block of five trials in a condition.

Statistical analyses

Alpha was set *a priori* at $\alpha = .05$. For each dependent variable, a repeated-measures analysis of variance was undertaken with group (less-skilled & more-skilled) as the between-subjects factor. The within-subject variable(s) were: putt length (short & long) for task self-efficacy; stress condition (low & high) for each of (a) cognitive anxiety, (b) somatic anxiety, and (c) self-confidence; putt length and method (no-think-aloud & think-aloud) for task performance; putt order (first putt & second putt within a putt trial), stress condition, putt length, and method for task duration; and putt order, stress condition, and putt length for each of (a) task-relevant thoughts, (b) strategy thoughts, and (c) mechanics thoughts. Given the binary nature of the task performance data, holed putts were aggregated over putt order and stress condition by calculating a mean for the no-think-aloud trials and, separately, the think-aloud trials at each putt length. The analysis featured the putt length and method factors rather than putt order and stress condition factors because the putt length factor was the most powerful factor and the method factor afforded a reactivity test for thinking aloud. Data sets were evaluated for their normality before analysis. Data sets for task duration, strategy thoughts, and mechanics thoughts were positively skewed. The task duration data were normalized following log transformation. The strategy thoughts and mechanics thoughts data were normalized using a square root transformation. Where transformations were used to normalize data sets, we report back-transformed means and confidence intervals instead of standard deviations.

Results

Preliminary analyses

Task self-efficacy. The interaction of putt length by group was not significant. There was a significant main effect of putt length, F (1, 50) = 205.98, $p < .001$, $\eta_p^2 = .81$, where the golfers' self-efficacy was significantly lower for the long putts (M = 58.85, SD = 18.86) than the short putts (M = 85.58, SD = 12.43). There was a significant main effect of group, F (1, 50) = 5.02, $p = .030$, $\eta_p^2 = .09$, where the more-skilled golfers (M = 76.54, SD = 12.31) were more self-efficacious than the less-skilled golfers (M = 67.88, SD = 15.27).

Competitive state anxiety. The stress condition by group interaction was not significant in any of the three associated analyses. For cognitive anxiety, there was a significant main effect of stress condition, F (1, 50) = 11.04, $p = .002$, $\eta_p^2 = .18$, where the golfers were more cognitively anxious in the high-stress condition (*M* = 3.38, *SD* = 2.13) than the low-stress condition (*M* = 2.54, *SD* = 1.63). There was also a significant main effect of group, *F* (1, 50) = 5.55, *p* = .022, η_p^2 = .10, where the more-skilled golfers (*M* = 2.44, *SD* = 0.94) were less cognitively anxious than the less-skilled golfers (*M* = 3.48, *SD* = 2.04). For somatic anxiety, there were no significant main effects of stress condition or group. For self-confidence, there was a significant main effect of stress condition, *F* (1, 50) = 8.47, *p* = .005, η_p^2 = .15, where the golfers were less confident in the high-stress condition (*M* = 8.38, *SD* = 1.76) than the low-stress condition (*M* = 8.90, *SD* = 1.59). There was also a significant main effect of group, *F* (1, 50) = 10.68, *p* = .002, η_p^2 = .18, where the more-skilled golfers (*M* = 9.29, *SD* = 0.97) were more confident than the less-skilled golfers (*M* = 8.00, *SD* = 1.76).

Task performance. The results revealed a significant interaction of putt length by group, *F* (1, 50) = 11.30, *p* = .001, η_p^2 = .18. For the short putts, the more-skilled golfers' task performance was not significantly different from the less-skilled golfers' task performance. However, for the long putts, the more-skilled golfers (*M* = 72.84% of putts holed, *SD* = 17.54) performed significantly better than the less-skilled golfers (*M* = 46.51%, *SD* = 23.41), *F* (1, 50) = 21.06, *p* < .001, η_p^2 = .30. There was a significant main effect of putt length, *F* (1, 50) = 51.20, *p* < .001, η_p^2 = .51, where task performance was better for the short putts (*M* = 83.47%, *SD* = 14.21) than the long putts (*M* = 59.68%, *SD* = 24.41). Consistent with previous research (Fox et al., 2011), there was no significant main effect of method (i.e., think aloud vs. no think aloud). There were no other significant main effects or interactions.

Task duration. The results revealed a significant main effect of group, *F* (1, 50) = 6.21, *p* = .016, η_p^2 = .11, where the more-skilled golfers' task duration (*M* = 22.18 s, 95% CI [19.77, 24.89]) was longer than the less-skilled golfers' (*M* = 18.11 s, 95% CI [16.14, 20.32]). There was a significant main effect of putt length, *F* (1, 50) = 107.10, *p* < .001, η_p^2 = .68, where task duration was longer for the long putts (*M* = 21.78 s, 95% CI [20.09, 23.60]) than the short putts (*M* = 18.45 s, 95% CI [16.90, 20.09]). There was also a significant main effect of stress condition, *F* (1, 50) = 20.42, $p < .001$, $\eta_p^2 = .29$, where task duration was longer in the high-stress condition (*M* = 21.13 s, 95% CI [19.32, 23.12]) than the low-stress condition (*M* = 18.97 s, 95% CI [17.50, 20.56]). Consistent with previous research (Fox et al., 2011), there was a significant main effect of method, *F* (1, 50) = 108.48, $p < .001$, $\eta_p^2 = .69$, where task duration was longer when participants took time to verbalize their thoughts during the think-aloud trials (*M* = 22.44 s, 95% CI [20.56, 24.49]) compared to the silent no-think-aloud trials (*M* = 17.86 s, 95% CI [16.48, 19.41]).

The results revealed a significant interaction of putt order by stress condition [*F* (1, 50) = 4.45, $p = .040$, $\eta_p^2 = .08$], method by stress condition [*F* (1, 50) = 7.01, $p = .011$, $\eta_p^2 = .12$], method by putt order [*F* (1, 50) = 58.25, $p < .001$, $\eta_p^2 = .54$], and method by putt order by stress condition by putt length, [*F* (1, 50) = 4.42, $p = .041$, $\eta_p^2 = .08$]. There were no other significant main effects or interactions. Among these significant higher-level interactions, the putt order by stress condition was the only interaction that did not include method as one of the factors. Differences in the amount of verbalized thoughts between conditions would lead to differences in the lengthening of the task duration and thus would be a likely source of the significant interactions.

Interpretation of results in terms of task complexity. The lower task self-efficacy, poorer task performance, and longer task durations observed for the long putts (vs. short putts) condition imply that putting complexity was higher in this condition. The higher cognitive state anxiety, lower self-confidence, and longer task durations observed for the high-stress (vs. low-stress) condition imply that putting complexity was higher in this condition.

Verbal report data analysis

Task-relevant thoughts. The results revealed a significant main effect of group, *F* (1, 50) = 8.25, *p* = .006, η_p^2 = .14, where the more-skilled golfers (*M* = 5.97, *SD* = 2.52) verbalized more task-relevant thoughts than the less-skilled golfers (*M* = 4.08, *SD* = 2.22). There was a significant main effect of putt length, *F* (1, 50) = 28.00, *p* < .001, η_p^2 = .36, where more task-relevant thoughts were verbalized during the long putts (*M* = 5.30, *SD* = 2.60) than the short putts (*M* = 4.75, *SD* = 2.54). In addition, a significant interaction of putt length by group was found, *F* (1, 50) = 5.37, *p* = .025, η_p^2 = .10. The increase in putt length led to the verbalization of more task-relevant thoughts for both the less-skilled golfers, *F* (1, 50) = 5.37, *p* = .041, η_p^2 = .08, and the more-skilled golfers, *F* (1, 50) = 28.95, *p* < .001, η_p^2 = .37, but the increase was greater (*d* = 0.20) for the more-skilled golfers. The less-skilled golfers verbalized a mean of 3.93 (*SD* = 2.16) thoughts during the short putts and 4.24 (*SD* = 2.31) thoughts during the long putts; whereas the more-skilled golfers verbalized a mean of 5.58 (*SD* = 2.66) thoughts during the short putts and 6.37 (*SD* = 2.45) thoughts during the long putts.

There was also a significant interaction of putt order by group, *F* (1, 50) = 4.25, *p* = .045, η_p^2 = .08. The more-skilled golfers verbalized significantly more task-relevant thoughts during the first putts (*M* = 6.31, *SD* = 2.60) than the second putts (*M* = 5.64, *SD* = 2.49), *F* (1, 50) = 23.77, *p* < .001, η_p^2 = .32. However, for the less-skilled golfers, there was no significant difference on this variable between the first putts and the second putts. There was a significant interaction of putt order by stress, *F* (1, 50) = 5.02, *p* = .030, η_p^2 = .09. During the first putts, more task-relevant thoughts were verbalized in the high-stress condition (*M* = 5.51, *SD* = 2.61) than the low-stress condition (*M* = 5.01, *SD* = 2.70), *F* (1, 50) = 8.82, *p* = .005, η_p^2 = .15. However, during the second putts, there was no significant difference on this variable between the high-stress condition and the low-stress condition. There were no other significant main effects or interactions.

Strategy thoughts. The results revealed a significant main effect of group, *F* (1, 50) = 12.12, $p = .001$, $\eta_p^2 = .20$, where the more-skilled golfers (*M* = 1.47, 95% CI [1.11, 1.88]) verbalized more strategy thoughts than the less-skilled golfers (*M* = 0.67, 95% CI [0.44, 0.96]). There was a significant main effect of putt length, *F* (1, 50) = 9.09, $p = .004$, $\eta_p^2 = .15$, where more strategy thoughts were verbalized during the long putts (*M* = 1.15, 95% CI [0.92, 1.41]) than the short putts (*M* = 0.92, 95% CI [0.70, 1.17]). There was a significant main effect of putt order, *F* (1, 50) = 38.15, $p < .001$, $\eta_p^2 = .43$, where more strategy thoughts were verbalized during the first putts (*M* = 1.27, 95% CI [1.00, 1.57]) than the second putts (*M* = 0.82, 95% CI [0.63, 1.03]). The main effect of stress condition was not significant. None of the interactions was significant.

Mechanics thoughts. The main effects of group, putt length, and stress condition were not significant. There was a significant main effect of putt order, *F* (1, 50) = 7.90, $p = .007$, $\eta_p^2 = .14$, where more mechanics thoughts were verbalized during the first putts (*M* = 0.95, 95% CI [0.65, 1.30]) than the second putts (*M* = 0.81, 95% CI [0.54, 1.13]). None of the interactions was significant.

Summary and Discussion

According to the automaticity account (Beilock & Carr, 2001; Fitts & Posner, 1967), the more-skilled golfers were predicted to verbalize fewer thoughts during the putting task than the less-skilled golfers, consistent with the pattern observed by Beilock and Carr (2001) in their participants' written descriptions. Our study, which used a think-aloud verbal report method, revealed essentially the reverse pattern: The more-skilled golfers verbalized significantly more thoughts per putt (~2 more) than the less-skilled golfers. This result is consistent with the cognitive control account of skilled performance (Ericsson & Kintsch, 1995).

According to the cognitive control account, both the more-skilled and less-skilled golfers were predicted to verbalize more thoughts during higher-complexity putts (i.e., longer distance putts & putts under higher stress) than lower-complexity putts. The automaticity account would not predict an effect on verbalized thoughts of these “complexity” manipulations for the more-skilled golfers; only the less-skilled golfers would be predicted to generate more thoughts during higher-complexity putts. Our results indicate that both the more-skilled and the less-skilled golfers verbalized more task-relevant thoughts when performing longer distance putts. The effect of increasing putt length on the number of verbalized thoughts was greater for the more-skilled golfers than the less-skilled golfers. These results are consistent with the cognitive control account. The results also showed that both the more-skilled and the less-skilled golfers verbalized more task-relevant thoughts when putting under higher stress, but only if they encountered a new putting location (i.e., the first putt within a two-putt trial); see the results of the analyses of the effect of putt order on task-relevant thoughts. If the golfers executed the same putt from the same location (i.e., the second putt within a two-putt trial), putting under higher stress did not affect the number of task-relevant thoughts. In addition, the more-skilled golfers verbalized more task-relevant thoughts when they encountered a new putting location, as compared to executing the same putt from the same location; in contrast, this difference was not observed for the less-skilled golfers. These results are more consistent with the cognitive control account of skilled performance than the automaticity account.

The analyses of mechanics thoughts revealed that the number of verbalized thoughts related to putting mechanics did not significantly differ between the groups. Putting from a new location was the only condition that affected the number of mechanics-related thoughts. Specifically, during the first putt within a two-putt trial, almost one thought on average (M = 0.95) was verbalized related to putting mechanics, whereas this value was slightly but significantly less for the second putt (*M* = 0.81). Both skill groups verbalized less than one thought related to putting mechanics per putt on average, which corresponds to less than 15% of all task-relevant thoughts.

The analyses of the strategy thoughts revealed that the more-skilled golfers verbalized a considerable amount of thoughts concerning strategic features of putting (~1.5 per putt on average) and significantly more of these thoughts (~1 more per putt on average) than the less-skilled golfers. One of the two putt complexity manipulations affected the number of strategy thoughts verbalized. Specifically, more strategy thoughts were verbalized during the long putts than the short putts; but the number of strategy thoughts did not differ between the low- and high-stress conditions. Also, more strategy thoughts were verbalized during the first putt within a two-putt trial than the second putt within a two-putt trial.

General Discussion

The purpose of this study was to test the automaticity and cognitive control accounts of skilled performance by examining thoughts reported by less-skilled and more-skilled golfers during putting. The results of our study support the cognitive control account of skilled performance. Note that our conclusions differ from those reported in related studies by other researchers (e.g., Beilock & Carr, 2001; Toner & Moran, 2011). We will now address those differences in detail.

Toner and Moran (2011) studied a single group of expert golfers with a mean handicap of 3.56, which is similar to that of our more-skilled group. They used a longer putt distance (i.e., more complex putt) than our longest putt distance. Therefore, based on the cognitive control account, Toner and Moran's group of golfers should have verbalized more thoughts than our more-skilled group. However, Toner and Moran's golfers reported only two thoughts per putt on average, which is roughly four thoughts less than our more-skilled golfers. An informal review of the verbalized thoughts presented by Toner and Moran (see

Table IV, p. 680) shows that, although their skilled golfers reported fewer thoughts than ours, the content of the thoughts is similar across the two studies. Consistent with our study, Toner and Moran found relatively few thoughts related to putting mechanics: An average of approximately one such thought per putt was reported, which is similar to our findings.

Thus, the primary difference between Toner and Moran’s (2011) study and our study concerns the amount of strategy thoughts verbalized, which might be due to procedural differences. In our study participants were given the standard think-aloud instructions, which included warm-up exercises lasting 15–20 minutes (Ericsson & Simon, 1993; Fox et al., 2011), prior to their first putt while thinking aloud. In contrast, Toner and Moran’s expert golfers were not provided with such warm-up exercises. They first took 5 practice putts under silent (i.e., no-think-aloud) conditions. Then, within a main testing phase, they took another 20 putts. Immediately after the 10th putt in this 20-putt series, “The dictaphone was switched on and participants were instructed to state aloud any thoughts relating to the task of which they were consciously aware. Participants were instructed to state aloud any task-related thoughts while they were addressing the ball and once the putt had been executed” (p. 678). When the golfers had finished stating such thoughts, the dictaphone was switched off and the golfers completed the final 10 putts in the 20 putt series under silent conditions. There were several other details of their procedure that might have affected the amount of thoughts verbalized. Most importantly, all 15 putts prior to verbalization involved the same putting task with the same putting location and distance to the hole. Our study found a significant reduction of verbalized thoughts after repeating the same putt only once, so performing the same putt 15 times is likely to lead to further reductions in thoughts and thus verbalized thoughts. Only future research will tell whether the procedural differences between the studies can account for the differences in the amount of thoughts verbalized, especially strategy thoughts.

There are qualitative differences in methodology between our study and the study by Beilock and Carr (2001). Nonetheless, some results concerning the amount of overall reported steps/thoughts were comparable across the two studies. For example, on average, the amount of steps per putt reported by the expert golfers in Beilock and Carr's Experiment 1 was 5.56 and the amount of thoughts per putt reported by our more-skilled golfers was 5.97. However, unlike our study, Beilock and Carr found fewer recalled thoughts for expert golfers than novice golfers. Also, when the reported information is analysed in terms of content, we find striking differences between our study and Beilock and Carr's study in terms of reports concerning putting mechanics and putting strategy. For example, the expert golfers in Experiment 1 by Beilock and Carr reported an average of 3.63 mechanics-related steps per putt, whereas this value was 1.14 for our more-skilled golfers.

Differences in the methodology between the two studies likely account for most of the differences in the results of the two studies. In our study, participants were instructed to verbally express their thoughts while putting without any direction as to what should be reported. In contrast, as we stated above, Beilock and Carr (2001, Experiment 1) instructed their participants to describe the last putt they took to a friend so that the friend could perform the same putt. An example of a description provided by an expert in their study is as follows: "1) Look up at putt, 2) Place putter behind ball with the head square at the target, 3) Look at target, 4) Look at putter and ball, 5) Take putter back, 6) Swing through ball, 7) Look up at target" (p. 706). The written steps do not appear to reflect the sequence of the golfer's inner thoughts but instead the sequence of the golfer's external actions, which actually could have been observed by an observer of the golfer, assuming the observer considered the direction of the golfer's eyes. This is the type of report that Nisbett and Wilson (1977) described as an introspective report, where thinking and perception is inferred from observed actions. If Beilock and Carr had collected their written descriptions on multiple occasions for every golfer, one would expect the descriptions to be very similar because they appear to primarily contain steps that would not differ from putt to putt. These introspective reports are fundamentally different from concurrent verbalizations of thinking produced using the think-aloud procedure (Ericsson & Simon, 1993). If Beilock and Carr's findings reflect introspections rather than direct verbalizations of thoughts, then these findings do not have any relevance for understanding skill-related differences in thinking during putting.

Limitations

This study included a range of putting conditions that could be realized in a laboratory setting and found that longer distance putts, and putts made under higher stress from a new starting location led to increases in the amount of thoughts verbalized during the putt. However, attempting a novel putt at a golf course during a real competition on a real putting green, with its undulating grass surface, is undoubtedly more complex. In particular, our stress manipulation cannot come close to producing the stress of playing in an actual golf tournament. The disparity between the experimental and real environments is likely to explain why somatic anxiety was not significantly affected by our stress manipulation. The disparity is also likely to explain why, even though cognitive anxiety and self-confidence were significantly affected by the manipulation, cognitive anxiety remained relatively low and self-confidence remained relatively high in absolute terms following the manipulation. Thus, we predict that under conditions that involve executing each putt only once on a real green and/or better representations of the stress of a real tournament, golfers will generate even more thoughts and the content of these thoughts will differ as a function of skill.

An additional consideration when interpreting our results is that we did not assess or control for golfers' experiences of yips, a motor phenomenon characterized by an involuntary movement that can affect putting performance (Klämpfl, Lobinger, & Raab, 2013). A reviewer (Dr. Martin Klämpfl) also proposed that golfers use putting routines and therefore similar thought profiles should be observed regardless of the type or complexity of putt, which is not what was found here. Unfortunately, we did not collect data on the golfers' personal putting routines. We accept that some studies of how skilled performers of closed skills prepare to execute these skills have revealed that their preparatory behaviours, and the sequence of these behaviours, are relatively invariant and thus routine, even in the face of changes to perceived task difficultly (e.g., Jackson & Baker, 2001). However, there are currently few available data in the form of concurrently verbalized thoughts during preparatory routines. Research is needed to identify using the think aloud method the extent to which the quantity and quality of such thoughts depend on task difficulty, even if the behavioural sequence of the routines stays the same. Finally, our study was not double-blind concerning group membership, so the possibility must be considered that the experimenter implicitly encouraged the more skilled-golfers to verbalize more thoughts than the less-skilled golfers. Nonetheless, to reduce this possibility, all thought elicitations procedures were standardized, such that these procedures were identical for members of each group.

Concluding Remarks

The present study provides evidence that supports the cognitive control account of skilled performance and is mostly inconsistent with the automaticity account of performance on the putting task. Our findings suggest that different cognitive mechanisms mediate expert performance than the habitual performance of "everyday" tasks. The performance of everyday tasks may rely on recognition and direct retrieval of actions from LTM and thus require little attention (Anderson, 1982; Dreyfus & Dreyfus, 1986; Fitts & Posner, 1967), whereas expert performance may depend on rapidly accessible storage and retrieval structures in LTWM (Ericsson & Kintsch, 1995) that allow participants to generate controlled actions appropriate to the task at hand.

Our results also provide evidence that cognitive control in skilful action is a key to the control of strategic features of a task, and this control becomes progressively more important as the complexity of the task increases. Jack Nicklaus, a former world-class golfer, claims that setting up for a putt took him a long time because he needed “time to concentrate on all the factors of speed and line and grain involved.” (1974, p. 78). Ericsson (2001) argues that expert golfers like Nicklaus are very deliberate in their assessment about how to aim a putt in a given putting situation.

Consequently, we propose that the recommendation that athletes should avoid thinking when performing must be reconsidered. However, we are not proposing that more thinking is always better in all situations. In our analysis of the putting task, we distinguish between the processes involved in preparing and planning to generate a putt with desired characteristics, where these characteristics serve as input to the execution of the motor system, and the actual mechanical execution of the putt. We find evidence of considerable thinking occurring during the preparatory and planning period prior to the initiation of the putting action (i.e., strategic thoughts) and comparatively few thoughts involved in the mechanical execution of the putt (i.e., mechanics thoughts). There is strong evidence that golfers generate a stable mental state prior to executing the putt (c.f. the quiet eye period, Vine, Moore, & Wilson, 2011). However, the distinction between preparation and the actual execution is not evident in Beilock et al.’s (2004, p. 379) recommendation to experts to “Just do it”, which could be interpreted by expert golfers as a direction to avoid thinking both before and during the actual execution of the putt. In fact, Beilock and Carr (2001) explicitly referred to a complete procedure for performing the entire putt task, including both putt preparation and execution in their study of expert golfers.

Consistent with our rejection of the recommended avoidance of thinking by athletes, Winter et al. (2014) suggest avoiding general instructions that imply that “actual thinking” is problematic. Likewise, Montero (2015) proposes that athletes practice “motor routines in such a way so that they do not become proceduralized to such a degree that attention and control interfere with their performance” (p. 382). One means of avoiding such proceduralization that has theoretical and empirical support involves seeking out deliberate practice activities (Ericsson et al., 1993). Such activities are specifically designed by coaches and teachers to improve particular aspects of skills that enable performers to overcome plateaus and avoid the arrested development associated with automaticity. Expert performance involves the acquisition of mental representations for imaging desired outcomes, planning the execution of performance, and modifying and refining performance during practice (Ericsson, 2006a; Ericsson & Pool, 2016).

Our results also showed that the execution of putts from the same location again and again can be a confounding factor that influences the amount and content of thinking during laboratory experiments. The number of factors that are relevant to the putting task on real greens is far greater than on laboratory putting greens and thus skilled golfers are likely engage in more thinking when playing on real courses than lower-skilled players. Whitehead, Taylor, and Polman (2016) showed that the thought processes of highly skilled golfers playing on a real golf course change in response to competitive pressure, but this was not true for less-skilled golfers. An important challenge for future research studying differences in putting skill will be to have participants perform identical putting tasks on actual golf courses.

In conclusion, this study has provided evidence that skilled task performance does not become fully automatic, as suggested by skill acquisition theories of everyday habitual activity, but remains mediated by thinking, especially when there is need to adapt performance when facing complex and variable conditions. Expert performers are motivated to continue to improve their current level of performance by refining and increasing their control of at least some aspects of their performance. Their efforts to refine such aspects are inconsistent with the development of full automaticity that is typically observed in individuals habitually performing everyday tasks. The central finding of this study is that expert performers build mental representations and engage in thinking that supports the preparation and planning of their performance. Researchers and practitioners should therefore encourage the development of knowledge about when and how skilled performers can improve their performance by acquiring mental representations for planning, evaluating and modifying their performance.

Endnotes

1. We appreciate that there was a gender imbalance across the groups. To check the effect of this imbalance on our findings, we conducted additional analyses using only the less-skilled golfers' verbal report data. Repeated-measures analyses of variance were undertaken with gender as the between-subjects factor. The results showed no significant main effect of gender for task-relevant, strategy, and mechanics thoughts.
2. Task duration was not operationalized identically for the first and second putts within a trial because, immediately following putter-ball contact for the first putt, participants often verbalized thoughts concerned with evaluations of the first putt. These thoughts likely affected their preparation for the second putt, in part because the putt starting location for the second putt was always the same as for first putt within a trial. Consequently, the appropriate onset point for the task duration measure of the second putt was putter-ball contact for the first putt. Unlike the second putt within a trial, the first putt was not taken immediately after the previous putt (i.e., the second putt in the *previous* trial) because trials were separated by a short break, and was not taken from the same starting location as the previous putt, because this location was always different between any two contiguous trials. Thus, for the first putt in a trial, participants typically did not

begin to assess the demands of the putt until after retrieving the ball from the stand to begin that putt, and thus the appropriate onset point for the task duration measure for the first putt was act of retrieving the ball from the stand.

3. Ambiguous statements accounted for approximately 15% of task-relevant thoughts within each group. Excluding ambiguous statements from subsequent analyses does not change any result.

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