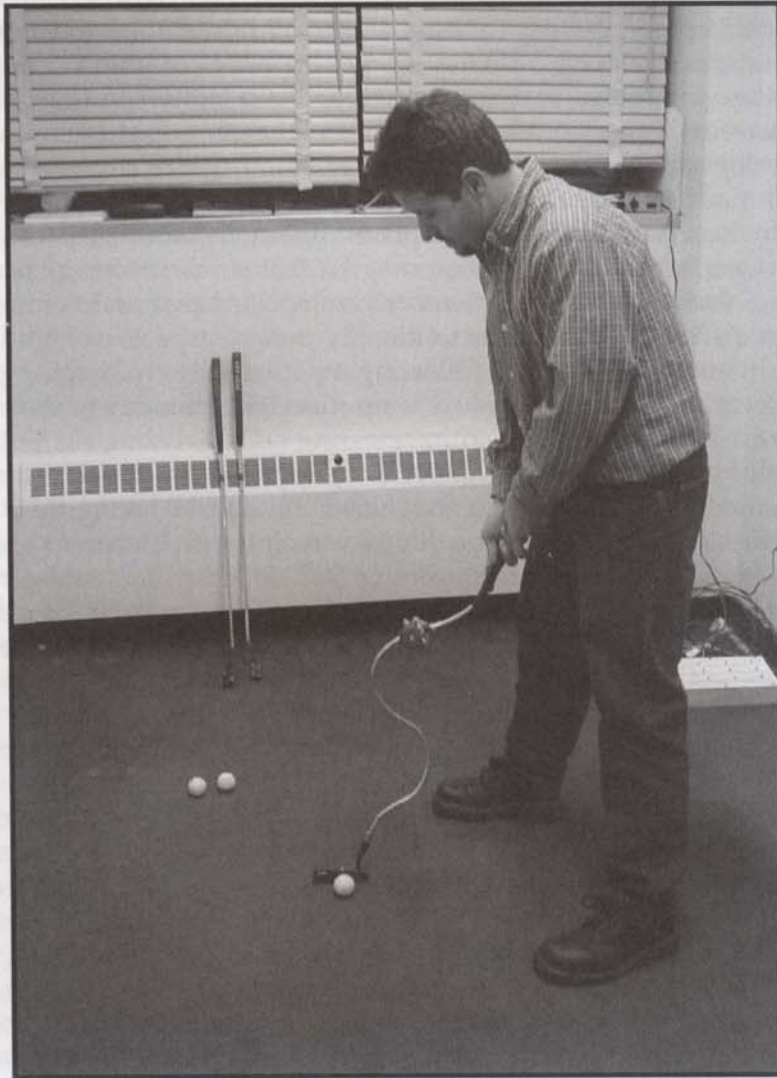


Chapter 12

Memory and Expertise



What Do Experienced Athletes Remember?



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Examinations of the memory structures associated with novice and well-learned skill performance shed light on the cognitive substrate governing performance at high levels of skill execution across diverse cognitive and sensorimotor skill domains. From the chess studies of De Groot (1946/1978) and Chase and Simon (1973) to more recent research in the sensorimotor domains of basketball, field hockey, and dance (for a review, see Starkes, Helsen & Jack, 2001), expert performers' abilities to retain and recall information within their area of expertise have been assessed in the hopes of illuminating the cognitive properties that support exceptional skill execution. These assessments have included memory for the step-by-step unfolding of performances, structured and unstructured game situations, and performance outcomes.

Why has such emphasis been placed on the memorial capacities of expert performers? One reason may be that similar to overt performance, various aspects of memory can be compared and contrasted across skill level as a means to identify unique aspects of high-level performance. For example, following a particularly challenging putt, an expert golfer might be asked to recollect their memory of the exact steps (i.e., the steps involved in assessing and analyzing the putting situation, as well as those underlying the actual mechanical act of implementing the putt) that they went through in taking their last putt. Researchers can compare this information with the same types of episodic performance recollections of less skilled golfers to ascertain whether differences as a function of skill level exist in the memories of on-line performance processes (i.e., the ability to recall the processes and properties of skill execution as it actually unfolds).

But what could be learned from such a comparison? Because episodic memory is thought to depend on explicit attention at the time of encoding (Craik, Govini, Naveh-Benjamin, & Anderson, 1996; Naveh-Benjamin, Craik, Guez, & Dori, 1998), an understanding of what expert golfers remember may lead to inferences that concern the representation of their skill in working memory (i.e., the skill information that is attended to and monitored) as performance actually occurs (Beilock & Carr, 2001). Researchers have found that a critical ingredient in the successful, explicit retrieval of information from memory is attention to this material at the time of encoding. Thus, we can examine one particular aspect of experts' and novices' memory structures (explicitly accessible memories of step-by-step instances of performance) in order to infer what these performers are paying attention to during skill execution.

Utilizing episodic memories, however, to infer explicitly attended information during real-time performance is only one strategy that

may be deployed in accessing the contents of working memory. Another logic commonly proposed in the expertise literature relies on introspective reports of the conscious contents of working memory as evidence for on-line information processing (Ericsson & Simon, 1993). Concurrent verbal report protocols are often utilized in an attempt to determine what performers are thinking about as they perform a skill. Under this logic, reported thought processes are thought to reflect information heeded during skill execution and, ultimately, the representation of this skill in working memory. It is an empirical question whether these two methods designed to access the contents of working memory will produce similar conclusions regarding information attended during skill execution and ultimately the cognitive processes driving this performance. We will return to this issue later.

In this chapter we first begin with a review of past research that assessed the memorial capabilities of expert performers. Along with episodic performance recollections, three other memorial capacities have been examined in an attempt to differentiate the memory structures supporting novice and well-learned skill execution: the ability to recall performance outcomes, that is, the end result of performances (Backman & Molander, 1986); recollections for briefly presented stimulus arrays within a domain of specialization, the kinds of stimuli to which a skill is applied (for a review see, Ericsson & Lehmann, 1996); and retrospective verbal report protocols that detail high-level strategies and game plans (McPherson, 2000). We then discuss new and emerging findings that concern the relationship between the attentional processes and memory structures governing sensorimotor skill performance at various levels of learning. Finally, some implications of memory research for the acquisition and maintenance of high-level performance in real-world settings are presented.

Research on Memory and Expertise

Explorations of the memory structures that support experienced skill execution have reached across skill domains. Nonetheless, many parallel findings regarding experienced performers' memorial capabilities have emerged from these separate areas of interest. One such finding centers on experts' exceptional ability to recall task-relevant stimuli. It has been repeatedly demonstrated that when experienced performers are briefly presented with structured stimuli from within their domain of expertise, they are better able to recall this information than less skilled performers. In their classic chess studies, Chase and Simon (1973) found that chess masters were better able to recall

briefly presented chess positions than were less experienced players (for confirmatory data see De Groot, 1978; and for similar results from computer programmers see Soloway & Ehrlich, 1984). Analogous results have been found in sensorimotor skill domains. In dance, for example, Starkes, Deakin, Lindley, and Crisp (1987) demonstrated that when expert and novice ballet dancers were presented with a series of choreographed movement sequences and then asked to recall these movements either verbally or physically, expert dancers were better able than their novice counterparts to do so. Across cognitive and sensorimotor skill domains, parallel findings of experts' superior memories have led to the conclusion that expertise serves to enhance memory capacity within performers' domain of specialization.

Not only do experts appear to be better at recalling task-relevant stimulus information in comparison with less skilled players, experts also appear to have superior memory for the outcome of their performance. In a study that assessed skill execution and performance memory of low- and high-skilled miniature golf players of different ages, Backman and Molander (1986) found that when asked to recollect the outcomes of particular shots, expert miniature golfers were better able to do so than were less-skilled golfers—even when these recollections were tested unexpectedly. Experts' superior memory for outcomes included successful performances, such as a hole-in-one, and also shots that missed the hole either as a result of direction or speed. Furthermore, through the examination of concurrent and retrospective verbal report protocols of novice and experienced tennis players, McPherson (2000) has found that experienced players retrieve past performance outcomes and use this information for the diagnosing and updating of subsequent performance strategies to a greater degree than less skilled individuals. The type of outcome information recalled by experienced players included information about the success of their opponents' prior shots as well as the style of shots their opponents had a tendency to make.

Such findings demonstrate quite clearly that experts have superior explicit memory for certain kinds of information within their domain of specialization, including incidental explicit memory as revealed by unexpected memory tests. So what exactly does this mean? Some have suggested that because "experts' incidental memory for task-relevant information is superior to that of novices . . . most forms of expert performance remain mediated by attention-demanding cognitive processes," (Ericsson & Lehmann, 1996, p. 291). However, despite the well-documented dependence of explicit memory on attention, it is possible that this suggestion does not apply to all types of memory processes nor

does it apply to all components of high-level skill execution. Experts may have better episodic recollection for the stimuli in the environment that they operate on, for example, chess game configurations, basketball play scenarios, or choreographed dance sequences. They may also have better recollection for the perceptible changes in that stimulus environment created by the outcomes of their performance. To our knowledge, however, it has not been demonstrated that experts are better able to recall step-by-step components involved in their own superior performance as it actually unfolds in real time, such as heavily practiced mechanical aspects and low-level (or local) cognitive planning and decision strategies. Therefore, it remains an open question whether on-line production of expert performance—the sequence of operations itself, rather than the stimuli being operated on—is mediated by the kind of attended implementation of capacity-demanding knowledge structures that one might infer from the quote by Ericsson and Lehmann.

We would like to make salient a distinction about the type or mode of expert performance that we are addressing in the present chapter. Within the expertise literature, care has been taken to make a distinction between performance for the sole purpose of maximizing real-time execution and “deliberate practice” for the alteration, fine-tuning, and long-term improvement of specific skill components. These two types of performance are thought to occur in different contexts (Ericsson & Charness, 1994), with the former presumably determining the successful demonstration of expertise in current competitive situations and the latter occurring during training situations and more strongly contributing to the acquisition of high-level performance in the future. It may very well be the case that experts demonstrate superior episodic memory for performance when the goal is to explicitly analyze skill components to alter or change performance processes. Experts presumably have more experience and skill knowledge about the diagnosis and altering of performance patterns than do novices. Thus, when their goal is to attend to performance, experts may be proficient at retaining episodic memories of the skill parameters they are modifying. As will be seen in the following studies, this ability does appear to be the case, at least under some conditions. However, attending to and remembering a specific performance may not always be easy for an expert, and in situations in which an individual’s goal is to perform at the current highest level possible without the added objective of attending to that performance or necessarily remembering it later, we suggest that experts’ memories of step-by-step skill execution are not superior at all. Explaining why we make such a suggestion brings us to the literature on skill acquisition and automaticity.

In this literature, the unpracticed performances of novices are thought to be controlled by declarative knowledge that is held in working memory and attended step-by-step. In contrast, highly practiced or overlearned performances are thought to be automated, supported by procedural knowledge that operates without the need for explicit or attended monitoring (Anderson, 1983, 1993; Fitts & Posner, 1967). As skill level increases, information is restructured into a new type of skill representation (which is usually called a "procedure" in the domain of cognitive skills, but is often called a "motor program" in the domain of sensorimotor skills). This skill representation does not mandate the same degree of attention and control that was necessary at lower levels of practice (Brown & Carr, 1989; Keele, 1986; Keele & Summers, 1976), and it is supported by different neural structures than were active early in learning (Karni et al., 1998; Raichle et al., 1994).

Although proceduralization is one available concept about the automatization of practiced task performance, alternative explanations of automaticity have also been put forward. Logan (1988) has proposed that automaticity is based on the direct retrieval of specific past episodes or instances of performance from long-term memory, rather than the reliance on a procedure or program that can effectively and efficiently generate new performances. Performance based on retrieval of instances is thought to differ from earlier, less practiced stages of execution in which problem solutions and task performances are derived through the implementation of an explicit rule-based algorithm. From Logan's "instance theoretic" perspective, efficient, experienced skill execution is constrained by the stimuli, contexts, and problems actually encountered during practice; hence, they are stored in memory as retrievable instances of past performance. Thus, skill supported by instance retrieval is not easily transferable to new exemplars of a problem, except through simple processes of similarity-based stimulus generalization (Logan, 1988, 1990; Ericsson, 2001).

Differences exist in the predictions of the proceduralization and instance-based theories of automaticity regarding flexibility and breadth of transfer of performance. These differences have been used to argue that practiced sensorimotor skills are in fact supported by procedures rather than by the retrieval of instances (Koh & Meyer, 1991). However, despite the fact that transfer may occur in proceduralized skills, it is our view that there is a cost associated with such transfer. Specifically, if the required control parameters of high-level performance are altered by new task demands, transfer of a skill may still occur. However, if this alteration is sufficiently dramatic, experts may be forced to devote more attention to performance than they would ordinarily in an at-

tempt to implement the new, less-proceduralized control parameters, which would result in a diminished working memory capacity during skill execution. Such attended transfer might occur without apparent performance consequences when the skill environment is not overly complicated. For example, a competitive skier who is adjusting to a new pair of racing skis may need to attend to controlling those skis to a degree not required by her old, familiar pair. Nevertheless, this skier may not exhibit performance deficits on a familiar and unchallenging race course. This scenario may not be the case, however, when this skier finds herself in a new situation with distracting attention demands or significant strategic and executional challenges. In this scenario, the skier might be forced to race on new skis and on a difficult course that she has never seen before. The added attention the skier must devote to controlling her new skis may not leave enough attentional capacity to implement the planning strategies required to race a novel course. Consequently, performance may suffer, either as a result of planning failures, control failures, or both.

If the relationship we have just described between attention and automaticity is correct—that skills automatized through proceduralization do not require constant attentional monitoring and thus rely less heavily on the active maintenance of information in working memory in comparison with less practiced skills—then memory for the on-line processes involved in skill execution may actually decrease as skill level increases, at least when novel task properties are not involved. Abernethy, Thomas, and Thomas (1993) have suggested that experienced skill execution is “automated” in just this way, not based on consciously accessible declarative knowledge. As a result, specific performances cannot be accurately described or reported through the explicit retrieval of performance rules or general principles because they were not attended or entered into working memory during skill execution—nor can specific performances be described by retrieving actual, explicitly accessible episodic memories of the performances. This deficiency is due to the fact that such memories depend on the allocation of attention to the information that must be stored, which does not actually occur during the real-time skill execution of experienced performers. Thus, although high-level performers may have superior memories for certain aspects of their skill execution (such as the stimulus situations they attend to), if they are not explicitly attending to step-by-step execution in real time, they may actually possess impoverished memories for the component details of how that performance was planned, controlled, and executed on-line. If so, then the relation between expertise and memory may be more complex than

the simple notion that experts remember more. We now turn to recent findings concerning the relationship between memory and expertise that support these hypotheses.

New Findings in Memory and Expertise

In an attempt to assess the memory structures and attentional processes that govern high-level sensorimotor skill execution, Beilock and Carr (2001) conducted a series of experiments exploring generic knowledge of golf putting and episodic memories of particular putts in expert and novice golfers. "Generic" knowledge captures prescriptive information about how a skill is typically done; "episodic" knowledge captures an autobiographical record of a particular performance, a memory for a specific instance of skill execution. Golf putting was chosen as the experimental task because it is a complex sensorimotor skill that is thought to become proceduralized with practice. Although this laboratory putting task lacked many of the variables that make actual putting so difficult (e.g., changing environmental conditions, rolling terrain), individuals in a large majority of the studies performed golf putts that varied in length and angle dimensions. Thus, the putting task was similar to real-world situations because it required the mechanical instantiation of golf swing movements as well as the assessment and planning of putting processes and procedures.

Regardless of one's viewpoint regarding the attentional processes that govern skilled performance, it is generally believed that experts have more explicitly available generic or prescriptive knowledge about the domain in which they are skilled than do their novice counterparts (for reviews, see Ericsson & Smith, 1991; Proctor & Dutta, 1995; Van Lehn, 1989). Experienced golfers should, in theory, give a more detailed and systematic generic description of the steps involved in a typical golf putt than novices. In terms of episodic memories for specific instances of performance, however, the situation may be reversed. If on-line, well-learned golf putting is supported by procedural knowledge that reduces the need to attend to the specific procedures of skill execution, then expert golfers may provide diminished episodic accounts of their performance in comparison with novices, especially those aspects of performance that have been repeatedly practiced, such as mechanics and low-level (or local) planning strategies. In contrast, if expertise is indeed mediated by attention-demanding cognitive processes, expert golfers should give more extensive and descriptive episodic accounts of their performance than their novice counterparts.

In the first experiment, expert golfers (Division I intercollegiate golf team members) and novice golfers (with no previous golf experience) performed a series of putts on a carpeted indoor putting green (3.0 meters by 3.7 meters). Participants were instructed that the object of the task was to putt a golf ball as accurately as possible, making it stop at a target marked by a square of red tape that was located 1.5 meters away. A standard golf putter and golf ball were supplied. All participants took part in identical pretest, practice, and posttest conditions that consisted of 20 putts, 30 putts, and 20 putts, respectively. Putting accuracy was recorded after every putt, and an average putting accuracy was computed for each of the putting conditions. Following the pretest condition, participants were asked to produce a generic knowledge protocol—what one ought to do on a typical putt. Following the posttest condition, participants were asked to describe their episodic memory of their last putt taken—their memory of what they actually did on that specific putt (for questionnaire instructions, see figure 12.1).

The memory protocols were analyzed in two ways. First, a quantitative analysis documented the number of steps given in each protocol. Second, a qualitative analysis divided steps into three categories. The first category was *assessment*, or *planning*, and it referred to deciding how to approach a particular putt, what problems it might present, and what properties the putt ought to have. Examples include “read the green,” “read the line” (from the ball to the hole or target), “focus on the line,” and “visualize the force needed to hit the ball.” The second category was *mechanics*, or *execution*, and it referred to the components of the mechanical act that implements the putt. Examples include “grip the putter with your right hand on top of your left,” “bring the club straight back,” and “accelerate through the ball,” all of which deal with the effectors and the kinesthetic movements of the effectors required to implement a putt. The third category was *ball destinations*, or *outcomes*, and it referred to where the ball stopped or landed—hence, its degree of success.

Experts demonstrated superior putting accuracy in comparison to novices as measured by putting performance in both the pretest condition (experts $M = 13.89$, $SE = 0.99$; novices $M = 23.35$, $SE = 1.61$) and the posttest condition (experts $M = 8.96$, $SE = 0.79$; novices $M = 19.37$, $SE = 1.48$). In terms of the memory protocols (figure 12.2), novice golfers produced shorter generic descriptions and longer episodic recollections of specific putts, whereas the expert golfers produced an opposite pattern. Experts' generic descriptions were longer than novices', reflecting golf expertise. Additionally, experts gave less detailed

Generic Questionnaire (Experiments 1 and 2)

Certain steps are involved in executing a golf putt. Please list as many steps that you can think of, in the right order, which are involved in a typical golf putt:

Episodic Questionnaire (Experiment 1)

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:

[Note: Additional explanation was given to make it clear that what was being asked for was a recipe, or set of instructions, that would allow the putt to be duplicated in all its details by someone who had not seen it. Participants were told that the friend was not an expert golfer, but someone with an ordinary knowledge of the game. This context was provided to prevent excessive use of jargon or in-group shorthand, in an attempt to equate the need for knowledge that would be assumed by the describers across groups.]

Episodic Questionnaire (Experiment 2)

Pretend that your friend just walked into the room. Describe the last putt you took, in enough detail so that your friend could duplicate that last putt you just took in detail, doing it just like you did:

[Note: This episodic questionnaire was changed slightly from Experiment 1 in an attempt to elicit the most detailed episodic descriptions possible from participants.]

Figure 12.1 Generic knowledge and episodic memory protocol instructions for the novice and expert golfers.

episodic recollections in comparison with their generic descriptions and in comparison with the episodic recollections of the novice golfers. Beilock and Carr (2001) have termed experts' impoverished episodic recollection "expertise-induced amnesia." Expertise-induced amnesia centers on the notion that highly skilled on-line performances are controlled by automated procedural knowledge that operates largely outside the scope of attention and is therefore substantially closed to explicit analysis and report. As a result, memories for the step-by-step processes involved in performance are diminished in comparison with less skilled individuals due to the dependence of explicit memory on attention.

In terms of the types of steps given by participants, expert golfers' generic descriptions dealt considerably more with assessing and planning a putt than did novices'. This finding is consistent with research on expert performers across a wide range of task domains (Chi, Feltoivitch, & Glaser, 1981; Lesgold et al., 1988; Priest & Lindsay, 1992; Proctor & Dutta, 1995). Expert golfers' episodic recollections included fewer assessment steps than did their generic descriptions. Expert golfers also made fewer references to putting mechanics in their episodic recollections than did novices (see figure 12.2). To interpret these differences, we again applied the logic described earlier, that the explicitly accessible content of an episodic recollection is a function of how attention was allocated during the experience being recollected. Thus, by this logic, both the qualitative and quantitative protocol analyses demonstrate that although experts' extensive generic knowledge of putting may be declaratively accessible during off-line reflection, it is not used or attended to during real-time performance, which is instead controlled by automated procedural knowledge.

One might worry that the experts' exclusion of assessment steps from their episodic recollections was merely an artifact of our simple and highly repetitive situation, in which assessment was not much needed after a short amount of practice on our putting green. To guard against this alternative explanation, a reanalysis of the experts' protocols was done, and it dropped from each generic protocol all assessment steps that (a) did not appear in the corresponding episodic protocol and (b) were likely to be unnecessary once multiple putts had been taken in our laboratory situation. Excluded were steps such as "read the green" and "read the lie of the ball," since neither the green nor the lie of the ball changed during the experiment. Steps that would always be necessary in order to execute a putt, such as "taking aim," were maintained. This reanalysis of assessment produced a significant

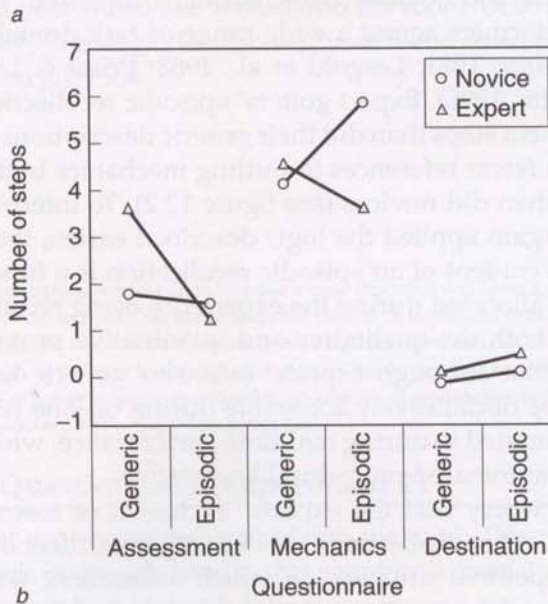
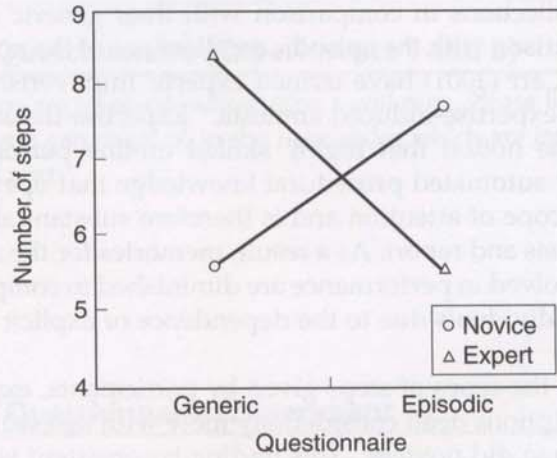


Figure 12.2 (a) Total mean number of steps for the generic questionnaire and the episodic questionnaire and (b) mean number of steps in each category for the generic and episodic questionnaire for both expert and novice golfers.

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interaction between expertise and type of protocol whose shape was the same as the original.

The results of the experiment described above support the notion that high-level skill execution is encoded in a procedural form that

supports effective real-time performance without requiring continuous on-line attentional control. As a consequence, experienced golfers' memories for specific instances of performance are less complete than less skilled golfers. However, if novel task constraints are imposed, thus requiring experienced performers to alter skill execution processes, then proceduralized skill execution should be disrupted and experts should be forced to attend to step-by-step task control. Though accuracy of execution may decline, this restoration of attention should improve episodic memory.

In a second experiment, Beilock and Carr (2001) again compared putting performance and generic and episodic memory descriptions in expert and novice golfers under normal putting conditions (i.e., using a regular putter). Additionally, a subset of the expert and novice golfers performed the putting task with a "funny putter" made from a regular putter head attached to an S-shaped and arbitrarily weighted putter shaft. The design of the "funny putter" required experienced golfers to alter their well-practiced putting form to compensate for the distorted club. The idea was to force participants to allocate attention to the new task constraints.

Novice golfers with no previous golf experience and experienced golfers with either two-plus years of high school varsity golf or a PGA handicap under eight performed the same putting task as in the first experiment in a two (novice, expert) by two (regular putter, funny putter) design. All participants took part in identical pretest and practice conditions that consisted of 20 putts and 30 putts respectively, followed by two posttest conditions. The first posttest consisted of 20 putts while the second posttest consisted of 10 putts. Similar to the first experiment, putting accuracy was recorded after every putt, and an average accuracy score was computed for each condition. To ensure that the performers were not adapting to the highly repetitive task of putting from one specific spot on the green, we had all the participants in the second experiment alternately putt from nine different spots, located at varying angles and distances from the target. Following the pretest and practice conditions, participants produced a generic knowledge protocol. Following both the first and second posttest conditions, participants were asked to describe, in as much detail as possible, their episodic memories of their last putt (see figure 12.1). As in the first experiment, the first episodic memory protocol was a surprise. Just before the last putt taken prior to the second episodic memory protocol, participants were warned to attend to their performance because they would be subsequently asked to produce an episodic memory protocol of their next putt.

Results indicated that novices' putting accuracy was not affected by type of putter. This result might be expected considering that the novice golfers were not experienced with either type of putter before the experiment. Experts' putting accuracy was superior to novices, and was more accurate with the regular putter than with the "funny putter" (figure 12.3). Protocol data showed that novice golfers produced short generic descriptions and longer episodic recollections (figure 12.4). Again, the type of putter did not influence novices' protocols. Experts who used the regular putter produced an opposite pattern. These experts gave longer and more detailed generic descriptions than the novices did. In addition, experts who used the regular putter gave shorter episodic recollections in comparison with their generic descriptions and also in comparison with novices' episodic recollections, again demonstrating "expertise-induced amnesia."

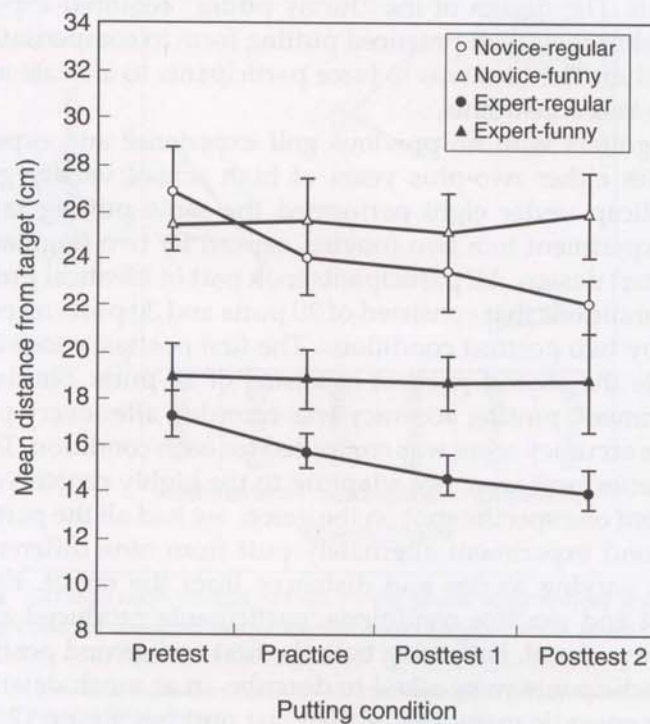
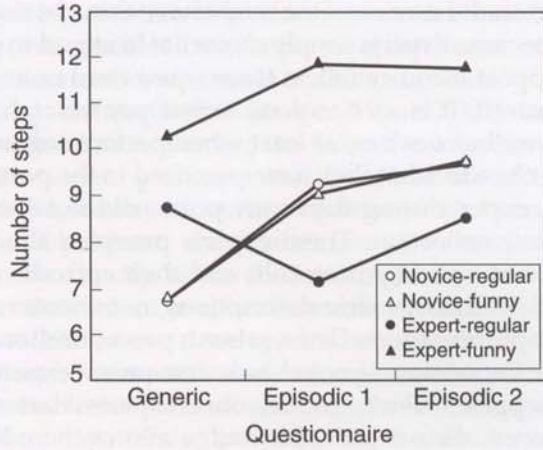
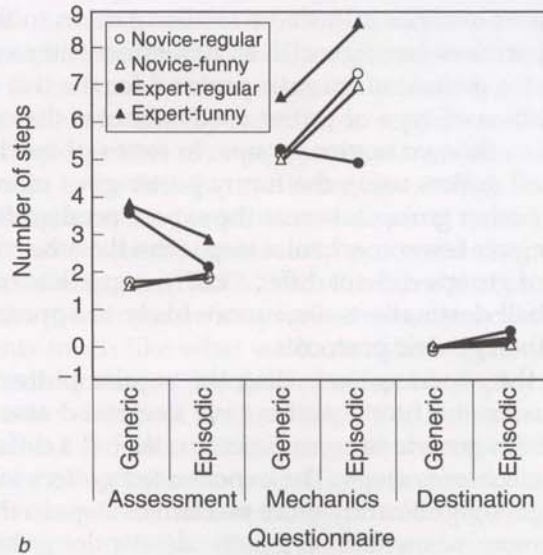


Figure 12.3 Mean distance (cm) from the target that the ball stopped after each putt in the pretest, practice, posttest 1, and posttest 2 conditions for each group. Error bars represent standard errors.

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a



b

Figure 12.4 (a) Total mean number of steps for the generic questionnaire and the two episodic questionnaires and (b) mean number of steps in each category for the generic and first episodic questionnaire for each group.

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The second episodic memory test, in which participants knew in advance that they would be required to produce an episodic memory of their last putt, generated the same results. Even when forewarned of the memory test, experts using the regular putter recalled less about a

specific putt than did novices. One might have thought that our earlier results arose because experts simply *choose* not to attend to performance enough to support memory unless there was a need or an incentive to remember. Instead, it is as if experts *cannot* pay enough attention to remember as well as novices, at least when performing under routine conditions so close to what they have practiced in the past.

In contrast, experts using the funny putter did not show impoverished episodic recollection. These experts provided the most elaborated generic and episodic protocols, and their episodic recollections were longer than their generic descriptions, not shorter as produced by the regular putter experts. Thus, when a proceduralized skill is disrupted by the imposition of novel task demands, "expertise-induced amnesia" disappears. Furthermore, once experts start attending to task performance, their expert knowledge allows them to remember more of what they are attending to than novices.

The qualitative analysis followed a similar pattern to that obtained in the first experiment (see figure 12.4). Assessment steps decreased in number from the generic to episodic protocol for the two experienced groups, regardless of type of putter used, whereas the opposite pattern occurred in the two novice groups. In terms of mechanics steps, the experienced golfers using the funny putter gave more mechanics steps than any other group, whereas the experienced golfers using the regular putter gave fewer mechanics steps than the other three groups. The two novice groups did not differ. Finally, regardless of putter type or expertise, ball destinations were more likely to appear in episodic recollections than generic protocols.

Thus, both the expert golfers using the regular putter and the expert golfers using the funny putter gave decreased assessment step descriptions from generic to episodic protocols, but a different pattern occurred for mechanics steps. The experienced golfers who used the funny putter gave significantly more mechanics steps in their episodic protocol in comparison with their generic description, whereas the experienced golfers who used the regular putter gave somewhat fewer steps (see figure 12.4). The design of the funny putter was intended to specifically distort the mechanical act of implementing the putt in the present experiment. Attention to the assessment and planning of the putt should not have been significantly influenced by putter type. Thus, the results demonstrating that the experienced golfers using the regular putter and the experienced golfers using the funny putter did not differ in terms of assessment steps included in their episodic memory protocols, yet did vary in their accounts of the mechanical properties involved in putting performance, is consistent with the no-

tion that increased attention to performance as a result of novel task constraints serves specifically to enhance episodic memories for the altered parameters and components of skill execution.

In the studies just described, Beilock and Carr (2001) used measures of episodic performance memory to infer the attentional demands of on-line performance processes at different levels of expertise. As mentioned earlier, however, another approach has been utilized for the same general purpose, and it attempts to access the contents of working memory directly, rather than relying as we do on the impact of attention on the content of episodic recollections. Specifically, Ericsson and Simon (1993) have developed a framework for the collection of concurrent and retrospective verbal reports of the conscious and hence introspectable contents of working memory. These contents are thought to reflect the attended processes, or "heeded" processes (held consciously in working memory), that govern skill execution. Under this framework, instructions to verbalize conscious thoughts are distinguished from instructions to verbalize reasons and explanations for performance. Ericsson and Simon suggest that only the former type of verbalization, which focuses specifically on conscious thoughts, accurately reflects the cognitive processes supporting skill execution. This distinction is due to the fact that the latter type, which focuses on reasons and explanations, may require an individual to add information that might not otherwise be consciously processed during the actual unfolding of performance. That is, verbalizations that elicit rationales and reasons for performance may reflect reconstructions of performance elements much like what we have called "generic" protocols, rather than the information "heeded" during task deployment.

How do our two kinds of protocols relate to Ericsson and Simon's (1993) framework? It is clear that our generic protocols fall into the second category of verbalizations. Our generic protocols are descriptive and explanatory in nature, and they provide a general account of a golfer's putting knowledge. They need not and almost certainly do not correspond to a specific memory trace of any particular performance. In our experiments, we used the generic protocols to illustrate that experts do indeed have more domain-relevant knowledge than their novice counterparts, a finding that has been repeatedly upheld in the expertise literature (for a review, see Ericsson & Smith, 1991). Our experiments also illustrate that we can capture this difference within our laboratory putting paradigm.

Similar to the generic protocols, our episodic protocols are also "descriptive," and from Ericsson and Simon's (1993) perspective, it may be legitimate to worry about exactly what they are describing and

why. However, in contrast to our generic questionnaire, it does not appear that our episodic questionnaire is eliciting “verbal rationales and reasons” (Ericsson & Simon, 1993, p. xviii). We formulated our episodic question under the assumption that attention leaves explicit memory traces and that one needs to explicitly attend to a stimulus to encode it and later be able to retrieve this information from memory and report it in a recall task. Such an assumption is standard fare in the memory literature, and as such, it should be uncontroversial (see, for example, Craik et al., 1996; Naveh-Benjamin et al., 1998). Nevertheless, although recall of episodic content increases in amount and accuracy when attention is paid during encoding, one must take into account the constructive nature of any recall attempt. That is, there is the possibility that recall does not represent *just* an episodic memory trace of a particular performance instance, but instead, it includes reconstructed information based on general knowledge. This possibility might be especially likely in our episodic protocols because performers were instructed to describe their memory of their last putt so that another individual could duplicate this putt. Specifically, participants in our studies may have been tempted to give a general account of their performance that included considerable generic information, perhaps highlighting what the golfers believed to be the unique characteristics of their own skills, rather than the intended memory description of a specific instance of skill deployment.

If the episodic protocols obtained in the previously mentioned studies were constructed accounts of what might have been—or worse, for our purposes, what *ought* to have been—then one would expect experts to be much more able to engage in such an exercise, because, as demonstrated in our generic protocols, they have more domain-relevant knowledge to work with in creating such a construct. However, this expectation is falsified by the results, since it predicts that experts should produce more elaborate episodic protocols, not the less elaborate ones that they did in fact produce when using the regular putter. That is, if our episodic questionnaire was eliciting a theoretical or schema-driven explanation rather than an attempt to produce a specific memory of performance, then one might hypothesize that the expert-novice differences in episodic memory protocols presented earlier in this chapter would be reversed. Experts, with their extensive domain-relevant knowledge base, certainly should be able to explain and elaborate their performance to a greater degree than novices.

A second piece of insurance against the concern that our episodic questionnaire is eliciting reasons and explanations for performance (rather than episodic memory traces reflecting information attended during on-line execution) is provided by the detailed episodic memories

of performance given by the funny-putter experts in the second experiment. If reconstructed or schema-driven explanations of performance produced our results, then it is difficult to account for the differences in protocols between the experts using the regular and funny putters. That is, why would experts using the funny putter produce different memory protocols than experts using the regular putter, considering that they were given the same episodic questionnaire. Our explanation is that the accounts of the experienced golfers' memories differ because they attended to different things and hence encoded different information into memory. Again, this logic follows uncontroversially from the memory literature. Furthermore, the types of steps that were enhanced by the funny putter were mechanical in nature (see figure 12.4). These are precisely the types of steps that one would predict experts would need to attend to with the instantiation of novel mechanical parameters (i.e., the unevenly shaped and distortedly weighted funny putter).

Nevertheless, one lingering issue concerns whether or not concurrent verbal reports would have produced the same pattern of information. That is, although we have followed one logic to determine what was attended (i.e., the collection of retrospective episodic memory measures), another logic could be followed that would collect concurrent or immediately retrospective verbal reports of conscious thoughts. We do not know whether this method would produce the same results or different ones. This issue is important. One way to corroborate our retrospective memory findings might be to collect verbal report protocols following Ericsson and Simon's (1993) techniques during skill execution. A comparison could then be made between concurrent protocols based on instructions to verbalize conscious thought processes and episodic memory protocols designed to access the information attended and encoded during performance. This is a line of work that we plan to pursue in the future in collaboration with Anders Ericsson.

Finally, in an attempt to provide converging evidence on Beilock and Carr's (2001) inferences that regard the cognitive processes supporting novice and experienced skill execution (as well as to further understand the relationship between memory, attentional demands, and skill level), Beilock, Wierenga, and Carr (2002) performed an experiment that compared the single-task and dual-task performance of expert and novice golfers. If high-level performance processes do not require constant attentional control, then the addition of secondary task demands should not significantly impinge on experienced performers' primary task performance. In contrast, because of the attentional demands of novel or unpracticed performances, the addition of secondary task demands should result in a decrease in primary task performance because novices must allocate attention to skill performance processes.

Novice and experienced golfers took a series of golf putts on an indoor green using either a standard golf putter or a funny putter under single-task and dual-task putting conditions in a two (novice, expert) by two (regular putter, funny putter) by two (single-task, dual-task) design. In the single-task condition participants performed the putting task in isolation. In the dual-task condition, participants completed the putting task while simultaneously performing an auditory word monitoring task. The monitoring task consisted of a series of auditorially presented words in which participants were instructed to listen for a specified target word and, on hearing the target word, repeat it out loud. A subset of the words presented during the monitoring task were used as the basis for a subsequent recognition memory test.

In terms of putting performance, the novice groups, as well as experienced golfers using the funny putter, showed performance decrements from the single-task to the dual-task putting condition. In contrast, experts using the regular putter continued to improve in putting accuracy from the single- to dual-task condition (figure 12.5). Word recognition performance followed a similar pattern. The novice groups and the expert golfers using the funny putter showed decrements in recognition memory for words heard while putting in comparison to a single-task word recognition test given as a base-line measure. The expert golfers using the regular putter, however, did not show this decrement in word recognition performance (figure 12.6).

Thus, as illustrated by putting performance and word recognition data, performing in a dual-task environment harmed novice golfers and those experts using the funny putter, but it did not disrupt putting performance or word recognition ability in expert golfers putting under normal conditions. These results once again suggest that expertise leads to the encoding of task components in a proceduralized form that supports effective real-time performance, without the need for constant on-line attentional control. As a result, experts performing under normal, practiced conditions are better able than novices to allocate a portion of their attention to other stimuli and task demands if the situation requires it—even though these experts are less inclined and less able to allocate attention to and remember the step-by-step details of their performance, as shown by the expected and unexpected episodic memory tests of the previous two experiments.

These results also demonstrate that high-level proceduralized performance is transferable to novel task situations. Specifically, experts performing with the funny putter under single-task conditions that allowed them the attention necessary to concentrate on putting execution were able to attend to and adapt to the altered putter constraints without decrements in primary task performance. However, a decrease

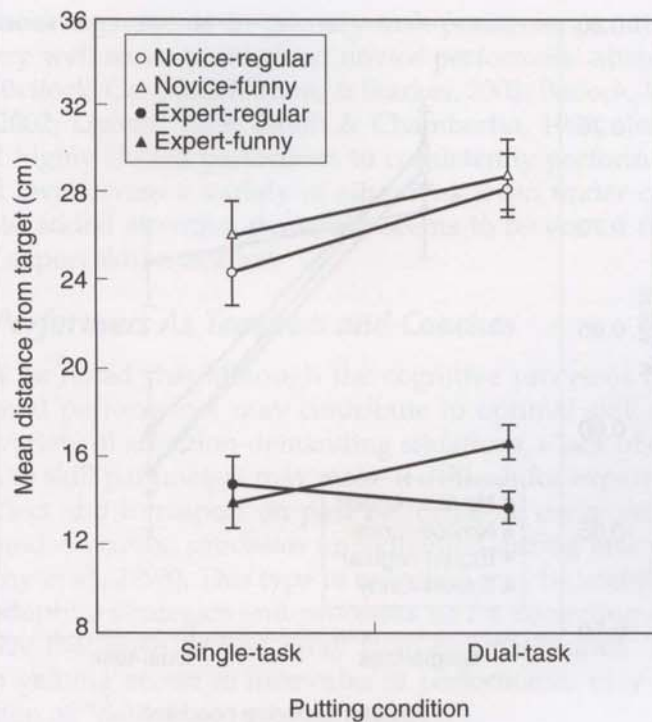


Figure 12.5 Mean distance (cm) from the target that the ball stopped after each putt in the single-task and dual-task conditions for each group. Error bars represent standard errors.

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in primary and secondary task performance occurred with the implementation of the secondary auditory monitoring task. Under dual-task conditions, the experienced golfers using the funny putter were forced to allocate attention to the altered putting task and the secondary auditory monitoring task. As a result, attentional capacity was stressed, and performance suffered—similar to what might happen when an experienced skier is forced to simultaneously attend to the parameters of her new skies and a novel, challenging race course.

In the studies discussed earlier in this chapter, episodic memory protocols, dual-task performance, and recognition memory for secondary stimuli presented during performance were used as support for the following notion: Well-learned sensorimotor skills are based on a proceduralized skill representation that (a) requires little attention to the well-practiced mechanical aspects and low-level planning strategies involved in skill execution, (b) operates largely outside of working

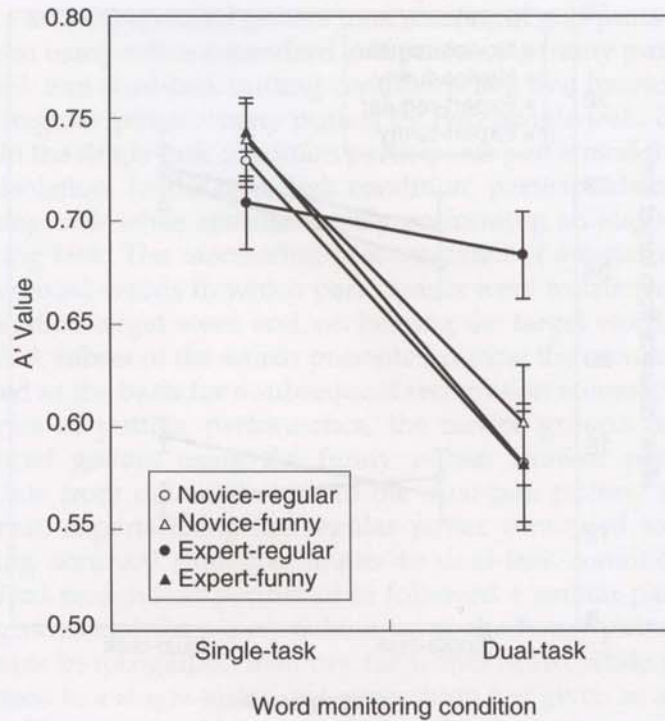


Figure 12.6 Mean A' value for the single-task and dual-task recognition memory tests for each group. Error bars represent standard errors.

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memory, and (c) is substantially closed to introspection and report. This is in contrast to novel performance processes that must be explicitly attended to in real time.

Implications for Real-World Performance

What exactly does the high-level athlete gain and lose with the changes in memory structure that accompany skill acquisition? The ability of experts when performing under normal task constraints to withstand the impact of dual-task conditions demonstrates that high-level skills may be performed at an optimal level under circumstances in which novice performance suffers. Because experienced skill execution does not mandate constant on-line attention and control, expert performers are able to encode and react to extraneous stimuli and environmental

cues without decrements in primary task performance, stimuli that might very well serve to overload novice performers' attentional resources (Beilock, Carr, MacMahon, & Starkes, 2002; Beilock, Wierenga, & Carr, 2002; Leavitt, 1979; Smith & Chamberlin, 1992). Indeed, the ability of highly skilled performers to consistently perform at an exceptional level across a variety of situations, even under conditions that create added attention demands, seems to be one of the benchmarks of expert skill execution.

Expert Performers As Teachers and Coaches

It should be noted that although the cognitive processes that drive well-learned performance may contribute to optimal skill execution across a variety of attention-demanding situations, a lack of conscious attention to skill parameters may make it difficult for expert performers to reflect and introspect on past performance decisions, strategy choices, and execution processes implemented during task execution (Abernethy et al., 1993). This type of reflection may be useful for altering maladaptive strategies and processes or for correcting execution parameters that have drifted away from optimal values. Thus, difficulty in gaining access to memories of performance may harm the formulation of "deliberate practice" regimens.

Furthermore, experienced performers' inability to access explicit knowledge about performance processes carries implications for how effective experts will be in teaching their skill to others. A series of experiments (Hinds, 1999) were designed to assess the ability of experienced and less skilled individuals to predict novices' competence in solving both a Lego building task and a cellular-phone technology task. Hinds found that experts were poor predictors of novice performance and that they had difficulty understanding the types of problems that novices might face. In addition, experts were found to be ineffective in accurately recalling their own performances when they themselves were less skilled. Experts consistently underestimated their novice performance time and left out imperative steps involved in deriving the problem solution. Hinds explained experts' inability to assess novice performance as the "curse of expertise," whereby expert performers' lack of insight into their own high-level performance processes interferes with their ability to capitalize on superior task-relevant declarative knowledge in predicting the task performance of less skilled individuals.

Experts' inability to introspect on their performance has also been documented in real-world teaching settings. In Brown and Burton's (1978) assessment of the arithmetic skills of experienced elementary

school math teachers, it was found that although experienced teachers were able to perform actual arithmetic operations at a high skill level, they had a great deal of difficulty in verbalizing the steps they went through in solving the math equations.

The findings of both Hinds (1999) and Brown and Burton (1978) suggest that although experts know *what* to do and are able to do it, they may not have explicit access to a detailed representation of *how* to do it that can be communicated to others (Adelson, 1984). This finding obviously carries serious implications for how experts may perform in roles as coaches, teachers, and educators. That is, although expert performers may be exceptional players, they may not necessarily make the best coaches. Can you imagine, for instance, how Michael Jordan might explain to young aspiring basketball players how he performs a dunk?

Expertise and "Choking Under Pressure"

The findings of recent memory research carry implications for high-level skill execution under pressure. "Explicit monitoring," or "execution focus," theories of choking suggest that suboptimal performance of a well-learned skill under pressure results from an attempt to exert explicit monitoring and control on proceduralized knowledge that is best run off as an uninterrupted and unanalyzed structure (Baumeister, 1984; Lewis & Linder, 1997). Thus, high-level skills based on an automated or proceduralized skill representation may be more susceptible to the negative consequences of performance pressure than less practiced performances. Beilock and Carr (2001) have found support for this notion in sensorimotor skill performance.

Participants learned a laboratory golf putting task to an asymptote in performance under different training conditions and were then exposed to single-task situations of both low and high pressure. The first training regimen involved ordinary single-task practice, which provided a baseline measure of the occurrence of choking. A second regimen involved practice under a distracting, dual-task condition (while monitoring an auditory word list for a target word), which was designed to expose performers to being distracted from the primary task by execution-irrelevant activity in working memory. The third training regimen exposed performers to the particular aspects of high-pressure situations that explicit monitoring theories of choking propose cause performance decrements. In this "self-conscious," or "skill focus," training condition, participants learned the putting task while being videotaped for subsequent public analysis by experts. This manipulation was designed to expose performers to having attention

called to themselves and their performance in a way intended to induce explicit monitoring of skill execution. It was found that choking occurred for those who were trained on the putting task in a single-task, isolated environment and also for those trained in a dual-task environment that simply created distraction. Choking did not occur, however, for those trained in the self-conscious condition. This group actually improved under pressure. Beilock and Carr (2001) concluded that training under conditions that prompted attention to skill parameters served to adapt these performers to the type of attentional focus that often occurs under pressure. That is, self-consciousness training served to inoculate performers against the negative impact of pressure, which enticed them to overattend to well-learned proceduralized performance processes.

Summary

Researchers have attempted to assess a number of components that constitute the memory structures supporting skill performance so that they can illuminate the cognitive substrate that governs high-level skill execution. Extensive evidence of experts' superior memory for stimuli encountered or operated on within their domain of interest has been collected across cognitive and sensorimotor skill domains. These results have been taken as support for the notion that expert performance is mediated by reportable attention-demanding explicit cognitive processes (Ericsson & Lehmann, 1996). Recently, however, researchers have attempted to document another property of the cognitive substrate of sensorimotor skill execution—namely, the declarative accessibility, or openness to introspection and report, of real-time skill planning and execution processes at different levels of expertise. Measurements of experts' episodic memory representations permit inferences that concern the underlying control structures driving real-time performance. Namely, these results suggest that well-learned sensorimotor skill execution is controlled by proceduralized knowledge structures that are not attended to and hence not included in the memories left over from task performance. As a result, experts may have less detailed memories for some aspects of performance in comparison with less skilled performers.

However, reduction in episodic memory may not hold across all conditions of performance. In practice situations, for example, in which performers are consciously attempting to dismantle their skill and modify certain parts to more closely align their performance with desired goal states, experts may retain extremely detailed memories

of performance in comparison with novices. That is, once experts do attend to performance processes, their greater knowledge base should afford them the ability to identify skill problems, derive solutions, alter performance processes, and ultimately encode this information for subsequent use to a greater degree than their novice counterparts. However, it may be difficult for experts to achieve and maintain this state of heightened attention to performance as indicated by the contrast between expert golfers' intentional memories when using a regular putter and their much-improved intentional memories when using the funny putter. These conclusions regarding skill expertise and memory are not only relevant to understanding the cognitive mechanisms that underlie expert skill execution, but they may also lend insight into the optimal conditions for exceptional performance in real-world situations.

EXPERT'S COMMENTS

■ *Question*

Beilock and colleagues cite evidence that being an expert presents occasional disadvantages, particularly when one has to recall individual portions of well-practiced movements. Have you seen other examples in sport where you think this might be the case?

■ *Player's Perspective: Therese Brisson*

Beilock, Weirenga, and Carr present the curious finding that expert golfers were not able to verbalize elements of expert performance immediately after their performances. This is an interesting finding that supports my long-held belief that recently retired hockey players who played at high levels rarely make the ideal coaches for youth hockey. They know what to do, but they can't communicate how they do it! When I run hockey camps for children, given the choice between the skilled hockey player with little instruction experience and the experienced physical education teacher with no elite playing experience, I always select the teacher. Teaching skating skills is one of those problem areas. How exactly do you skate faster? What do I need to do to execute a sharp turn and to stop? The good news is that with experience in coaching and communication, former players can learn how to break down skills and, even more important, communicate teaching points to the learner. But this comes with coaching experience, not playing experience.

