

SPORT AND EXERCISE PSYCHOLOGY: INTERNATIONAL PERSPECTIVES



**TONY MORRIS
PETER TERRY
SANDY GORDON**
editors

11

Understanding Skilled Performance: Memory, Attention, and Choking under Pressure

SIAN L. BEILOCK

Life is full of difficult tasks, ranging from playing a round of golf, to taking a college entrance exam, to giving a talk in front of your friends and colleagues. One thing that we as psychologists try to understand is the mental processes that support such skills. However, it is not just psychologists who are interested in the cognitive mechanisms that govern successful skill execution. In commenting on hitting a baseball for example, the famous Yogi Berra once said this: "How can you hit and think at the same time?" Yogi's words of wisdom suggest that thinking too much about on-line execution can be detrimental to performance. Whereas this notion might apply to the high-level hitting performance of a baseball expert, it may not extend across all levels of skill expertise or to all task types. In this chapter, I will

discuss several lines of research that my colleagues and I have conducted in an attempt to shed light on differences in the attentional mechanisms governing execution across skill levels and task domains. Moreover, I will explicate how we have been using these differences in the executive control structures governing performance as a means to understand the execution failures that ensue when the attentional demands of performance are not met.

Theories of Skill Acquisition and Automaticity

The essence of Yogi Berra's quote, "How can you hit and think at the same time?" is reflected in skill acquisition and automaticity theories of high level

performance. In essence, highly practiced, well-learned skills are thought to be controlled by procedural knowledge that operates largely outside of working memory (Anderson, 1993). This is in contrast to novice skill execution, which is based on declarative knowledge held in working memory and attended to in a step-by-step fashion (Fitts & Posner, 1967; Proctor & Dutta, 1995). These proposed differences in the attentional demands of novice and skilled performance reflect the idea that performance proceeds through identifiably different learning phases, characterized by both qualitative changes in the cognitive substrate governing execution and changes in performance itself.

Fitts and Posner's (1967) three-stage model of skill acquisition suggests that early in learning, novices use explicit cognitive processes to control execution in a step-by-step fashion. Because of the involvement of conscious cognitive processes, this initial stage of skill learning has been termed the *cognitive phase*. After learners understand the nature of the task, they are thought to enter an *associative phase* in which the need to consciously control real-time performance diminishes and the performer begins to develop associations between specific stimulus situations and corresponding action responses. With extended practice, performance reaches the *autonomous phase*. In this final stage of skill learning, execution is believed to be based on an automatic task representation in which conscious attentional control is no longer required to execute a particular action when confronted by a specific stimulus situation.

Although Fitts and Posner's (1967) characterization of skill level differences has been extremely influential to the study of human skill acquisition, it should be noted that their framework is mostly descriptive. Nonetheless, it does allow one to form explicit hypotheses regarding differences in the attentional demands of novice and expert performance and the memory structures associated with performance at different levels of skill learning. Importantly, these differences can be empirically verified. In the first line of work described below, my colleagues and I have attempted to test the above-mentioned hypotheses regarding differences in the attentional substrate governing novice and expert performance (Beilock, Wierenga, & Carr, 2002). Our

method involved three lines of evidence and the sensorimotor task of golf putting as our test bed.

Attention, Memory, and Control of Novice and Experienced Performance

The first comparison involved the generic knowledge and episodic memories of experienced and novice performers. *Generic* knowledge captures schema-like or prescriptive information about how a skill is typically done, whereas *episodic* knowledge captures a specific memory, an autobiographical record of a particular performance. We predicted that experienced golfers would give longer, more detailed generic descriptions of the steps involved in a typical or "generic" putt compared to the accounts given by novices. After all, experienced golfers have spent thousands of hours honing their sport skill. Such practice opportunities should provide them with an opportunity to acquire a large amount of general knowledge about how their skill is typically performed (Beilock & Carr, 2001). In contrast, if on-line, well-learned golf putting is supported by procedural knowledge (as theories of automaticity and skill acquisition would predict), experienced golfers may well give shorter, less detailed episodic recollections of any particular putt in comparison to less skilled golfers. Because proceduralization reduces the need to attend to the specific processes by which skill execution unfolds, experienced golfers' episodic recollections of step-by-step real-time performance should be impoverished. This logic is driven by demonstrations that the successful explicit retrieval of information from memory is dependent on attention to this material at the time of encoding (Craik, Govoni, Naveh-Benjamin, & Anderson, 1996; Naveh-Benjamin, Craik, Guez, & Dori, 1998). Thus, if experienced golfers are not explicitly attending to on-line performance, their memories for the specific execution processes that supported performance may suffer.

The second comparison involved the attentional demands of single versus dual-task performance. Putting performance in a single-task, isolated environment was compared to performance in a dual-task condition in which individuals performed a series of putts while simultaneously engaging in a secondary

auditory monitoring task (participants monitored a series of words for a specified target word). Upon hearing the target word, individuals repeated it out loud. A recognition memory test for a subset of the distractor words heard while putting was administered after the dual-task was complete. Dual-task putting, word monitoring performance, and recognition memory for words heard while putting were used as measures of the attentional requirements involved in the golf putting task.

If well-learned putting does not require constant on-line attentional control, then the addition of a secondary monitoring task should not harm putting performance in comparison to single-task conditions. Furthermore, because experienced golfers' attentional resources should not be overly taxed by the putting task, they should have attention available to devote to the secondary task. As a result, both their target detection performance and their recognition memory for words heard while putting should be similar to that based on an auditory monitoring task performed in isolation as a baseline measure (i.e., when participants are not simultaneously performing a putting task). In contrast, novel skill execution that must be attended in real time should be differentially impacted by secondary task demands. The addition of a secondary monitoring task should not only harm novice putting performance, but should also result in poorer recognition memory for words heard while putting in comparison to the performance of either of these tasks in isolation. Novices should not be able to devote adequate attention to the monitoring task when simultaneously performing the putting task, and vice versa.

The third comparison involved our "funny putter" manipulation. My colleagues and I compared putting performance and memory protocols for experienced and novice golfers under both single-task and dual-task conditions. A subset of our novice and experienced golfers used a normal, regular putter while performing in this experiment. Another group of novices and experienced golfers used an altered "funny putter." The funny putter consisted of a regular putter head attached to an "s" shaped and arbitrarily weighted putter shaft. The design of the funny putter was intended to require experienced golfers to alter their well-practiced putting form in order to compensate for the distorted club, forcing them to al-

locate attention to the new skill execution processes. If the novel, funny putter requires experienced performers to alter skill execution processes, they should be forced to attend to task control in a step-by-step fashion in much the same way as individuals in less-practiced states. As a result, experienced golfers using the funny putter may no longer be able to attend to multiple tasks simultaneously. This would result in a decrease in dual-task putting performance and/or secondary auditory monitoring performance and recognition memory. Although the addition of novel task constraints via the funny putter may hinder performance, use of the tool should direct one's attention back to controlling the step-by-step execution of the primary task at hand, which in turn may enhance the experienced golfers' memories of how their skills unfolded. In contrast, novice performers should not be affected by the funny putter in the same way as more experienced golfers. Because novices have not yet adapted to putting under normal conditions, performance should not be drastically influenced by an altered putting environment. That is, to the novice, all putters are funny.

Eighty-four novice and experienced golfers participated in this study. Novice participants ($n = 42$) had no previous golf experience. Experienced participants ($n = 42$) were local high school and college students with 2 or more years of high school varsity golf experience or a Professional Golfers' Association (PGA) handicap less than 8. Individuals were randomly assigned within skill level to either a regular putter or funny putter condition in a 2 (novice golfer, experienced golfer) \times 2 (regular putter, funny putter) experimental design, with 21 participants in each group.

All participants took part in the same experimental procedure. Individuals first took 2 blocks of 20 putts followed by a generic memory questionnaire. The first block was designed to familiarize participants with the putting task and served as a pre-test measure of performance. The second block served as the single-task condition. Next, participants completed a word monitoring task in which they listened for a target word embedded in a series of words being played from a tape recorder, and upon hearing the target, repeated it aloud. The monitoring task was followed immediately by a short arithmetic task. The purpose of this task was to eliminate recency

effects associated with the word list in the monitoring task. A recognition memory test for a subset of the words presented in the single-task word monitoring condition was then administered. Participants next performed a dual-task putting and word monitoring task followed by an episodic memory questionnaire. Finally, participants completed a second arithmetic task after which they received another recognition memory test based on a subset of the words presented during the dual-task putting and word monitoring condition.

Thus, all participants, regardless of skill level or putter type, went through the exact same experimental procedure. We can now look to putting performance, recognition memory for words heard while putting, and generic and episodic memory protocols to explore differences in the on-line attentional demands of golf putting performance at different levels of expertise.

In terms of putting performance, as can be seen in Figure 1, both novice groups (regular and funny putter), as well as experienced golfers using the

funny putter showed performance decrements from the single-task to the dual-task putting condition. In contrast, experienced golfers using the regular putter continued to improve in putting accuracy from the single to dual-task condition.

There were no significant differences in target word identification across novice and experienced golfers for either the single-task auditory monitoring task or the dual-task auditory monitoring condition. This is likely due to the fact that target word identification failure occurred relatively infrequently across both conditions. In terms of recognition memory for words heard while putting, however, differences similar to those observed in primary putting performance are evident. As seen in Figure 2, both of the novice groups and the experienced golfers using the funny putter showed decrements in recognition memory (A) for words heard while putting, in comparison to a single-task word recognition test given as a base-line measure. The experienced golfers using the regular putter did not show this decrement in word recognition performance.

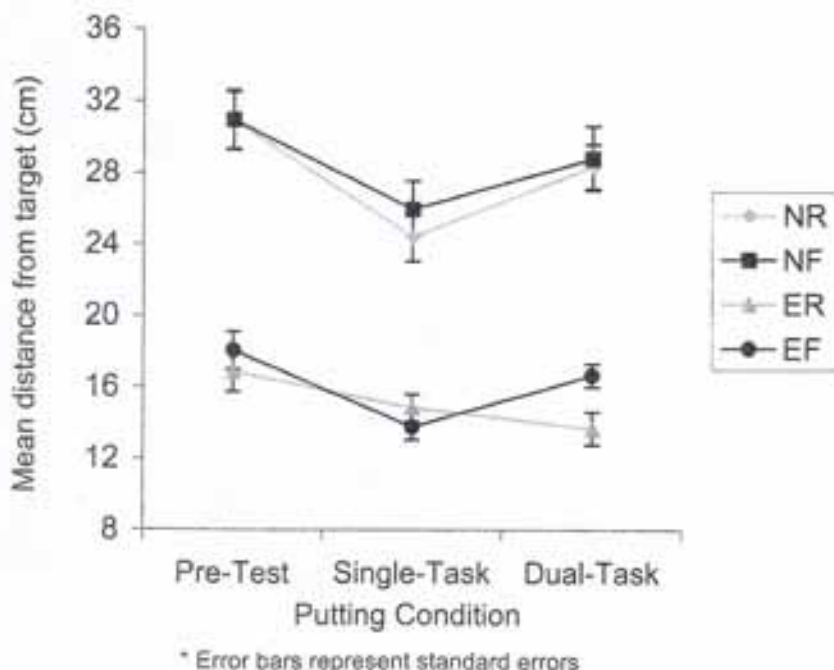


Figure 1. Mean distance (cm) from the target that the ball stopped after each putt in the pre-test, single-task, and dual-task conditions for the novices using the regular putter (NR), the novices using the funny putter (NF), the experts using the regular putter (ER), and the experts using the funny putter (EF). Reprinted from Bellock, S.L., Wierenga, S.A., & Carr, T.H. (2002). Expertise, attention, and memory in sensorimotor skill execution: Impact of novel task constraints on dual-task performance and episodic memory. *The Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 55, 1211-1240.

Thus, as illustrated by both putting performance and word recognition data, performing in a dual-task environment harmed novice golfers and experienced golfers using the funny putter, but did not disrupt putting performance or word recognition ability in experienced golfers putting under normal conditions. These results 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, experienced golfers, 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. However, these experienced golfers should be less able to allocate attention to and remember the step-by-step details of their performance. We can look to the generic and episodic memory protocols as a means to address this question.

As seen in Figure 3, protocol data showed that novice golfers produced short generic descriptions and longer episodic recollections. The type of putter

did not influence novices' protocols. This is to be expected, given that the novices were not experienced with either putter type. Experienced golfers using the regular putter produced an opposite pattern. Their generic descriptions were longer than those of the novices, reflecting golf expertise. Additionally, regular putter experts gave shorter episodic recollections in comparison to their generic descriptions and also in comparison to novices' episodic recollections. This impoverished episodic recollection demonstrates what Beilock and Carr (2001) have termed "expertise-induced amnesia." Although the extensive generic knowledge of experts may be declaratively accessible during off-line reflection, it does not appear to be accessed during real-time performance controlled by automated procedural knowledge. In contrast, experienced golfers using the funny putter did not show impoverished episodic recollection. These experts provided the most elaborate generic and episodic protocols, and their episodic recollections were longer than their generic descriptions, as opposed to those produced by the regular

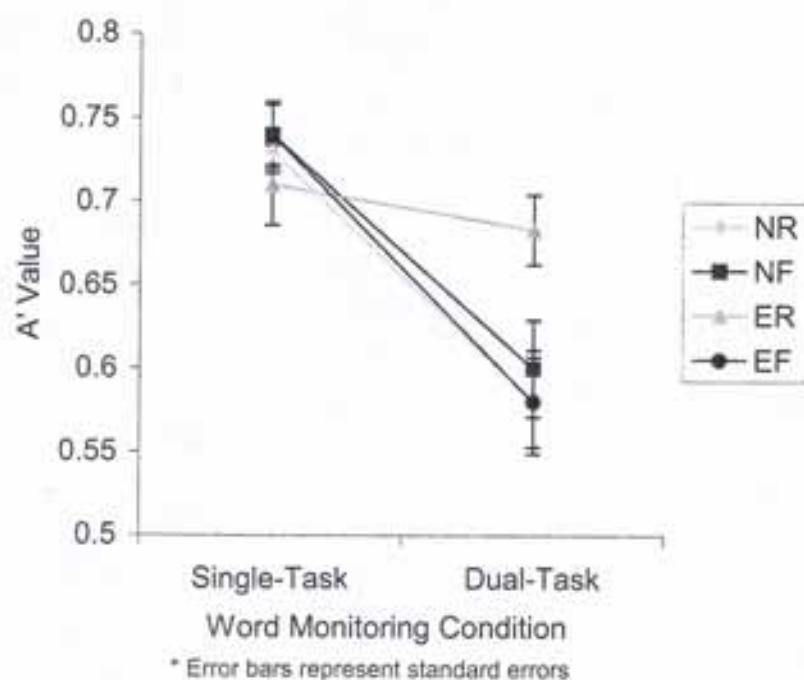


Figure 2. Mean A' value for the single-task and dual-task recognition memory tests for the novices using the regular putter (NR), the novices using the funny putter (NF), the experts using the regular putter (ER), and the experts using the funny putter (EF). Reprinted from Beilock, S.L., Wierenga, S.A., & Carr, T.H. (2002). Expertise, attention, and memory in sensorimotor skill execution: Impact of novel task constraints on dual-task performance and episodic memory. *The Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 55, 1211-1240.

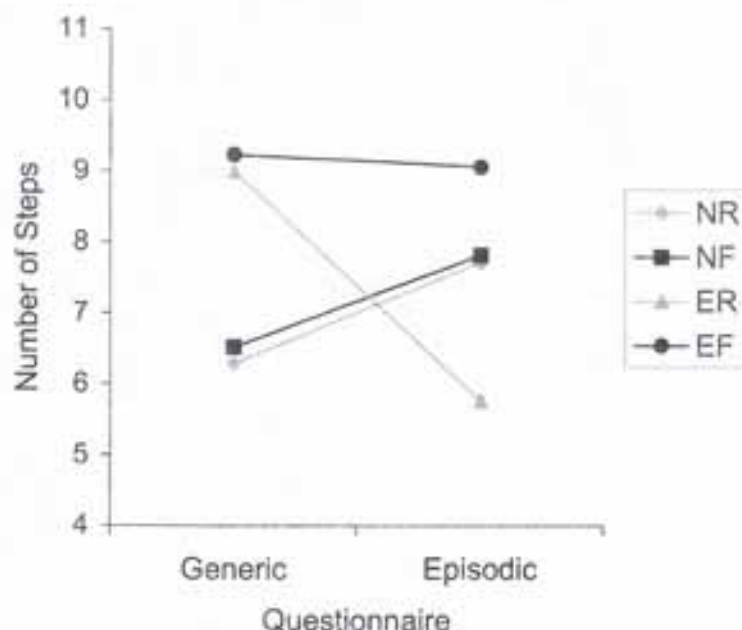


Figure 3. Mean number of steps for the generic and episodic questionnaires for the novices using the regular putter (NR), the novices using the funny putter (NF), the experts using the regular putter (ER), and the experts using the funny putter (EF). Reprinted from Bollock, S.L., Wierenga, S.A., & Carr, T.H. (2002). Expertise, attention, and memory in sensorimotor skill execution: Impact of novel task constraints on dual-task performance and episodic memory. *The Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 55, 1211-1240.

putter experts. Thus, when a proceduralized skill is disrupted by the imposition of novel task demands, expertise-induced amnesia disappears. Furthermore, when experts start attending to task performance, their expert knowledge allows them to remember more of what they are attending to than novices.

Although examining the overall number of steps reported in the memory protocols lends some insight into what our golfers were attending to during on-line execution and, thus, what they were able to explicitly retrieve after the fact, one way to more specifically address this issue is to look at the types of golf-related steps participants reported in their generic and episodic memory protocols. To achieve this goal, we divided protocol steps into three categories. Assessment or planning referred to deciding how to take a particular putt and what properties the putt ought to have. Examples are "I looked to see how far from the target I was," "there is little or no break in the putt," "look at the contour of the green," and "mentally create a line of sight" (from the ball to the hole or target). Mechanics or execution referred to the components of the mechanical act that implements the putt. Examples are "grip the

putter," "take the putter back," and "follow through as far as putter was taken back," all of which deal with the effectors and the kinesthetic movements of the effectors required to implement a putt. Ball destinations or outcomes referred to where the ball stopped or landed.

Because the altered weight and shape of the funny putter was designed to directly affect the mechanical aspect of the putting task in the present study, one might imagine the most striking differences in memory protocols would be observed as a function of putter type and expertise in the reporting of mechanical steps. This is precisely what occurred. Experienced golfers using the funny putter gave somewhat more mechanics steps in their episodic protocol in comparison to their generic description. In contrast, experienced golfers using the regular putter gave significantly fewer. Thus, both sets of golfers gave varied accounts of the mechanical properties involved in their putting performance in a manner consistent with the fact that one group used a tool designed to specifically alter how one attends to the mechanics of putting. The novices using regular and funny putters did not differ in

their mechanics accounts. Both groups gave more detailed mechanical descriptions in their episodic, in comparison to generic, protocols. Because novices must attend to execution in a step-by-step fashion, this explicit on-line attentional control affords them the ability to remember how their execution actually unfolded. For a detailed description of protocol reports, see Beilock et al. (2002).

This experiment documents a particular property of the cognitive substrate of sensorimotor skill execution—namely, the declarative accessibility, or openness to introspection and report, of skill processes and procedures at different levels of expertise. Inferences can be made from experienced and novice golfers' generic and episodic memory representations concerning the underlying control structures driving real-time performance. Specifically, the real-time control structures supporting performance differ as a function of skill level. Novice performances are attended to on-line. Experienced skill execution (especially mechanical instantiation) does not mandate step-by-step attentional control, as long as experienced golfers are operating in a normal environment with normal task tools. These conclusions are relevant to understanding expertise, and may also lend insight into performance decrements in situations (e.g., high pressure situations) that tend to force attention to performance in ways that may be non-optimal, especially for highly skilled performers. The next section, detailing the cognitive mechanisms governing suboptimal performance in high-pressure situations, addresses just this issue.

Choking under Pressure

The desire to perform as well as possible in situations with a high degree of perceived importance is thought to create performance pressure (Baumeister, 1984; Hardy, Mullen, & Jones, 1996). Paradoxically, despite the fact that *performance pressure* often results from aspirations to function at an optimal level, pressure-packed situations are where suboptimal skill execution may be most visible. The term *choking under pressure* has been used to describe this phenomenon. Choking is defined as performing more poorly than expected given one's skill level, and is thought to occur across many diverse task domains where incentives for optimal performance

are at a maximum (Beilock & Carr, 2001; Lewis & Linder, 1997; Masters, 1992; Wang, Marchant, & Morris, 2004).

Although documenting instances of choking under pressure (in both laboratory and real world settings) provides insight into the conditions under which this type of skill failure occurs, it is an understanding of the cognitive mechanisms governing pressure-induced failure that will truly advance our knowledge of the choking phenomenon. Moreover, a clear picture of choking processes sets the stage for the development of training regimens designed to alleviate these unwanted performance failures. The obvious question then is "Why does choking under pressure occur?"

The following sections outline two of the main attentional theories that have been used to account for performance decrements under pressure and the empirical research my colleagues and I have conducted in an attempt to test these accounts of less-than-optimal performance. It should be noted that, although the majority of this research focuses on how high-demand situations change the deployment of attentional resources during on-line execution, there is also work examining the physiological and biomechanical processes associated with less-than-optimal performance. A full account of these processes is outside the scope of the current work. For a detailed review, see Beilock and Gray (in press).

Explicit Monitoring Theories

Explicit monitoring theories suggest that pressure situations raise self-consciousness and anxiety about performing correctly (Baumeister, 1984). This focus on the self is thought to prompt individuals to turn their attention inward on the specific processes of performance in an attempt to exert more explicit monitoring and control than would be applied in a non-pressure situation (Baumeister, 1984; Beilock & Carr, 2001; Lewis & Linder, 1997). Such explicit attention to step-by-step skill processes and procedures is thought to disrupt well-learned or proceduralized performance processes that normally run largely outside of conscious awareness (Beilock, Bertenthal, McCoy, & Carr, 2004; Kimble & Perlmuter, 1970; Langer & Imber, 1979). Masters' (1992) *reinvestment theory* suggests that the specific mechanism governing explicit monitoring is "dechunking."

Pressure-induced attention to execution causes an integrated or proceduralized control structure that normally runs off without interruptions to be broken back down into a sequence of smaller, independent units—similar to how the performance was organized early in learning.

Recently, researchers have conducted a number of studies to examine the attentional correlates of suboptimal performance under pressure in high level sensorimotor skills using explicit monitoring theories as a guideline. Many of these studies do not involve pressure at all, but attempt to mimic the attentional demands that pressure might induce. The logic here is that if researchers can discover the types of attentional manipulations that compromise performance, they can then use this evidence to begin to infer how pressure might exert its impact.

Beilock, Carr, MacMahon, and Starkes (2002) directly manipulated the attentional focus of experienced soccer players while they were performing a soccer dribbling task. Experienced soccer players dribbled the ball through a series of cones while performing either a secondary auditory monitoring task (designed to distract attention away from execution—similar to the auditory monitoring task used in Beilock et al.'s (2002) golf putting work mentioned earlier) or a skill-focused task in which individuals monitored the side of the foot that most recently contacted the ball (designed to draw attention to a component process of performance, mimicking the proposed mechanism of explicit monitoring theories). Performing in a dual-task environment did not harm the dribbling skill of experienced soccer players in comparison to a single-task practice condition used as a baseline. When the soccer players were instructed to attend to performance (i.e., monitoring the side of the foot that most recently contacted the ball), their dribbling skill deteriorated in comparison to both the dual-task condition and a single-task baseline. Consistent with explicit monitoring theories of choking, step-by-step attention to skill processes and procedures appears to harm well-learned performance.

Supporting evidence regarding the differential impact of distraction versus skill-focused attention has also been obtained from a different kind of manipulation: speed versus accuracy performance instructions. Beilock et al. (2004) found that simply

limiting the opportunity for skill-focused, explicit monitoring through instructions to perform a putting task rapidly improved the performance of experienced golfers, relative to a condition in which the same golfers were told to take as much time as they needed to be accurate. The impact of this manipulation was phenomenologically noticeable. Several golfers reported that the speed instructions aided their performance by keeping them from thinking too much about execution.

Although these types of attention studies lend indirect insight into the cognitive mechanisms driving skill failure in high stakes situations, it is also possible to more directly assess the impact of pressure to perform at a high level on skill execution. In a recent study, Gray (2004) directly investigated the effects of performance pressure on baseball batting in highly skilled Division I Intercollegiate baseball players. Individuals performed a virtual batting task in a pre-test situation and were then split into two groups. Batters in the "pressure group" were instructed that they had been paired with one other batter in the study and they would receive a monetary reward if both of them could increase their total number of hits in the next block of trials by a designated amount. Batters in this group were further instructed that their teammate had already successfully reached the criterion for reward. Thus, both social pressure and monetary incentives were used to induce feelings of performance pressure in the baseball players (a manipulation first used by Beilock & Carr in 2001). Batters in a second, "control group," were given no further information. Both groups (i.e., pressure and control) then continued to perform the virtual batting task (i.e., in a post-test).

Batters in the pressure group exhibited clear choking effects. Mean temporal batting errors were significantly higher following the pressure manipulation in comparison to previously. Not only did these batters fail to reach the incentive criterion, their performance under pressure was actually worse than their baseline performance—direct evidence of choking. In terms of batters in the control group, there was no significant difference between mean temporal errors in the two blocks of trials. The most interesting result, however, comes from evidence documenting how the pressure situation changed the attentional focus of the baseball players. While

performing in the post-test, both the pressure and control participants were asked to judge the direction their bat was moving at specified intervals. In the pressure group there was a significant decrease in the percentage of judgment errors in this task in comparison to a pre-test used as a baseline. This decrease was not seen for control group participants. This result indicates that the pressure caused batters to turn their attention inwards and explicitly monitor their swing execution. Although this pressure-induced change in attentional deployment resulted in more accurate skill-focused judgments, it also appeared to disrupt automated execution processes, resulting in less-than-optimal batting performance.

Explicit monitoring theories of choking under pressure 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; Beilock & Carr, 2001; Beilock et al., 2002; Lewis & Linder, 1997; Masters, 1992). 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. This is due to the fact that the former operate largely outside of working memory, and pressure-induced attention should most strongly disrupt processes that are normally devoid of step-by-step attentional control.

Beilock and Carr (2001) have found support for the notion that well-learned, but not novice, sensorimotor skill execution is susceptible to performance decrements under pressure via this mechanism of inappropriate explicit monitoring or execution focus. Participants learned a golf putting skill to a high level and were exposed to a high-pressure situation both early and late in practice. Early in practice, pressure to do well did not harm performance. At later stages of learning, performance decrements under pressure emerged. Thus, it appears that the proceduralized performances of experts are negatively affected by performance pressure. Novice skill execution, however, is not harmed by pressure-induced attention to execution, because less skilled performance is already explicitly attended to in real time. This finding is consistent with Marchant and Wang's (2001) assertion that most of the evidence for choking under

pressure has been derived from well-learned sensorimotor tasks that automate via proceduralization with extended practice (see also, Wang, Marchant, Morris, & Gibbs, 2004).

All of this evidence suggests that explicit monitoring theories account quite well for the choking phenomenon. One might notice, however, that a majority of the skills used in the research mentioned here were well-learned sensorimotor skills that are thought to run largely outside of working memory with extended practice (Fitts & Posner, 1967; Keele, 1986; Proctor & Dutta, 1995). Working memory is a short-term memory system that is involved in the control, regulation, and active maintenance of a limited amount of information with immediate relevance to the task at hand (Miyake & Shah, 1999). Although the types of well-learned sensorimotor skills that have been studied so far (e.g., a well-learned golf putt on a straight, flat green) may not rely heavily on working memory, there are sports skills that likely utilize working memory resources. This applies, in particular, to skills that involve holding and manipulating information on line, such as the types of decision making and strategizing that are important components of high level performance (e.g., reading a complex green, strategizing about an upcoming move). Thus, it is an open question as to how skills that *do* rely heavily on working memory fare in a demanding high pressure situation. It seems unlikely that such skills would fail because of pressure-induced attention to execution, as these skills are presumably already attended to on line. Thus, are there other mechanisms by which such skills might fail?

Distraction Theories

If we look to literature in which heavily working memory-demanding skills have been tested (e.g., the test-taking and math anxiety literature), most individuals believe pressure-induced distraction underlies such unwanted performance decrements (as opposed to the type of pressure-induced over-attention that explicit monitoring theories support). Specifically, *distraction theories* propose that pressure influences task performance by creating a distracting environment that compromises the working memory resources available for primary task performance. Distraction-based accounts of suboptimal performance suggest that performance pressure

shifts attentional focus to task-irrelevant cues, such as worries about the situation and its consequences. This shift of focus changes what was single-task performance into a dual-task situation in which controlling the task at hand and worrying about the situation compete for the limited working memory resources of the performer.

The most notable arguments for the distraction hypothesis come from research involving academic test anxiety (Ashcraft & Kirk, 2001; Eysenck, 1979; Wine, 1971). Individuals who become highly anxious during test situations, and consequently perform at a suboptimal level, are thought to divide their attention between task-relevant and task-irrelevant thoughts more so than those who do not become overly anxious in high pressure situations (Wine, 1971).

Additional support for a distraction account of choking comes from recent work specifically examining the impact of performance pressure on cognitive task performance. Beilock, Kulp, Holt, and Carr (2004) had individuals perform easy math problems, as well as those that placed heavy demands on working memory, in both low and high pressure situations. The high pressure scenario was based on several sources of pressure that commonly exist across skill domains—monetary incentives, peer pressure, and social evaluation. Although it is an empirical question as to exactly how these different sources of pressure exert their influence, the purpose of the study was to capture the real-world phenomenon of choking. Thus, we created a pressure scenario that incorporated as many components of high pressure performance as possible. In athletics, for example, performance is frequently scrutinized by others, there are often monetary consequences for winning and losing, and team success is dependent on the performance of individual athletes, which may generate peer pressure to perform at an optimal level. In academic arenas, monetary consequences for test performance are manifested in terms of scholarships, and future educational opportunities and social evaluation of performance come from mentors, teachers, and peers.

Beilock, Kulp et al. (2004) found that pressure does indeed cause individuals to worry. Moreover, only those math problems that were strongly reliant on the working memory resources that such worries are thought to consume caused signs of failure

under pressure. Thus, there is evidence that pressure can compromise working memory resources, causing failure in tasks that rely heavily on this system. Support comes from working-memory-intensive math problem solving under pressure (Beilock, Kulp et al., 2004). There is also added support in terms of susceptibility to choking under pressure as a function of working memory capacity.

In particular, my colleague and I have examined the relation between pressure-induced performance decrements in mathematical problem solving and individual differences in working memory capacity (Beilock & Carr, 2005). As mentioned earlier, working memory at heart involves control, regulation, and active maintenance of a limited amount of information with immediate relevance to the task at hand (Miyake & Shah, 1999). Some people have more of this ability (high working memory individuals) and some have less (low working memory individuals). In this work, individuals lower or higher in working memory performed both easy and difficult math problems under low pressure and high pressure conditions. The pressure condition was created by implementing the same scenario described in the Beilock, Kulp et al. (2004) research previously outlined.

As can be seen in Figure 4, decrements under pressure were limited to difficult problems that made the largest demands on working memory, as one might expect. Surprisingly, however, only individuals high in working memory capacity showed these decrements. Individuals lower in working memory capacity performed less well on high-demand problems in the absence of pressure, but did not decline from their established (though significantly lower) level of achievement when pressure was applied. Under normal conditions, high working memory individuals outperform low working memory individuals because they have superior attentional allocation capacities of these types. When such attentional capacity is compromised, the advantage for high working memory individuals disappears. Thus, this work provides support for a distraction-based account of performance pressure by demonstrating systematic differences in susceptibility to performance pressure as a function of individual differences in working memory capacity. That is, to the extent that pressure can operate by impacting the working memory resources available for performance, it follows that

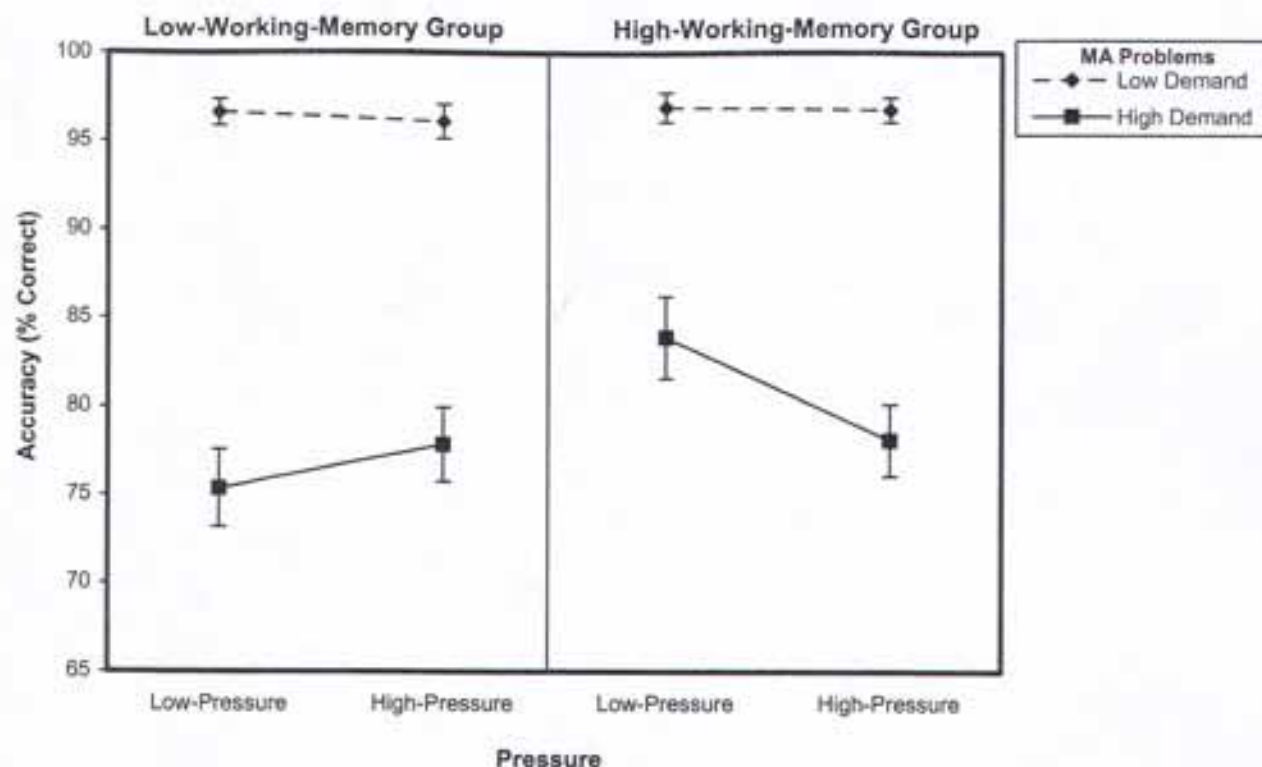


Figure 4. Mean accuracy (upper graph) and mean reaction time (lower graph) for the low-working-memory group (left panel) and for the high-working-memory group (right panel) for the easy (low demand) and difficult (high demand) math problems in the low-pressure and high-pressure tests. Error bars represent standard errors. Reprinted from Beilock, S.L., & Carr, T.H. (2005). When high-powered people fail: Working memory and "choking under pressure" in math. *Psychological Science*, 16, 101-105.

individual differences in this resource should moderate the impact of pressure on performance.

Performance Pressure's Dual Impact

Explicit monitoring and distraction theories essentially make opposite predictions regarding how pressure exerts its impact. Distraction theories suggest that pressure shifts needed attention away from execution; explicit monitoring theories suggest that pressure shifts too much attention to skill execution processes. Can both theories be correct?

Beilock, Kulp, et al. (2004) have suggested that performance pressure creates two effects that alter how attention is allocated to execution: (1) Pressure induces worries about the situation and its consequences, thereby reducing working memory capacity available for performance, as distraction theories would propose. (2) At the same time, pressure prompts individuals to attempt to control execution in order to ensure optimal performance, in line with explicit monitoring theories. This suggests that how

a skill fails is dependent on performance representation and implementation.

Tasks that require executive control of a sequence of steps or maintenance of intermediate products may fail via pressure-induced consumption of working memory (e.g., complex math tasks, sport strategizing). In contrast, tasks that automate via proceduralization should fail when attention is drawn to step-by-step execution (e.g., a well-learned and repeatedly executed golf putt). It is important to note that it does not seem to be merely a cognitive versus motor distinction that predicts how a skill will fail under pressure. That is, just because one is performing an academically based, cognitive task does not mean this task will show signs of failure via pressure-induced distraction. Likewise, sports skills do not necessarily fail via pressure-induced explicit monitoring. Rather, it appears to be the manner in which skills utilize on-line attentional resources that dictates how they will fail (though this is often related to skill domain).

Thus, sports skills that make heavy demands on working memory, such as strategizing, problem solving, and decision making (i.e., skills that involve considering multiple options simultaneously and updating information in real time) will likely fail as a result of pressure-induced working memory consumption—similar to a working-memory-dependent academic task. These skills, however, will be relatively impervious to attempts at focusing one's remaining attention on step-by-step control that is also induced by pressure. In contrast, sensorimotor skills that run largely outside of working memory will fail when pressure-induced attention disrupts automated control processes—and not because the overall capacity of working memory has been reduced. Of course, future work is needed to fully understand how pressure situations exert their impact across the entire range of skills for which important performances sometimes result in disappointing outcomes.

Conclusion

In conclusion, in this chapter I have presented two different lines of work that focus on the acquisition and maintenance of complex skills. The first line utilizes differences in the memory structures and on-line attentional demands of novice and expert sensorimotor skill execution (e.g., golf putting) to develop an account of the real-time control structures supporting motor skill performance across levels of learning. This work was followed by a presentation of my recent research examining the executive control processes supporting higher level cognitive tasks (e.g., mathematical problem solving) in demanding and high pressure situations. Together, these two lines of work demonstrate how task type and skill level differences in the attentional demands governing performance can be used to understand the nature of successful skill execution and why, at times, it fails to occur. Thus, if one brings the chapter back full circle to Yogi Berra's quote presented in the first paragraph (i.e., "How can you hit and think at the same time?"), the answer seems to be that it depends—it depends on the skill level of the performer and the cognitive demands of the skill being performed.

References

- Anderson, J. R. (1993). *Rules of mind*. Hillsdale, NJ: Erlbaum.
- Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General*, 130, 224-237.
- Baumeister, R. F. (1984). Choking under pressure: Self-consciousness and paradoxical effects of incentives on skillful performance. *Journal of Personality and Social Psychology*, 46, 610-620.
- Beilock, S. L., Bertenthal, B. I., McCoy, A. M., & Carr, T. H. (2004). Haste does not always make waste: Expertise, direction of attention, and speed versus accuracy in performing sensorimotor skills. *Psychonomic Bulletin & Review*, 11, 573-579.
- Beilock, S. L., & Carr, T. H. (2001). On the fragility of skilled performance: What governs choking under pressure? *Journal of Experimental Psychology: General*, 130, 701-725.
- Beilock, S. L., & Carr, T. H. (2005). When high-powered people fail: Working memory and "choking under pressure" in math. *Psychological Science*, 16, 101-105.
- Beilock, S. L., Carr, T. H., MacMahon, C., & Starkes, J. L. (2002). When paying attention becomes counterproductive: Impact of divided versus skill-focused attention on novice and experienced performance of sensorimotor skills. *Journal of Experimental Psychology: Applied*, 8, 6-16.
- Beilock, S. L., & Gray, R. (in press). Why do athletes "choke" under pressure? In G. Tenenbaum and B. Eklund (Eds.), *Handbook of sport psychology* (3rd ed.). Wiley.
- Beilock, S. L., Kulp, C. A., Holt, L. E., & Carr, T. H. (2004). More on the fragility of performance: Choking under pressure in mathematical problem solving. *Journal of Experimental Psychology: General*, 133, 584-600.
- Beilock, S. L., Wierenga, S. A., & Carr, T. H. (2002). Expertise, attention, and memory in sensorimotor skill execution: Impact of novel task constraints on dual-task performance and episodic memory. *The Quarterly Journal of Experimental Psychology: Human Experimental Psychology*, 55, 1211-1240.
- Craik F. I. M., Govoni R., Naveh-Benjamin M., & Anderson N. D. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology: General*, 125, 159-180.
- Eysenck, M. W. (1979). Anxiety learning and memory: A reconceptualization. *Journal of Research in Personality*, 13, 363-385.
- Fitts, P. M., & Posner, M. I. (1967). *Human performance*. Belmont, CA: Brooks/Cole.
- Gray, R. (2004). Attending to the execution of a complex sensorimotor skill: Expertise differences, choking and slumps. *Journal of Experimental Psychology: Applied*, 10, 42-54.
- Hardy, L., Mullen, R., & Jones, G. (1996). Knowledge and conscious control of motor actions under stress. *British Journal of Psychology*, 87, 621-636.
- Keele, S. W. (1986). Motor control. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance* (Vol. 7). New York: Wiley.
- Kinble, G. A., & Perlmuter, L. C. (1970). The problem of volition. *Psychological Review*, 77, 361-384.
- Langer, E., & Imber, G. (1979). When practice makes imperfect:

- Debilitating effects of overlearning. *Journal of Personality and Social Psychology*, 37, 2014-2024.
- Lewis, B., & Linder, D. (1997). Thinking about choking? Attentional processes and paradoxical performance. *Personality and Social Psychology Bulletin*, 23, 937-944.
- Marchant, D. B., & Wang, J. (2001). Choking: Current issues in theory and practice. Paper presented at the 10th World Congress of Sport Psychology, Skiathos Island, Greece.
- Masters, R. S. W. (1992). Knowledge, knerves and know-how: The role of explicit versus implicit knowledge in the breakdown of a complex motor skill under pressure. *British Journal of Psychology*, 83, 343-358.
- Miyake, A., & Shah, P. (1999). Toward unified theories of working memory: Emerging general consensus, unresolved theoretical issues, and future research directions. In A. Miyake & P. Shah (Eds.), *Models of working memory: Mechanisms of active maintenance and executive control* (pp. 442-481). New York: Cambridge University Press.
- Naveh-Benjamin, M., Craik, F. I. M., Guez, J., & Dori, H. (1998). Effects of divided attention on encoding and retrieval processes in human memory: Further support for an asymmetry. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 24, 1091-1104.
- Proctor, R. W., & Dutta, A. (1995). *Skill acquisition and human performance*. Thousand Oaks, CA: Sage.
- Wang, J., Marchant, D. B., & Morris, T. (2004). Coping style and susceptibility to choking under pressure. *Journal of Sport Behavior*, 27, 75-92.
- Wang, J., Marchant, D., Morris, T., & Gibbs, P. (2004). Self-consciousness and trait anxiety as predictors of choking in sport. *Journal of Science in Medicine and Sport*, 7, 174-185.
- Wine, J. (1971). Test anxiety and direction of attention. *Psychological Bulletin*, 76, 92-104.