Expert Performance in Sports

Advances in Research on Sport Expertise

Janet L. Starkes, PhD
McMaster University

K. Anders Ericsson, PhD
Florida State University

Editors

Human Kinetics

Contents

Acknowledgments vii

Foreword ix

Part I Introduction 1

Chapter 1 The Magic and the Science of Sport Expertise: Introduction to Sport Expertise Research and This Volume 3
■ Janet L. Starkes

Part II Where Are We and How Did We Get There? 17

Chapter 2 Expert Performance in Sport: Current Perspectives and Critical Issues 19
■ Christopher M. Janelle and Charles H. Hillman

Chapter 3 Development of Elite Performance and Deliberate Practice: An Update From the Perspective of the Expert Performance Approach 49
■ K. Anders Ericsson

Part III Developing and Retaining Sport Expertise 85

Chapter 4 From Play to Practice: A Developmental Framework for the Acquisition of Expertise in Team Sports 89
■Jean Cote, Joseph Baker, and Bruce Abernethy

Chapter 5 A Search for Deliberate Practice: An Examination of the Practice Environments in Figure Skating and Volleyball ■Janice M. Deakin and Stephen Cobley 115

Chapter 3

Development of Elite Performance and Deliberate Practice

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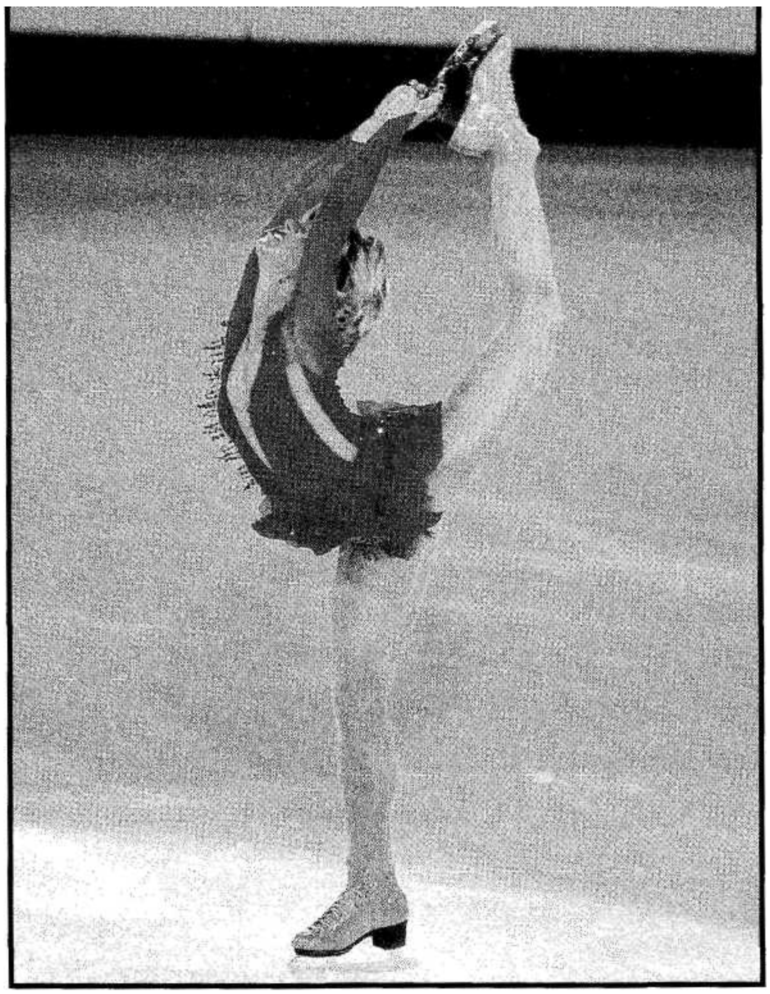
An Update From the Perspective of the Expert Performance Approach



K. Anders Ericsson

When elite athletes such as ice skaters, divers, and soccer players demonstrate their outstanding skills at public competitions, their performances often look exquisitely natural and gracefully effortless. To the casual observer, these exhibitions appear so extraordinary that it seems unlikely that most other performers—regardless of any amount or type of training—can ever achieve similar performance levels. It is tempting to view these amazing performances as a reflection of some unique, innate talent, which is required before anyone can achieve such a performance. Indeed, some athletes have body builds with the requisite flexibility, strength, and speed to suggest that they must have been born to be superior athletes. Some would even argue that these athletes seem to possess a general athletic ability that would allow them to excel in virtually any type of sport.

If general athletic ability and innate talents were the primary constraints on elite achievement, then one would naturally expect the same athletes to excel at a wide range of sports. For example, one would expect that an elite gymnast would be able to display similarly superior performance as a diver or an ice skater with a minimum of additional training. However, among contemporary athletes, such transfer of elite performance across domains of sport is rare. International level of performance has never (to my knowledge) been demonstrated across different sports without prior extended training. In the late 20th and early 21st centuries, athletes are able to attain international-level performance only in a few highly related events that are consistent with their current and past training. Is it even possible that the development of elite athletic performance can be fully explained as the results of extensive training?

In chapter 2 of this book, Janelle and Hillman provide a clear and comprehensive account of the ongoing discussion about the relative role of innate factors (genetics) versus training (environment) in attaining the highest levels of performance. They demonstrate that the scientific discussion has moved beyond arguing about the relative importance of genetics and environment for the development of performance. This chapter will therefore explore both environmentally induced mechanisms and genetic mechanisms, both of which influence and control the development and structure of expert performance.

If one favors a genetic account to explain why some select athletes can attain exceptional levels of performance, then researchers are now expected to demonstrate the influence of specific genes on the development of nerves, muscles, and other physiological systems of their bodies. In other words, which genes do only the select athletes possess as part of their DNA? Similarly researchers who favor an account based on acquired skills need to identify the effects of specific types of practice. That is, what exact activities lead these select individuals to acquire the cognitive skills and the physiological adaptations to attain their superior performance? Researchers may even have to specify the particular stages of development. They may have to illustrate when the developing child and adolescent should engage in the practice and training because anatomical structures and physiological systems would theoretically be maximally modifiable during certain critical periods (Ericsson, 2002; Ericsson & Lehmann, 1996).

In this chapter, I sketch the development of accounts regarding expert performance. In an initial section on its historical background, I discuss how recent findings have led many researchers to question the traditional theories of expertise. Specifically, I examine how the dramatic effects of training and extended practice transformed the assumption that performance and cognitive processes were constrained by innately determined capacity. In the remainder of the chapter, I use the expert performance approach (Ericsson & Smith, 1991) as a framework to discuss how we can describe elite performance in each domain and how we can reproduce the associated superior performance under controlled conditions. I discuss advances in the analysis of the mechanisms that mediate the reliably superior performance of elite athletes. I also focus on our improved understanding of how athletes attain their detailed mechanisms and abilities in the course of their developing expert performance. In particular, I examine how the performance of individual athletes develops longitudinally over decades of engagement in activities in their domain of expertise.

Historical Background

The pioneering research on expertise and expert performance focused not on sport, but on world-class chess players and on how these players differed from skilled players in local chess clubs (de Groot, 1946/1978). In the 1970s and 1980s, Simon and Chase (1973) developed and formalized de Groot's framework and thus proposed a theoretical perspective that would eventually dominate the concepts of expertise in a range of domains. Simon and Chase's theory proposed that world-class chess players did not differ from less accomplished players in terms of their mental "hardware" or basic abilities and general capacities. In other words, experts were constrained by the same unmodifiable limits of short-term memory (STM) and speed of processing.

Simon and Chase generalized that the performance advantage of experts was attributed to their vast storehouse of knowledge and complex patterns (chunks), which they had accumulated during their many years of experience in their respective domains of activity, either in chess or sport. In a compelling series of studies, Chase and Simon (1973) showed the dramatic effect of the experts' complex domain-specific patterns of memory for chess configurations. When representative situations from chess games were briefly presented to subjects, the chess experts' memory was found to be vastly superior to that of beginning chess players. However, when the same chess pieces were randomly arranged to eliminate any meaningful patterns, the experts' significant memory advantage over the beginners virtually disappeared, and the expert players—now exhibiting performances similar to novices—could only recall around four or five chess pieces.

The finding that superior memory performance of experts is limited to familiar meaningful stimuli from the domain was later replicated in several other domains of expertise. In an influential series of studies (for a review, see Starkes & Allard, 1991), the expert-level athletes demonstrated superior memory over less skilled players when the situations reflected representative situations from actual games. However, memory for unstructured situations, such as the same players' walking back to the sidelines at intermissions, is not any better for experts than for less skilled players.

Simon and Chase's (1973) theory of expertise predicted a close association between individual players' proficiency of performance during actual games (the crucial attribute of expert performers) and the capacity of their memory for representative stimuli. Simon and Chase's theory assumed that expert performance, such as playing chess or soccer, was mediated by the same patterns and knowledge that mediated the superior memory for representative game situations. However, several studies failed to find a close correlation, and moreover, they even uncovered superior memory without superior performance and vice versa (superior performance without superior memory). These findings raise issues about the sufficiency of the pattern-recognition model proposed by Simon and Chase (1973), and these results therefore suggest that more complex mechanisms must mediate expert performance (for an extended discussion, see Ericsson, Patel, & Kintsch, 2000).

In a review of expert performance, Smith and I (Ericsson & Smith, 1991) concluded that the traditional theories of expertise (cf. Simon & Chase, 1973) and skill acquisition (cf. Fitts & Posner, 1967) could not fully account for the new and emerging evidence on complex mechanisms of memory and perception that mediate expert performance. These theories had particular difficulties in explaining how the identified complex mechanisms could be acquired within the fixed limits of memory and perception. In our review, we argue that when experts extend their training over months and years, they are able to acquire mechanisms that can either circumvent or simply change the basic limits on information processing. These processing limits appear to provide valid constraints in typical training studies that last only a few hours. When the training is extended for *hundreds* of hours, however, regular college students were shown to be able to improve their memory performance dramatically and actually acquire qualitatively different cognitive mechanisms, as will be shown in the next section.

Expanding Working Memory With Practice

A fundamental assumption of Simon and Chase's (1973) theory of expertise is that experts' and novices' performances are constrained by the general limit of short-term memory, which can hold no more than seven chunks (plus or minus two; Miller, 1956). In an early study, Chase and I (Chase & Ericsson, 1981; Ericsson, Chase, & Faloon, 1980) showed that with practice, subjects could alter this general limit of seven. In our study, we afforded a few "unexceptional" college students the opportunity to practice recalling series of auditorily presented digits. As a result of their practice, all of the students became exceptional with their short-term memory. Each student could perfectly recall over 20 digits, as can be seen in figure 3.1. Two of the students continued their training, and after several hundred hours of practice, they were able to recall over 80 digits. Every one of our trained students started the memory training experiment with normal memory capacity for a series of digits—they could accurately recall about seven digits (such as a typical phone number). We concluded that the students' exceptional memory must thus be directly attributable to training.

Most important, we studied how the thought processes of our students changed as their memory for digits increased. At the start of training, the students rehearsed the presented digits to themselves—the same way that nearly all adults do when remembering digits. However, after more practice, our students started to segment the presented digits into groups in an attempt to store the groups into long-term memory (LTM), thus creating associations to numerical patterns and preexisting knowledge. For example, several of them encoded three-digit groups as running times—357 would be 3 minutes and

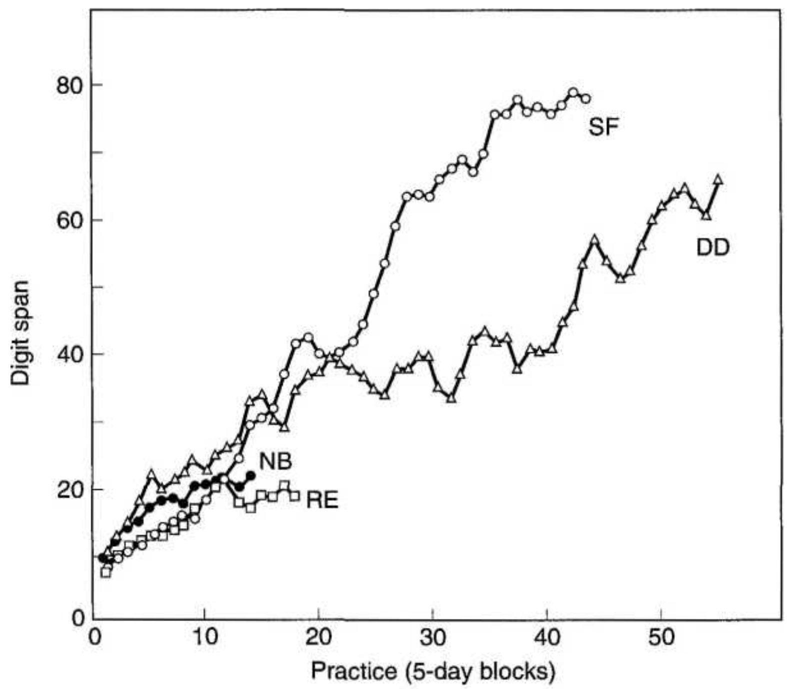


Figure 3.1 Ability to accurately reproduce series of rapidly presented digits (digit span) as a function of practice for four regular college students (whose initials are SF, RE, DD, and NB). The initial digit span for all students was about seven digits, which is the average memory performance of college students.

From W.G. Chase and K.A. Ericsson, Skilled memory. In *Cognitive skills and their acquisition* (Mahwah, NJ: Lawrence Erlbaum Publishing), 141-189. Adapted by permission of K.A. Ericsson.

57 seconds, a time just below the 4-minute mile. They also developed retrieval cues to encode the locations of the digit groups within the list so that they could recall all the digits in order (for a detailed description of the complex skills that the students developed to attain their exceptional memory, see Chase & Ericsson, 1981,1982).

Chase and I collected the students' verbal reports on their thoughts during the trials of memory testing; we also designed experiments to test and validate the mechanisms that the students developed through practice. We thus demonstrated that it was possible to understand the development of exceptional ability in initially "unexceptional" subjects. We then went on to describe the acquisition of specific mechanisms as a function of continued training. Based on subsequent training studies by other investigators, our conclusion is that it is now reasonable to argue that motivated "average" adults can acquire exceptional levels of memory performance by acquiring memory skills for specific types of information. The specific structure of these acquired memory skills will vary among participants as a function of their prior knowledge and skill (Ericsson, 1988).

To assess if these findings could be extended beyond skills acquired in the laboratory, my colleagues and I discovered various individuals with exceptional memory in all walks of everyday life, including a waiter who could remember complete dinner orders from 20 customers without any written notes, and an exceptional person who had memorized over 40,000 digits of the mathematical constant pi. With many other scientists, we have tested musicians, chess players, actors, and many others with exceptional abilities, and we have been able to identify the cognitive mechanisms that mediate the superior memory performance of many experts from a wide range of domains (for a review, see Ericsson and Lehmann, 1996). In a recent review, Kintsch and I (Ericsson & Kintsch, 1995) showed that experts were able to acquire memory skills that allowed them to expand their working memory to engage in planning, reasoning, evaluation, and other demanding activities that involved working memory. Hence, experts are indeed able to develop their skills to provide for the working memory needed for their superior performance.

A Broader View of Limits to Improvement of Performance

The improvements in working memory along with numerous other findings raise doubt about the view that fixed capacities limit an individual's ability to reach the highest levels of performance. In fact, virtually all elements of the human body can change and adapt to induced demands, and these changes can be particularly dramatic when practice is initiated during childhood and adolescence. For example, a ballet dancer's ability to turn out the feet and the range of motion of a baseball pitcher's shoulder joint are both influenced by appropriate practice (Ericsson & Lehmann, 1996).

More general, when the cells of the human body are put under exceptional strain, a whole range of extraordinary physiological processes are activated in the body. For example, adults' bodies can recover from surgery, and broken bones can heal. Similarly, when adults donate one of their kidneys, the remaining kidney grows automatically in size by approximately 70% during the two weeks following surgery. When adults expose themselves to demanding and physiologically straining activities or when they challenge themselves to improve their performance by deliberate practice, they are eventually able to transcend the stable structure of abilities and capacities that mediate activities in everyday life (Ericsson, 1996, 2002). Later in this chapter, I discuss the empirical evidence for the marked modifiability of human characteristics as a result of extended practice.

Reviews of expert performance have, in my opinion, been unsuccessful in uncovering any evidence of innate talents that are critical to expert performance, including factors that could not be altered or circumvented with the subjects' executing of extended practice (for a discussion, see Janelle and Hillman in chapter 2 of this volume). An exception, however, is one's height, which no known practice activity can increase. Excluding height-related characteristics, recent reviews (Ericsson & Lehmann, 1996; Howe, Davidson, & Sloboda, 1998) have not uncovered any firm evidence that innate characteristics are required for healthy adults to attain elite performance. When appropriately designed training is maintained with full concentration on a regular basis for weeks, months, or even years, inborn unmodifiable characteristics do not appear to constrain anyone from reaching high levels of performance. At this time, no solid empirical evidence exists to prove otherwise. (Of course, the genetic exceptions of height and body size deem a clear advantage in, for example, the high jump and basketball, and a distinct disadvantage in, for example, gymnastics.)

Outline of the Remainder of the Chapter

If "basic" capacities, physiological characteristics, and performance can be so greatly modified through extended training, one cannot simply conclude that some characteristic is innately determined because it is either physiological or assumed to reflect a basic capacity. It is entirely possible that the characteristics necessary for elite performance can be shaped and changed through some type of training during the period of an athlete's development. Consequently, Smith and I (Ericsson & Smith, 1991) argue that these issues can only be resolved by studying the stable performances that experts have attained after many years of practice—a unique body of reproducible empirical phenomena. If we were to analyze the structure of the mechanisms that mediate these achievements, we could provide psychological scientists with insights into the potential degree of physiological adaptation and the human complexity of skilled mechanisms.

In the following sections, I first briefly sketch the expert performance approach, then I discuss the recent issues that have emerged in the last decade that are reflected in the contributions in this volume.

The Expert Performance Approach

The empirical analysis of the mechanisms that mediate expert performance is based on three steps (Ericsson & Smith, 1991). First, researchers study the naturally observable expert performance to capture the essence of domain expertise and to identify the representative tasks that would allow them to reproduce the performance in the laboratory. Second, the researchers analyze the captured superior performance with standard methodology from cognitive psychology, such as designed experiments with reaction times, eye-movement recordings, and verbal protocol analysis, to trace the mediating cognitive processes (cf. the earlier described work in the introductory section on exceptional memory). Finally, once researchers identify the mechanisms that mediate experts' superior performance, they can then assess whether different types of experience and practice activities explain the acquisition of these mechanisms and whether expert performers engage in these activities during the development of their performance.

Capturing Superior Performance of Experts Rather Than Studying Mere Behavior of Experts

The focus on expert-novice differences (Chi, Glaser, & Rees, 1982; Simon & Chase, 1973) led investigators to search for highly experienced and knowledgeable people, who were later defined to be *experts*. It was simply taken for granted that these experts would display superior performance on relevant tasks in their respective domains. What researchers rapidly discovered, however, was that "experts" with extended experience and specialized knowledge frequently did not show a performance advantage over others. For example, highly experienced psychotherapists are not more successful in treatment of patients than are novice therapists (Dawes, 1994). In addition, stock market experts and professional bankers are not able to forecast stock prices any more reliably than university teachers and students can (Stael von Holstein, 1972). In fact, a range of experts have failed to exhibit a performance advantage over novices when they have been presented representative tasks under controlled conditions (for a review, see Ericsson & Lehmann, 1996).

Of course, many domains of expertise exist where experts repeatedly show a level of performance that vastly surpasses beginners and novices. For example, elite runners and swimmers can finish races under standardized and controlled conditions much faster than others, even subelite athletes in the same domain (see Starkes, Weir, & Young, chapter 10). Expert golfers can putt more accurately than novices can (see Beilock, Wierenga, & Carr, chapter 12). Similarly, elite ice skaters and gymnasts can perform challenging jumps and difficult combinations that are completely outside the current ability of less accomplished athletes (see Deakin & Cobley, chapter 5).

On the other hand, some events in sport involve judges, such as gymnastics and diving. Ste-Marie (chapter 7) shows that expert judges and referees are more accurate in detecting mistakes and errors of performance than are athletes. However, an increasing body of evidence exists that demonstrates how judges are not completely reliable and even exhibit systematic biases. For example, research in the evaluation of music performance has shown that judges show surprisingly low agreements among each other and that they are influenced by irrelevant factors, such as the gender, physical attractiveness, and reputation of the performer (Gabrielsson, 1999). The problems with judges' ratings are consistent with the well-known biases found in the performance ratings of employees in business (Landy & Farr, 1980). Systematic biases in judged aspects of performance, owing to factors such as fame, reputation, and past performance, can never be recorded by objective measures; thus, they cannot be explained by the theoretical mechanisms proposed to mediate performance. In certain cases, these judgment biases can be avoided by simply hiding the identity of the performer to the judges. In other cases, researchers can seek *objective* measures by which to judge performance (rather than subjective measures), even when such measures may not capture all the available information.

A particular challenge exists when one tries to capture superior performance in domains such as chess, tennis, and fencing, where each game consists of sequences that rarely (if ever) repeat themselves in that exact form. In a path-breaking and innovative research effort, de Groot (1946/1978) addressed this problem by identifying certain challenging situations in representative games that required some type of action. After identifying the situations, de Groot presented the same situations to all the participants, and he observed their cognitive processes as they selected the most appropriate actions. Subsequent research has shown that this methodology provides the best available measure of chess skill that can predict performance in chess tournaments (Ericsson, Patel, & Kintsch, 2000). Researchers have applied a similar methodology to measure superior performance in representative situations in medical diagnosis, snooker, and a range of other domains (Ericsson, 1996), including team sports such as soccer (see Helsen & Starkes, 1999, and Williams & Ward, chapter 9).

The complexity of elite performance is clearly seen in team sports where team members frequently have different roles and different performance expectations yet also have an associated goal. For instance, soccer players all have a common goal (to win the game), but each has a different role (goalkeepers, defensive players, and offensive players) with different expectations (prevent the ball from entering the goal, prevent the opposing team from advancing, score as many goals as possible, respectively). The representative situations during game conditions differ as a function of each person's role within the team. Thus, it is likely that the mechanisms that mediate superior performance for an elite offensive player may differ from those of an elite defensive player in each one's detailed structure.

We do know, however, that the detailed mechanisms that mediate superior performance differ among most experts. Virtually all experts have some aspects of their performance that are stronger or weaker than other performers at the same level. For example, research has shown that at the highest levels, expert musicians differ markedly in their performance on different musical activities. Some musicians excel in accompanying singers and soloists, where they typically play music from the notes without prior preparation and practice; other musicians excel at performing well-rehearsed pieces as a solo performer consistent with their chosen professional specialization (Lehmann & Ericsson, 1996). When experts show individual differences in the measured performance for different types of essential domain-related activities, it becomes necessary to separately measure and analyze superior performance in these activities. If investigators were to measure a composite index of performance by averaging all the many types of activities, then to do so will reduce reliability and the ability of investigators to explain both the structure of the mechanisms that mediate superior performance and how these mechanisms are acquired.

In sum, the principal challenge of the expert performance approach is to identify the essence of expertise in a domain and then design representative tasks that allow expert performers to reproduce their superior performance consistently under standardized conditions. Ideally, it should be possible to administer the same measurement procedure to children and other beginners as well as to advanced experts so that the development of performance can be objectively measured in a longitudinal design. For example, we can collect performance data in many individual sports (such as the 100-meter sprint) and in other types of activities, including music (by listening to someone perform specific pieces) and chess (by observing a player select moves from unfamiliar positions). In other domains, such as team sports, it is more difficult to measure individual performance in general; it is especially challenging to measure the performance on the same or similar tasks. Only when it has been possible to measure the reproducibly superior performance in specific activities can one profitably proceed to the next steps of analysis, namely that of identifying the mediating mechanisms of that performance. The less reproducible and the less precise the measurement of the superior performance, the harder it is to identify and describe its mediating mechanisms and their attainment during the extended development.

Identifying the Mechanisms That Mediate Expert Levels of Performance

Once researchers can reproduce experts' superior performance on representative tasks that capture the expertise in the domain, the next challenge is to identify the specific processes that account for the experts' performance advantage over those less skilled. For this type of investigation, researchers employ a general research method that starts by examining the overall performance to either find complex cognitive mechanisms or isolate intermediate actions and steps that differentiate the expert performance.

Particularly relevant to the study of elite performance of motor activities is the decomposition of the overall time to complete an event. For example, one can examine the advantage of an elite sprinter over subelite sprinters during different phases of the event, such as the time necessary to get out of the blocks, the time to accelerate to max speed, and the time of sustained speed to the finish line. Researchers can likewise measure and examine the characteristics of expert golfers' putting and driving shots that are associated with their superior motor consistency (Ericsson, 2001).

Many differences of superior athletes' performance have also been linked to anatomical differences, such as differences in the joints of the baseball pitchers' throwing arms, the structure of hearts of long-distance runners, and the distributions of fast muscle fibers of sprinters (Ericsson & Lehmann, 1996). However, this line of research has shown that the most important differences are not at the lowest levels of cells or muscle groups, but at the athletes' superior control over the integrated and coordinated actions of their bodies. For example, with respect to their hitting action, elite golfers and racket players reveal their highest consistency at ball contact rather than across the entire hitting motion. Elite long-distance runners differ from subelite runners by their running economy (the metabolic efficiency of maintaining their race pace). Elite runners also report monitoring their internal states more closely and planning their race performance with more focus (for a review, see Masters & Ogles, 1998).

The most compelling scientific evidence for preserved cognitive control of expert performance comes from laboratory studies where the task is to generate the most appropriate action in representative game situations (Ericsson & Smith, 1991). In his pioneering work that introduced this methodology, de Groot (1946/1978) showed expert and world-class chess players unfamiliar chess positions and asked them to select the best next move while verbalizing their thoughts. He found that chess players first rapidly perceived and interpreted the chess position, then they accessed from memory interesting potential moves. These promising moves were then evaluated mentally by planning the consequences of each potential move. During the phase of planning and evaluation, chess players would find the best move and sometimes even discover new and better moves. In sum, as players acquire increased chess skill, they acquire better and more refined mental representations that allow them to evaluate and manipulate chess positions mentally. In a review of similar studies, Ericsson and Lehmann (1996) found a similar pattern of experts' solving representative tasks in a range of domains of expertise, such as medicine, computer programming, and games. When experts solve representative tasks, their think-aloud protocols contain verbalized thoughts that reveal how deliberate preparation, planning, reasoning, and evaluation mediate their superior performance.

In their pioneering research, McPherson and French traced the development of mental representations and planning in baseball and tennis players using think-aloud protocols (Ericsson & Simon, 1993). Nevett and French (1997) showed how school-age baseball players who performed at higher levels of expertise used an increase in planning and updating of game situations. In chapter 6, McPherson and Kernodle propose a theoretical framework that describes the structure of tennis players' mental representations, which are based on the players' verbal reports when confronting simulated game situations as well as engaging in actual tennis matches. They describe the professional tennis players' refined representations of game situations with associated action plans, then they trace the development of these representations (as a function of attained level of skill) all the way back to the rudimentary representations of novice players. Researchers have used a similar verbal-report methodology to study other types of perceptual-motor expertise, such as playing snooker (Abernethy, Neal, & Konig, 1994), where experts have been presented with representative situations and asked to respond while thinking aloud.

In most sporting events, the demand for rapid execution of highly practiced activities has led investigators away from collecting verbal reports of the athletes' thoughts. However, even the superior speed of expert performers appears to depend primarily on acquired representations, rather than a faster base speed of their motor system.

Of all the domains, the most extensively researched motor skill is *typing*. Many studies have found that the source of the expert typists' advantage is linked to the experts' ability to look ahead in the text beyond the word that they are currently typing (Salthouse, 1984). By looking farther ahead, they can prepare future keystrokes in advance by moving relevant fingers toward their desired locations on the keyboard. These preparatory movements have been confirmed by analysis of high-speed films of expert typists' finger movements during typing. Furthermore, when expert typists are restricted from looking ahead, their performance is reduced almost to the level of novice typists, who don't rely on looking ahead.

Similarly, the rapid reactions of athletes, such as hockey goalies, tennis players, and baseball batters, have been found to reflect acquired skills that involve anticipation of future events. For example, when skilled tennis players are preparing to return a serve, they study the movements of their opponent's leading up to contact between the ball and the racket, which allows them to identify the type of spin and the general direction. Given the ballistic and biomechanical nature of a serve, it is often possible for skilled players to make these judgments accurately. It is important to note that novice tennis players use an entirely different strategy. They usually initiate their preparations to return the ball once it is sufficiently close and they can see where it will bounce. Similarly, Ste-Marie (chapter 7) shows how gymnastics judges use their anticipatory skills to gain an advantage in evaluating rapid movements in performance routines. This evidence supports the hypothesis that expert athletes have a learned speed advantage (rather than a biological speed advantage) over their less accomplished peers (Abernethy, 1991; Starkes & Deakin, 1984; Williams & Ward, chapter 9).

Expert athletes do not simply acquire superior anticipation skills; they also acquire superior control over their motor actions. At increased levels of expertise, athletes such as figure skaters and gymnasts are able to perform more complex behavior (for example, a triple-axel jump for figure skaters). Furthermore, expert performers attain the ability to consistently reproduce the same motor actions. For instance, expert golf players are more consistent in executing the same putt or drive than are less skilled players (Ericsson, 2001). Similarly, skilled jugglers and other athletes intentionally vary their movements to discover how to increase their control (Beek, Jacobs, Daffertshofer, & Huys, chapter 13). Additionally, studies of expert musicians' representations have shown how they are able to control their performance in a flexible manner (Ericsson, 2002).

In sum, expert performance is mediated by acquired mental representations that allow the experts to anticipate, plan, and reason alternative courses of action. These mental representations provide experts with increased control of the aspects that are relevant to generating their superior performance. In chapter 8, Tenenbaum discusses the complex mechanisms that control perception, attention, and memory, which allow expert athletes to gain their performance advantage in dynamically changing game situations.

Scientific Accounts of the Acquisition of Expert Performance and Its Meaning Mechanisms

A complete scientific account of expert performance needs to be able to explain the following: the acquisition and development of typical and elite performance per domain, and the process of how only the elite performers develop more refined mechanisms and advanced adaptations that mediate their superior performance. Based on an earlier account (Ericsson, 1998), my proposal is that the development of typical, novice performance is prematurely arrested in an effortless automated form; experts, however, engage in an extended, continued refinement of mechanisms that mediate improvements in their performance. In other words, most amateurs do not improve their performance only because they have reached (in their minds) an acceptable level!

The Development of Typical Performance in Recreational and Everyday Activities

When adults are first introduced to an activity, such as golf and tennis, their primary goal is to reach some level of mastery that is sufficient to allow them to perform the activity at an acceptable level. As shown in figure 3.2, the development of these types of performances has been described in three phases (Anderson, 1982; Fitts & Posner, 1967). During the first phase of learning (the cognitive/associative phase), performers attempt to understand the task and form a mental representation of it and its associated procedures. They have to concentrate on the execution of each step to reduce gross mistakes. With more experience, their obvious mistakes become rare, the mediating steps become more tightly associated, and the performance appears smoother.

After some limited period of training and experience—frequently less than 50 hours for most recreational activities, such as skiing, tennis, and driving a car—people can attain an acceptable level of performance without much effortful attention. No longer does the person feel a need to concentrate as hard before. The goal was to reach as rapidly as possible a satisfactory level that is stable and "autonomous." At this point, they have reached the second phase, the autonomous phase. As their behavior gradually meets the performance demands, the execution of the skill is increasingly automated. After the learners pass through the cognitive/associative phase, they can generate a virtually automatic performance with a minimal amount of effort (see the gray/white plateau at the bottom of figure 3.2). This newfound automation, however, reduces one's conscious control and limits one's ability to make intentional, specific adjustments. When this final automatic phase has been reached, further experience will not be associated with any marked improvements, and the amount of accumulated experience will not be related to any new attained level of performance.

In contrast, expert performers counteract automaticity by developing increasingly complex mental representations so that they can attain higher levels of control of their performance and therefore remain

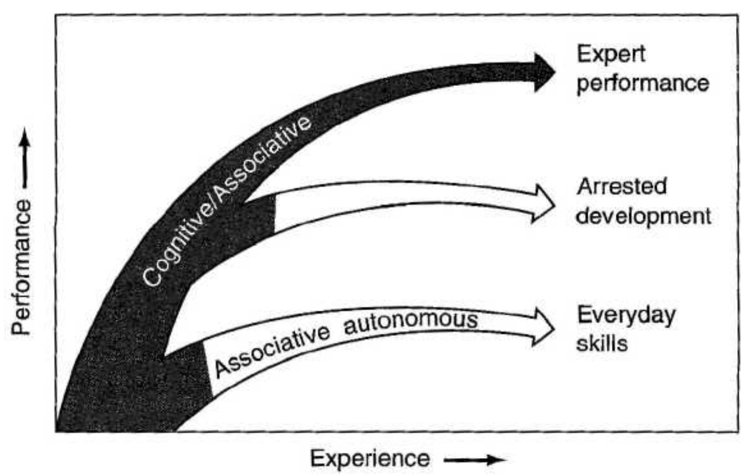


Figure 3.2 An illustration of the qualitative difference between expert performance and everyday activities during the course of improvement.

Adapted from K.A. Ericsson, 1998, "The scientific study of expert levels of performance: General implication for optimal learning and creativity" *High Ability Studies* 9:90. http://www.tandf.co.uk within the cognitive/associative phases. At some point in their career, however, some experts eventually give up their commitment to seek excellence. They stop engaging in deliberate practice and focus only on maintaining their performance, which results in premature automation (and "arrested development"). Beilock et al. (chapter 12) give a full description of traditional models of skill acquisition and study the development of automaticity by contrasting the putting by expert golfers with novices who have no prior experience of putting and golf.

Theoretical frameworks, such as the dynamical systems theory (Beek et al., chapter 13), have proposed learning mechanisms that can account for skill acquisition as well as the typical development of children and young adolescents. When children start engaging in an activity, such as walking or running, they slowly discover the essential factors needed for control. One can similarly explain how they reach an acceptable level so that they can playfully engage in recreational activities with their peers. One important difference between children's developing proficiency in a recreational activity versus adults' (see the previous paragraph) is that children keep growing and their performance keeps improving with age. These changes do not just reflect physical maturation and increased strength and body size; studies have shown that their cognitive representation of the game situations improves as well (French et al., 1996; Williams & Ward, chapter 9).

In chapter 4, Cote, Baker, and Abernethy discuss how the role of activities related to popular sports (such as soccer and ice hockey) changes as children grow older. They found that older children increase their involvement, especially in progressively structured activities, such as playing recreational games of hockey and soccer. These activities, referred to as *deliberate play,* are constrained by rules and involve direct competition between individuals or teams. The desire to win games and competitions increases one's motivation to improve performance. For example, there are interesting anecdotes in the literature (Ericsson, 1996) about competitive children who actually seek out other children who are performing at a higher level. Some children even design competitive activities that provide feedback on their performance and opportunities for repetitions. By engaging in these additional activities, these children are able to improve their performance relative to that of their peers. Hence, it is important to distinguish between enjoyable recreation and other types of activities where engagement is motivated primarily by the desire to improve one's performance.

The Development of Expert Performance

Research on the development of expert performance has found that those who eventually become expert performers do not start out in a domain of expertise with an already exceptional level of performance as compared with their peers, when the benefits from earlier engagement in other related activities are considered (Bloom, 1985). The level of performance of future experts continues to improve during years and decades of active involvement in domain-related activities. Their performance typically peaks when they reach their late 20s, 30s, or early 40s—long after they have reached physical maturity at around age 18 (see Ericsson and Lehmann, 1996, for a review). In well-established domains of expertise, even the most "talented" cannot reach an international level in less than approximately a decade of experience and intense preparation. Hence, in stark contrast to the performance of everyday and recreational activities, the performance of experts continues to increase for years, and even decades.

The aspiring experts do not allow their cognitive representation of situations and methods in the domain to become as firmly settled as seen in amateurs, whose performances become increasingly effortless and eventually automated, as shown in figure 3.2. The skill acquisition of experts involves a continued search for how to improve their cognitive representations of the tasks and situations. Like the amateurs, they are able to disregard irrelevant stimuli and execute skilled actions based on their immediate representation of a situation. Unlike the amateurs, however, the experts remain in the cognitive phase while they continue to change their mental representations and make them increasingly refined. Experts can view these developed mechanisms as tools to gain higher levels of access to (and control over) relevant aspects of performance, whenever they so desire (Ericsson, 1996,1998). These tools help the experts attain their highest levels of performance during competition and also help them to keep improving their performance during deliberate practice.

From retrospective interviews of international-level performers in several domains, Bloom and colleagues (Bloom, 1985; for a review, see Cote et al., chapter 4) showed that the developmental history of elite performers is fundamentally different from that of less accomplished performers and amateurs. Both future elite performers and their peers are typically introduced to their domains in a similar playful manner. As soon as the future elite performers show promise as compared to peers in the neighborhood, however, they are encouraged to seek out a teacher and initiate regular practice. Based on interview data, an argument was made by Bloom (1985) that access to sound training resources appears to be necessary to reach the highest levels.

To extend Bloom's and his colleagues' (1985) research and to further understand the development of differences among those with access to some of the best teachers and training resources, Krampe, Tesch-Romer, and I (Ericsson et al., 1993) tried to identify those training activities most closely associated with optimal improvement. Analyzing a review of laboratory studies of learning and skill acquisition during the last century, we found that improvement of performance was uniformly observed when people were given tasks with well-defined goals, were provided with feedback, and had ample opportunities for repetition. These deliberate efforts to increase one's performance beyond its current level involve problem solving and finding better methods to perform the tasks. When a person engages in a practice activity (typically designed by teachers) with the primary goal of improving some aspect of performance, we called that activity *deliberate practice.*

The importance of deliberate practice in attaining the highest levels of performance was first demonstrated in our study (Ericsson et al., 1993) of three groups of expert violinists who differed in level of attained music performance. We studied how these expert musicians spent their daily lives by interviewing them and having them keep detailed diaries for a week. Despite the fact that our expert violinists all spent about the same amount of combined time participating in all types of music-related activities, the two best groups were found to spend more time in solitary practice. When the experts practiced by themselves, they focused with full concentration on improving specific aspects of their music performance as identified by their master teachers, thus meeting the criteria for deliberate practice. The best group of young expert violinists spent around four hours every day, including weekends, in this type of solitary practice.

From retrospective estimates of practice, Ericsson and colleagues (1993) calculated the number of hours of deliberate practice that five groups of musicians at different performance levels had accumulated by a given age, as shown in figure 3.3. By the age of 20, the best groups of young and middle-aged violinists had spent over 10,000 hours of practice, which is 2,500 and 5,000 hours more than the two less accomplished groups of expert young violinists. This amount is 8,000 hours greater than that for amateur pianists of the same age. Even more interesting, the estimated amount of solitary practice was shown to be closely correlated with the objective speed of performance on a series of music-related tasks performed by amateur and expert pianists. Furthermore, greater amounts of solitary practice were reliably associated with faster speed of performing the tasks even when the data from only the expert pianists were analyzed.

In domains where the performance of experts is measured by solo performance on a representative task (such as in music, darts, and

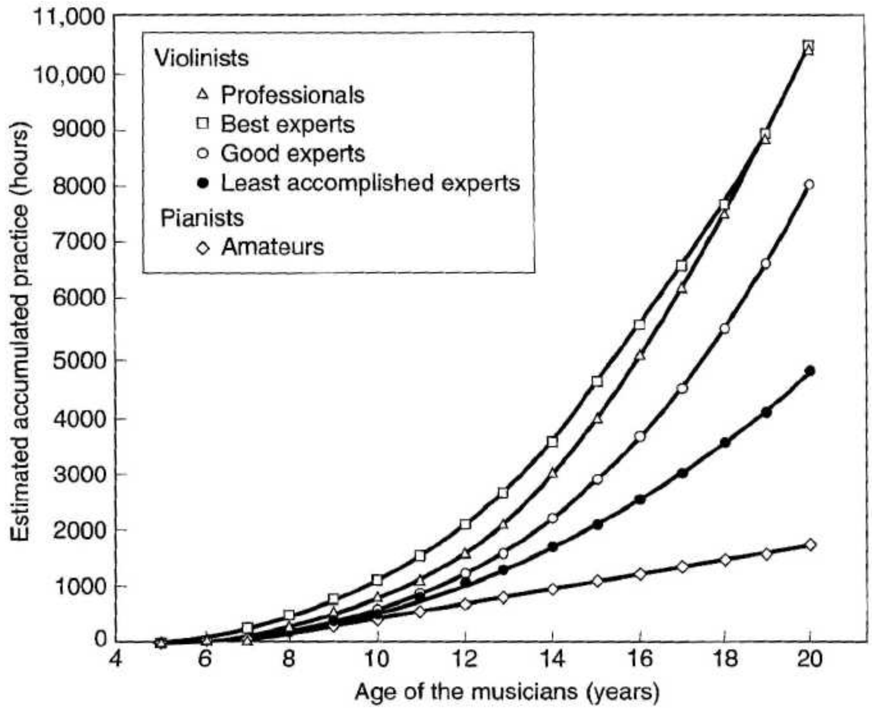


Figure 3.3 Estimated amount of time for solitary practice as a function of age for the middle-aged *professional* violinists (triangles), the *best* expert violinists (squares), the *good* expert violinists (empty circles), the *least accomplished* expert violinists (filled circles), and the *amateur* pianists (diamonds).

Adapted, by permission, from K.A. Ericsson, R.T. Krampe, and C. Tesch-Romer, 1993, "The role of deliberate practice in the acquisition of expert performance," *Psychological Review* 100: 363-406. Copyright © 1993 by the American Psychological Association. Adapted by permission.

individual sports), studies have found a consistent correlation between the level of attained performance and the amount and quality of solitary activities that meet the criteria of deliberate practice (for reviews, see Ericsson, 1996, 2002; Starkes, Deakin, Allard, Hodges, & Hayes, 1996). The same pattern of results has also been found in competitive games such as chess. Charness, Krampe, and Mayr (1996) showed that the amount of time of solitary study of chess games was the best predictor of attained chess-playing performance. Interesting enough, the amount of time that chess players played games did not explain any additional reliable variance. The distinction between deliberate practice and other types of domain-related activities for athletes, however, is more problematic (Starkes et al. 1996; Cote et al., chapter 4; Deakin & Copley, chapter 5). Research on team sports (Helsen, Starkes, &

Hodges, 1998; Starkes et al., 1996; Williams & Ward, chapter 9), such as soccer and field hockey, has shown a more complex picture when the duration of engagement in many types of domain-related activities has been associated with higher levels of achievement. In the following section, I attempt to develop a more precise description of deliberate practice that links the practice activity of individual performers to specific changes of the cognitive and physiological mechanisms that mediate improvements in performance.

In sum, the key challenge for aspiring expert performers is to avoid the arrested development associated with automaticity and the completed adaptation to the physiological demands of the current levels of activity (see figure 3.2). The expert performer actively counteracts such tendencies toward automaticity by deliberately constructing and seeking out training situations in which the set goal exceeds their current level of performance. They acquire mechanisms that are designed to increase their ability to monitor and control performance. In domains where strength, endurance, or flexibility is important, the expert performers keep pushing themselves during training to go beyond their current physiological adaptations to new and higher levels. The more time expert performers are able to invest in deliberate practice with full concentration, the further developed and refined their performance—thus, the observed correlation between the accumulated amount of solitary practice and attained performance (Ericsson, 1996).

Toward Detailed Causal Accounts of the Development of Expert Performance in Sport

The central assumption of the expert performance approach is that the development of expert performance occurs gradually, through incremental changes and refinements of the mediating mechanisms that through orderly accumulation lead to large observable differences in performance. Therefore, it should be possible, at least in principle, to describe the development of performance of each individual expert as a sequence of specific changes to their bodies and mediating mechanisms that ultimately combine with the mechanisms that explain the superior expert performance, as shown in figure 3.4. This framework proposes that reliable changes in the structure of performance have definite causes, such as developmental growth and adaptive responses to changes in practice activities. Each observable change in the structure of the mechanisms, as shown by the transitions in figure 3.4, must therefore be explained. Ultimately, a complete theory should be able to account for the development of all associated biological and cognitive mechanisms that contribute to the development of expert performance. The same theory must also be able to explain how induced stress from specific practice activities and genetic factors cause both physiological adaptations to the body and changes in the nervous system that explain observed increases in the experts' performance.

Detailed longitudinal descriptions that describe the development of expert performance for the 5 to 20 years in the domain are rare. Descriptions of the changes in the mediating mechanisms and the concurrent practice activities (as illustrated in figure 3.4) are not to my knowledge available. The best records consist of the detailed logs written by athletes on their practice and performance (Starkes et al., chapter 10), but we don't have the experimental assessment of the structure of their mediating mechanisms, which should be similar to those obtained for the different memory experts (Ericsson, 1988).

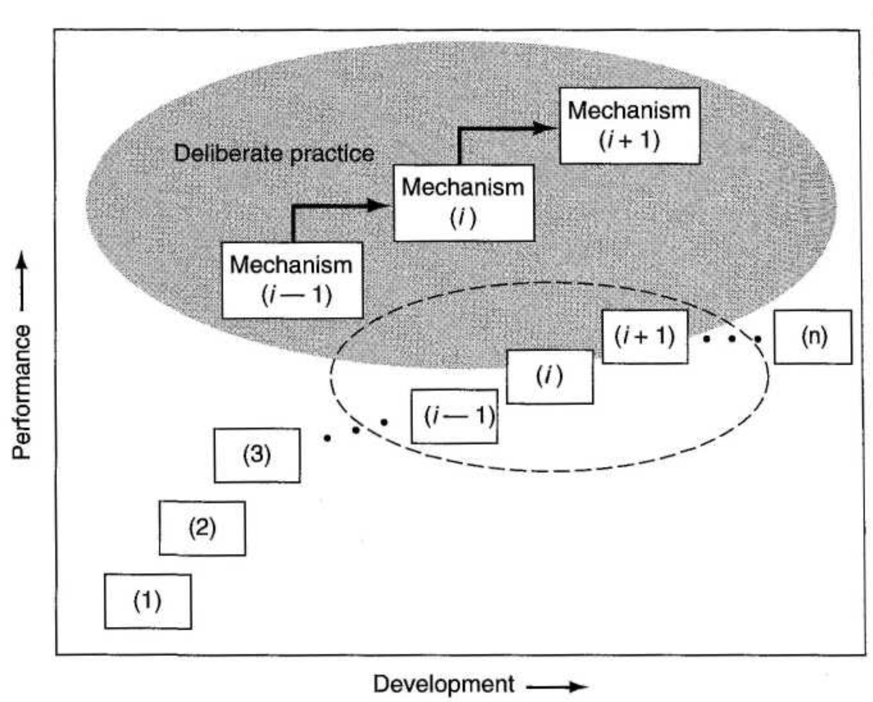


Figure 3.4 The acquisition of expert levels of performance is portrayed as a sequence of states where the performance is increased in gradual and incremental steps. Each *state* (stage of development/performance as indicated by a box with a number, such as 1,..., *j*-1, *j*, *j*+1,..., n) is mediated by associated *mechanisms* (deliberate practice), which are incrementally modified to generate the mechanisms of each subsequent state.

Lacking detailed concurrent records of the athletes' development and practice history, researchers have searched for the best available information and have thus asked athletes to retrospectively recall information. The retrospective approach has clear limitations: The accuracy of an athlete's memory after 5 to 20 years cannot be assumed, yet it has to be verified. Cote, Ericsson, and Beamer (2001), however, found that recalled levels of training during development met criteria of reliability and validity.

Studies using retrospective assessments show uniformly that elite athletes recall having engaged in more sport-related activity during their development, when compared with less accomplished peers. When Starkes et al. (1996) examined the development of reported weekly practice of future expert performers, they found that it increased gradually as a function of the number of years in the domain. However, it is well known that elite performers, especially athletes in team sports, are required by their coaches to participate in scheduled practice and that the amount of required weekly practice increases with the level of the team. Increased practice in those instances may thus be a consequence of being selected to play on a better team or being admitted to an international-level academy. However, evidence also exists that some young athletes engage in more solitary practice before they are recruited by elite teams, and thus in these cases, a higher initial level of practice may account for attained performance and their subsequent selection to the higher-level teams (Helsen et al., 1998). This finding is in agreement with research results from music, where the performers' higher levels of practice preceded their acceptance to a music academy. Similarly, those who reach high levels of performance in many domains of expertise, such as chess, music, and sports (Ericsson et al., 1993), have typically started practice at very young ages. Thus, they had the opportunity to accumulate more time for deliberate practice and on the average attain a higher level of skill than their peers who had later starting ages.

To advance our understanding beyond statistical correlations between reported amount of practice and levels of general performance, we need to search for causal mechanisms (preferably, biological) that can explain how expert performers attain the specific characteristics of superior performance by their engaging in particular practice activities. The greatest success in developing such detailed causal models has been made in improving physical performance and its associated physiological characteristics. We will discuss this area of research before we address the cognitive mechanisms that mediate performance.

Improving the Physiological and Anatomical Mechanisms That Mediate Performance

The human body is constantly trying to protect its homeostasis with its preferred temperature range and its ample supply of oxygen, water, and energy to every cell of the body. When people engage in physical activities, the metabolic rate of their muscles increases, which means that their bodies consume the supply of oxygen and energy at unusually high rates. To reestablish and preserve homeostasis, the body activates various countermeasures (negative feedback loops), that increase rates of breathing, overall metabolism, and blood circulation. However, when people push themselves beyond the comfort zone (Ericsson, 2001, 2002) and engage in sustained strenuous physical activity, they challenge the homeostasis sufficiently enough to induce a strained bodily state, with oxygen concentrations outside the acceptable range, which eventually yield biochemical waste products. The biochemical compounds lead to an expression of genes in the cells' DNA that initiates bodily reorganization and change. For example, it is well documented that adults have to engage in intense aerobic exercise to improve their aerobic fitness (Robergs & Roberts, 1997). Specifically, young adults have to exercise at least a couple of times each week, for at least 30 minutes per session, with a sustained heart rate that is 70% their maximal level (around 140 beats per minute for a maximal heart rate of 200). These activity levels lead to extreme conditions for some of the involved cells. For example, sustained activity in the muscles leads to low levels of oxygen in the capillaries that surround the critical muscles, which, in turn, trigger the growth of new capillaries (angiogensis). Similarly, improvements of strength and endurance require that people continue overloading (i.e., increase intensity, frequency, or duration on a weekly basis) and that they keep pushing the associated physiological systems outside the comfort zone to stimulate physiological growth and adaptation (Ericsson, 2001, 2002).

The numerous physiological and anatomical characteristics that distinguish the elite performers have been shown to be adaptations to the demands induced by their regular practice. For example, the larger heart size of endurance runners emerges only after years of extended intense practice. It continues to grow in response to continued challenge (higher levels of practice), but it eventually reverts back toward average size when the athletes stop their engagement in above-average physical exercise (Ericsson & Lehmann, 1996). Many examples also exist where practice during certain critical developmental periods can irreversibly change the course of one's development. For example, ballet dancers' ability to turn out their feet and baseball pitchers' ability to stretch back with their throwing arm are linked to practice overload at a certain age. These movements are established when the children's bones become calcified at around 8 to 10 years of age. Compelling evidence also supports that brain development can be changed at a critical developmental period when children engage in early practice with musical instruments (Ericsson & Lehmann, 1996). Starkes et al. (chapter 10) provide compelling evidence for the role of deliberate practice in attaining and maintaining the strength, endurance, and flexibility of older Master athletes who sustain an exceptional level of performance.

The anatomical and physiological characteristics of expert performers (with the exception of height and body size, as noted earlier) can be explained as the results of a long series of adaptations induced by biochemical responses to the strain induced by specific practice activities. These biochemical signals trigger the expression of previously inactive genes of the cells' DNA that guide the physiological changes. Given that all healthy people seem to have every critical gene as part of their cells' DNA, the effects of these genes cannot provide genetic explanations of individual differences in attained performance.

This general framework can account for individual differences in terms of the amount, type, and intensity of practice in terms of the strain that it induces on the physiological systems. For example, lengthy engagement in some training activity has minimal effect unless it overloads the physiological system sufficiently to lead to associated gene expression and subsequent changes (improvements) of mediating systems. Hence, logging many hours of practice at low levels of intensity is likely to allow the body to adapt to exactly that—namely, improvement in one's ability to exert low levels of intensity for extended periods of time. It is equally important to recognize that there is an optimal level for straining the targeted system. If the strain exceeds the systems' capabilities, it may result in irreparable damage to the tissue. To monitor and maintain the strain in the optimal range, athletes need to exert control and sustain full concentration. Furthermore, this account of improvement emphasizes the need for rest, whereby the body can engage in its restoration and physiological transformation and when athletes can recuperate so that they can engage with full concentration during the next practice session (Ericsson et al, 1993). Finally, to optimize deliberate practice, coaches need to help athletes design training programs that identify the best order for targeting physiological systems for improvement. Coaches can also motivate the athletes to push themselves as well as encourage them to seek rest to retain equilibrium on a daily basis (Salmela & Moraes, chapter 11).

Toward an Account of the Development of the Mental Aspects of Performance

The acquisition of most types of expert performance can be viewed as the sequential mastery of increasingly higher levels of performance through the acquisition of more complex and refined cognitive mechanisms, as is illustrated in figure 3.4. Performers with a given level of skill are already able to successfully complete certain tasks, such as an ice skater's single-rotation jump, but there are other specific tasks that the same performers cannot complete reliably or even at all, such as a double rotation during the same jump (and definitely a triple or quadruple rotation). To progress to higher levels, the performers need to practice and focus on the not-yet-attained and challenging tasks that define the desired superior level of performance (cf. the criteria of deliberate practice, Deakin & Cobley, chapter 5). This section describes how experts gradually attain mastery of increasingly difficult tasks and how the essential role of cognitive mechanisms and representations monitor and control the integration of complex behavior during learning. This section also focuses on how some types of practice activity lead to effective refinement of the mediating representations and associated improvements in expert performance.

Acquisition of Increasingly Difficult and Complex Motor Activities

In many types of sports, including gymnastics, figure skating, and platform diving, it is possible to rank the difficulty of movement combinations. Coaches and teachers instruct the performers to master the easiest movements first, then the basic movements, nearly always in their order of complexity and difficulty. In all of these domains, guidance and instruction are crucial, and no performer reaches elite levels without the help of coaches and teachers. These domains typically demonstrate a close relation between different individuals' overall achievement and the most difficult movement that they have mastered.

The training in these domains is centered on helping the athletes attain mastery of the complex movement sequences performed during competitions. When the young athletes start working with coaches, they perform the simplest movement sequences first with a focus on execution of fundamentals. The importance of acquiring fundamental posture and movement patterns is implied by the finding that the world-class rhythmic gymnasts started their careers by studying classical ballet as children (Beamer, Ericsson, Cote, & Baker, 2001). In contrast, rhythmic gymnasts at the national level started with less structured, playful gym activities.

As the athletes' mastery increases, the coaches select more challenging movements, in addition to raising expectations for artistic beauty and expression. When athletes try to learn new and difficult movement sequences, their initial attempts will almost certainly be unsuccessful. Eventual mastery therefore involves the athletes' removing weaknesses by changing the execution and control of their performance. Continued attempts for mastery require that the athlete always try to correct specific weaknesses, preserve the established aspects, and stretch the performance beyond its current level. This type of deliberate practice requires full attention and complete concentration, but even with such maximal effort, athletes will experience some kind of failure. These failures are aversive because they often lead to falls that can be quite painful on the ice or gym floor.

Deliberate practice for improving performance therefore requires that athletes extend themselves with full concentration, but the difficulty of the attempted tasks will (in spite of those efforts) probably still lead to initial failure and painful falls. It is indeed interesting then that Deakin and Cobley (chapter 5) found that the ice skaters spend a considerable portion of their limited practice time on already mastered jump combinations, rather than work on the not-yet-mastered combinations with the largest room for improvement. However, they also found that with increasing level of attained skill, skaters spent more time on jumps and other challenging activities that had the potential to improve their performance. These findings are consistent with studies where music students and musicians are observed as they engage in practice. As the skill level of the musicians increases, so does a similar progression toward increased quality of practice, where the expert-level musicians engage in problem solving and rely on specialized training techniques to master the remaining challenges (Chaffin & Imreh, 1997; Ericsson, 2002; Gruson, 1988; Nielsen, 1999).

In related domains, such as ballet and music, performers move through a similar progression of increasingly difficult tasks where the guidance of a teacher is often critical for acquisition of fundamentals and continued development to success. Despite these domains that are dependant on mentors, however, domains do exist where large improvements in performance can be attained without teachers.

Acquisition of Superior Speed of Motor Activities

In sports such as swimming, skiing, and tennis, the task conditions for competitions remain similar at all levels of performance. The experts' major type of superiority over less skilled performers involves strength and power (see section on improvements of physiological and anatomical mechanisms, p. 72), as well as their ability to control and reproduce their actions more accurately than novices. In this section, the focus is aptly on the experts' ability to initiate and complete series of actions faster than novices can. The earlier discussed speed advantage of experts can generally be attributed to their ability to anticipate the need for particular actions so that they can prepare such actions in advance.

The extensive research on typing provides the best evidence on how speed of performance can be increased through deliberate practice by refining the representations of future actions. The key finding is that one's typing speed is not fixed. Typists can systematically increase their speed by pushing themselves for as long as they can maintain full concentration, which is typically some 15 to 30 minutes per day (for untrained typists). While pushing themselves to type at a faster speed—typically around 10 to 20% faster than their normal speed-typists strive to improve their anticipation, in part by extending their gaze somewhat farther ahead.

The faster tempo also serves to uncover keystroke combinations that are comparatively slow and poorly executed. Typists then practice these specific combinations in special exercises and incorporate them in the typing of regular text, all of which ensures that any modifications typists make can be integrated into the representations of all other movement sequences that mediate regular typing. By successively eliminating weaknesses, typists can increase their average speed and practice at a rate that is still 10 to 20% faster than the new average typing speed.

The general approach of finding methods to push performance beyond its normal level—even if that performance can be maintained only for a short time—offers performers the potential to identify and correct weaker components and enhance anticipation, which will ultimately allow gradual improvements of performance during extended practice. More general, participants are able to engage in deliberate practice to attain specific performance goals by problem solving and experimentation (for verbal descriptions by world-class golfers and musicians, see Ericsson, 2001, 2002). These performers systematically search for the perceptual and internal stimuli that allow them to coordinate and control their performance by using learning methods similar to those proposed in ecological psychology and dynamical systems theory (Beek et al, chapter 13).

In sports such as swimming, skiing, and tennis, athletes should therefore be able to attain some improvements in their speed and control by using similar types of solitary deliberate practice without the necessity for supervision by coaches (see Salmela and Moraes, chapter 11). However, most sports differ from the relatively predictable nature of typing. Future game situations are far more difficult to anticipate for athletes to actually prepare any advance selection of actions. How those skills that represent game situations can be improved is discussed in the next section.

Improvement in the Selection of Actions in Tactical Situations

In many types of sports, athletes rapidly select or generate actions in game situations where they confront one or more opponents. Expert performers gain their advantage, at least in part, from being more capable of foreseeing consequences of their actions and their opponents' actions (see Tenenbaum, chapter 8; Williams & Ward, chapter 9). For performers to actually improve their ability to anticipate and plan, it is necessary for them to set up practice tasks where their planning and selected actions can be evaluated against the actions of better performers (or ideally the best experts) in the same situations.

How is it even possible to know what the best actions are in a given game situation? In chess, aspiring expert performers typically solve this problem by studying published games between the best chess players in the world. These players re-create and play the games one move at a time to determine if their selected move matches the corresponding move as originally selected by the master. If the chess master's move differed from their own selection, then it would imply that their planning and evaluation must have overlooked some aspect of the position. By more careful and extended analysis, the chess expert is generally able to discover the reasons for the chess master's move. Serious chess players spend as much as four hours every day engaged in this type of solitary study (Charness, Krampe, & Mayr, 1996; Ericsson et al., 1993). Players can increase the quality of their move selections by simply spending a longer time than would be available during a real chess game to analyze carefully different consequences of possible moves for a chess position. With sufficient time for planning, a weaker player can match the move selections of a better player who has to make their moves rapidly under the typical time pressure of matches in chess tournaments. With more chess study, players can refine their representations and access or generate the same information faster. Chess masters can typically recognize an appropriate move immediately whereas it takes a competent club player about 15 minutes to consistently uncover the same move by successive planning and evaluation.

Similar evidence (from studies of baseball and tennis) supports that expertise in sport is linked to more refined representations of game situations (see McPherson and Kernodle, chapter 6). As the athletes acquire better control and become able to execute several alternative actions, they develop better descriptions of the current game situation to improve their selections of their actions. During practice, coaches and teammates direct players to relevant factors for a given game situation and then give them feedback on their selected action. At higher levels of performance, coaches and elite athletes study videorecorded *games of sport performances, where they can remove the real-time* constraints of performance during *regular games. By analyzing* the game situations, they can identify the best actions available and perhaps determine how these opportunities could have been anticipated in real time. In chapter 9, Williams and Ward discuss how these perceptual skills and their associated representations can be effectively developed in training devices and simulators that capture the essential perceptual and cognitive factors of game situations.

Summary

The expert performance approach rejects the commonly held view that improvements in an expert's performance happen automatically in response to extended experience as long as the aspiring experts have the necessary innate talent. This approach instead proposes that these improvements actually correspond to changes both in the cognitive mechanisms that mediate how the brain and nervous system control performance and in the degree of adaptation of the body's physiological systems. This approach also argues that these changes are induced by practice activities that are specifically designed to modify the current mechanisms so that performance can be incrementally improved, as is illustrated in figure 3.4. This framework attempts to integrate our knowledge of the biochemical consequences of activity (environment) and how those consequences can lead to the expression of dormant genes that reside in the cells' DNA of not just a select group of talented athletes but rather of all healthy people (genetics). Hence, the requirement of select individual differences in genetic endowment (the pool of all available genes of someone's DNA) for the development of elite performance is assumed to be quite limited, perhaps even restricted to a small number of physical characteristics, such as height and body size. This framework therefore attempts to explain the large individual differences in performance in sport in terms of consequences of individual differences in sustained activity and deliberate practice.

The general rule (or perhaps even the law) of *least effort* theorizes that the human body and brain have been designed to find means to carry out activities at the minimum cost to the metabolism. Consequently, when physiological systems, including the nervous system, are significantly strained by new or altered activities, these systems produce biochemical signals that initiate processes that lead to physiological adaptation and mediation of simpler cognitive processes that reduce the metabolic cost. This phenomenon is evident in most types of habitual everyday activities, such as driving a car, typing, or strenuous physical work, in which people tend to automate their behavior to minimize the effort required for execution of the desired performance. After participants have engaged in the same activities on a regular schedule for a sufficiently long time that the physiological and cognitive adaptations have been completed, then further maintained engagement in this activity will not lead to any additional improvements and the performance will remain at the same level.

The central claim of the expert-performance framework is that further improvement of performance requires increased challenges and the engagement in selected activities specifically designed to improve one's current performance—or in other words, *deliberate practice.* The future expert performers must always search for aspects of their performance that they can improve. They and their coaches then need to identify the deliberate-practice activities that will most successfully improve specific, targeted aspects of their performance, without decreasing other aspects of their performance.

Once we conceive of expert performance as mediated by complex integrated systems of representations for the execution, monitoring, planning, and analyses of performance, it becomes clear that the acquisition of expert performance requires an orderly and deliberate approach. Deliberate practice is therefore designed to improve specific aspects of performance in a manner that assures participants that attained changes can be successfully integrated into representative performance. Hence, practice aimed at improving integrated performance cannot be performed mindlessly nor independent of the representative context for the target performance during competitions.

Successful development of elite performance requires more than the extended engagement in the typical domain-related activities. Elite athletes are found to shape the cognitive and physiological mechanisms that mediate their performance by engaging in deliberate practice (see figure 3.4). The modification of complex cognitive mechanisms during deliberate practice requires problem solving and full concentration. Shaping physiological mechanisms likewise requires the challenging of the associated systems by exerted effort. In fact, research on aerobic fitness shows that to merely *maintain* one's fitness level, athletes have to engage in the same high intensity of exercise with dramatically elevated heart rate to keep their bodies' current physiological adaptations. However, once an adaptation is attained, it is possible to reduce the duration of the weekly training time from the level originally required to attaining it. The core challenge of deliberate practice then is for performers to maintain effort at improvement for as long as they wish to improve performance beyond their current level, by modifying the physiological mechanisms that mediate their performance. With such an approach, as each individual's level of performance increases, the demand for further effort is not reduced—if anything, the demand for effort is actually *increased.*

The specification of the processes that mediate the changes induced by deliberate practice clarifies some issues in sport and training. Some athletes seem to believe that the willingness to exert effort is the key *factor for success. These athletes attempt to increase the* duration of their practice without concern for maintaining high levels of concentration and are thus unable to preserve the quality of their performance. It appears likely that "practice makes permanent" and that these athletes will not improve their performance on the target event; however, they will become increasingly able to sustain a lower level of performance for longer periods of time. Other athletes try to push themselves too hard, without monitoring their level of concentration and control, thus making themselves vulnerable to accidents and injuries as a result of overuse. Still other athletes push themselves too hard, well beyond sustainable daily levels of practice, which leads to eventual exhaustion and burnout. Only by better understanding the mechanisms that mediate the process of learning and physiological adaptation will coaches and teachers be able to guide athletes to acquire expert levels of performance safely and effectively. Expert performers simply need help to negotiate the many constraints for daily deliberate practice and to respect the essential need for intermittent rest and daily recuperation.

More general, the framework also challenges researchers to specify the particular causal mechanisms that explain correlations between perceived characteristics of athletes and the level of their attained performance. Compelling evidence now exists that many abilities of the elite performers are not signs of innate talent, but rather, they are the results of extended practice, sometimes amplified by early starts of practice during childhood. Similarly, it is quite possible that when coaches perceive a relation between high levels of motivation and attained performance, their ratings of motivation may really reflect the athletes' willingness to engage in deliberate practice with higher quantity and quality. Other personality characteristics, such as self-confidence and anxiety, might at least in part be viewed not as causes of performance but rather as consequences of success or failure during past competitions and practice sessions that were designed to improve aspects of performance.

In conclusion, I am impressed by significant advances in the scientific study of the extended development of elite levels of performance in sport that are reflected in the chapters in this volume. There used to be a time when coaches and teachers were relatively passive consumers of new research ideas from laboratory studies of skill acquisition and eagerly applying them to training practices. Now the tide is starting to turn, and the insights of coaches and elite athletes on advanced skill acquisition and deliberate practice are stimulating laboratory researchers who are interested in the remarkable plasticity of perceptual-motor performance and achievement potential of all healthy children and adults.

EXPERTS' COMMENTS

Question

In this chapter, Ericsson and colleagues (1993, 1996) suggest that the primary determinant of high-level performance is how much deliberate practice the athletes have engaged in throughout their athletic careers. What role do you feel practice plays in the development of expert athletes?

Coach's Perspective: Nick Cipriano

As athletic coaches around the world learn of Ericsson, Krampe, and Tesch-Romer's (1993) theory of deliberate practice, I am inclined to believe that many will embrace it with much enthusiasm because it reinforces what coaches have been advocating for years; namely, that the training process coupled with a focused attitude is fundamentally important to achieving success. From a coach's perspective, I believe is it likely that deliberate practice may prove more important than talent in the development of expertise. The

Ericsson et al. (1993) theory of deliberate practice is intuitively attractive because it validates the endless number of hours coaches spend teaching skills and tactics to eager young athletes who appear "not to have what it takes" in the formative stages of athletic development. Although coaches respect and understand the role that talent plays in expertise development, they also understand that deliberate practice produces a steady rate of improvement, which will prove to be more important than talent in propelling the athlete beyond any inevitable performance plateaus. In addition, deliberate practice will play a vital role in getting the athlete to resume training after suffering a serious injury or after a disappointing performance at an important competition.

Player's Perspective: Therese Brisson

Ericsson and colleagues (1993, 1996) suggest that the primary determinant of expert performance is how much deliberate practice the athlete has engaged in throughout an athletic career. This certainly fits with my own experience as a high-performance athlete. It seems to take about 10 years, or 10,000 hours of practice, to reach the level of performance needed to excel on the international stage. Over the past few years, I have observed a trend in which younger players are selected for our national team. I attribute this to the fact that girls are now introduced to hockey much earlier, because playing hockey has become more socially acceptable for girls in Canada. For example, the oldest player on our team at the 1998 Olympics was 39 years old. She started playing hockey at 18 years old, when she began university. In 1994, the average age of the team was around 27 years old, with most players finding it difficult to make the team before the age of 23. This was because most girls did not start playing hockey until around 12 years of age in the early 1980s. Almost 10 years later, the average age of the national team has dropped by almost 3 years, and it is common to see players make the team for the first time between the ages of 18 and 20 years. This fits with the 10-year rule because in the early 1990s and today, it is common to see girls begin playing hockey at 7 or 8 years of age.

In high-performance athlete circles, we recognize three stages in an athlete's career: training to train, training to compete, and training to win. The first phase takes 4 to 5 years; the focus is on developing general athletic ability, general strength and conditioning, and a repertoire of skills, techniques, and tactics. At this stage athletes learn how to train, and there is very little competition. During the second phase, the focus is on refining skills, building specific strength and conditioning, and adjusting tactics for competition; toward the end of the phase athletes are introduced to competitive strategies and international competition. This phase can take another 4 to 5 years. In the final phase, the emphasis is on competing internationally, adjusting competitive strategies, refining mental and decision-making skills, and sport-specific training. One of the most unfortunate trends with hockey in Canada over the past 10 years is that young children are introduced to competition at very early ages, around 7 years of age. Elite programming can begin as early as 9 years of age. A team of 10-year-olds in the Toronto area played more than 100 games in a season! Children spend more time playing games and less time practicing. The trend has had a negative impact on skill development. In a typical hockey game, a child will handle the puck for less than 30 seconds. However, the same child can handle the puck more than 30 minutes in a 60-minute practice. Which situation do you think is the best for skill development? Measures are now taken to increase the practice-to-game ratio in youth hockey, but change will be a slow process.

Practice makes perfect, or does it? Certainly, I would agree with Ericsson that the practice must be focused on improving performance. In general, I think that a lot of practice time is wasted on activities that do not transfer very well to game situations. For example, we routinely practice breaking the puck out of our zone with no forechecking pressure, and we practice the power play with no defenders. This is where the tactics usually break down—while athletes are under pressure. Introducing tactics in this manner is fine, but simulation of the competitive pressures is essential. So I would say that *perfect* practice makes perfect.

Finally, one of the elements of the deliberate practice theory that has not been my experience is that the practice itself is not inherently enjoyable. I have played hockey for almost 25 years, and although there have been good times and bad, I have always enjoyed practicing and looked forward to going to the rink.

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