Capturing the Naturally Occurring Superior Performance of Experts in the Laboratory

Toward a Science of Expert and Exceptional Performance

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ABSTRACT—Expertise researchers have traditionally shied away from studying the highest levels of achievement in favor of studying basic cognitive processes, such as memory and categorization. In this article, we present a different approach that is focused on capturing superior (expert) performance on representative tasks that reveal the essential characteristics of expertise in a given domain. In domains where expert performance is measurable, acquisition is gradual and the highest levels are only attained after 10 years of intense preparation—even for the most “talented.” Analyses of reproducibly superior performance show that it is mediated by physiological adaptations and cognitive skills acquired as a result of the cumulative effects of special practice activities (deliberate practice). It appears that the genes necessary to attain such adaptations and expert skills can be activated in healthy children—the only clear exceptions to date being genes that control body size and height. Our knowledge of how experts acquire their superior skills provides insights into the potential for human adaptation and skill acquisition and has important implications for theories of the structure of general and expert cognition, as well as for training interventions in applied psychology and education.

KEYWORDS—expertise; skill acquisition; experience; deliberate practice; physiological adaptation

The achievements of experts and eminent individuals are among the most admired and complex phenomena in our culture. They offer serious challenges to scientists attempting to study them. For example, how can a researcher fully understand the cognitive processes in which a chess master engages while generating moves when the researcher is unable defeat the master? Those who assume that eminent individuals are endowed with innately superior capacities will also question whether lesser-endowed scientists could fully understand the master's associated thought processes. As a consequence, there is a common misconception that the only legitimate judges of experts are their peers.

When the study of expertise flourished in the 1970s and 1980s, the research focus was not on the cognitive processes that mediate experts’ outstanding achievements but on more basic memory performance in the laboratory. In the last review of expertise for this journal over a decade ago, Bedard and Chi (1992) described studies that primarily examined differences between experts and novices in memory for representative stimuli or categorization of problems from introductory academic courses, such as physics. Bedard and Chi (1992) even questioned the relationship between such laboratory studies and real-world expertise. They observed that some experts performed poorly “on some real-world problems” (p. 136) and even described situations in which “novices not only can perform as well as experts, but actually surpass the experts” (p. 138).

Since their review, researchers have become increasingly dissatisfied with studies that define experts by social criteria (e.g., peer nominations), by extended domain experience, or by (high) education. When scientists measured the level of real-world performance of so-called experts they found that many were not reliably better than their less-experienced colleagues. For example, reviews (Ericsson, 2006) have described studies showing that a psychotherapist’s level of education and clinical experience is unrelated to their treatment outcomes. Recent reviews of performance in health-related fields show that extended experience of doctors and nurses...
(beyond the first couple of years of practice) is not associated with continued improvements, as most people had thought. In fact, performance has frequently been found to decrease without continued training (Choudhry, Fletcher, & Soumerai, 2005; Ericsson 2004).

There are numerous domains of expertise in which some performers are reproducibly superior to most others engaging in the domain. For example, chess masters, bridge experts, and experts in other games consistently beat less-skilled individuals. More generally, in the arts and the sciences some individuals reliably generate superior products that are selected for presentation in journals, conferences, and competitions. Some individuals are able to perform at a reproducibly higher level in professional domains too. Our framework focuses on understanding the mechanisms that mediate consistently superior performance, and to distinguish this approach from the traditional study of expertise we will refer to it as the expert-performance approach (see Feltovich, Prietula, & Ericsson, 2006, for a description of the historical development of several approaches to the study of expertise using psychological methods).

CAPTURING REPRODUCIBLY SUPERIOR PERFORMANCE UNDER STANDARDIZED CONDITIONS

In everyday life, each expert encounters unique challenges that make it nearly impossible to compare levels of performance between different experts. For example, some doctors treat clients with more complex and difficult problems, and some sales people may be assigned better territories. The key challenge for anyone interested in individual differences in expert performance is to measure highly representative performance under controlled conditions that are standardized for everyone tested. In a groundbreaking series of studies, de Groot (1978) was able to capture the superior performance of world-class chess players using standardized tasks.

The ultimate criterion for eminence in chess is consistent tournament success when competing against similarly skilled chess players. To reliably estimate a chess player’s rating on an interval scale, one would need outcomes from 20 to 50 tournament matches (roughly 40–100 hours of play). In contrast, de Groot (1978) identified critical chess positions from actual matches played between chess masters and recreated these situations under controlled conditions by presenting them to chess players during an individual testing session. In this pioneering approach, de Groot (1978) also asked chess players to “think aloud” while they generated the best possible next move. Differences in the quality of selected moves distinguished world-class from skilled club players. Subsequent research with large groups of chess players has shown that the ability to select the next best move is closely related to tournament ratings (van der Maas & Wagenmakers, 2005). More interestingly, de Groot (1978) was able to pinpoint the thought processes that led to the experts’ superior move selection by analyzing their think-aloud protocols.

In the early 1990s, the expert-performance approach, based on de Groot’s paradigm, was initially proposed and later elaborated (Ericsson, 2006). In this approach, experts’ real-world performance is scrutinized to identify naturally occurring situations that require immediate action and that capture the experts’ superior selection or execution of actions in the associated domain, as is illustrated in Figure 1. These situations are then standardized by recreating them in the laboratory, and experts and less skilled individuals are instructed to respond in real time by acting appropriately. By instructing participants to think aloud and collecting other observable evidence on their thought processes, such as eye

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**Fig. 1.** Model for capturing expert performance by representing naturally occurring tasks in standardized form in the laboratory. The top of the figure shows the stream of naturally occurring activities of experts, within which it is possible to identify a challenging situation requiring immediate action—such as making moves for chess positions during tournaments or returning a serve in a tennis match. As shown in the bottom part of the figure, one can present a chess position from an actual game and ask for the best next move in a laboratory setting. Alternatively, one can project a film of a player serving a tennis ball and ask the participants to attempt to return the “imaged ball” with the best shot using their racket. These representative tasks can then be presented to participants differing in skill, and reaction times, accuracy, and process-tracing data—such as eye-fixations and concurrent or retrospective verbal reports—can be recorded to permit explication of mechanisms that can account for the reproducible differences in performance.
movements, investigators can infer mechanisms that are capable of accounting for the reproducible differences in performance. The hypothesized mechanisms can then be submitted to experimental tests, in which the original tasks are manipulated by altering certain types of information.

THE DEVELOPMENT OF EXPERT PERFORMANCE

The expert-performance approach has now been successfully applied to a wide range of activities (Ericsson, 2004, 2006) including medical diagnosis, surgical procedures, music performance, design of experiments, writing, painting, Scrabble, darts, ballet, and numerous sports. From these reviews, particularly in domains in which the development of expert performance can be objectively measured and compared to the performance of adult experts, we find evidence for the necessity of an extended period of skill development (See Fig. 2). Expert performance develops gradually and reaches its peak typically more than a decade after physical maturation. Finally, there is no evidence that international competitions can be won, even by the most gifted, with less than a decade of prior intense involvement in domain-related activities (Ericsson, 2006; Simon & Chase, 1973).

THE STRUCTURE AND ACQUISITION OF EXPERT PERFORMANCE

The use of process-tracing methods during performance on representative tasks reveals that experts are able to give verbal reports on the thoughts that mediate the generation of their superior actions. Analyses of such reports reveal that the cognitive mechanisms responsible for the acquisition of expert performance involve complex acquired representations. These representations facilitate experts’ ability to plan, monitor, and reason about their performance (Ericsson & Kintsch, 1995). For example, expert players can anticipate the outcome of an opponent’s tennis serve before the ball has left the opposing player’s racket. Among proficient participants in a given domain, the level of performance is closely related to the acquired levels of domain-specific skills. Surprisingly, however, individual differences in more “basic” cognitive processes (e.g., intelligence, memory capacity, and perceptual functioning) have not, to date, been predictive of attained level of skilled performance (See Ericsson, Roring, & Nandagopal, 2007, along with commentaries and the authors’ response).

Similarly, many distinctive characteristics of experts, such as the larger hearts and greater maximal oxygen uptake of endurance athletes and the fast-twitch muscle fibers of sprinters, are accurately characterized as physiological adaptations to extended periods of intense training (see Ericsson 2007, along with commentaries and the author’s response). For some characteristics to develop, individuals have to engage in specific training within certain developmental windows when normal growth and development can be augmented. For example, with training (Ericsson et al., 2007), perfect pitch can be acquired between 3 and 5 years of age, and the structure of ballet dancers’ hip joints and baseball pitchers’ shoulder joints can be altered between age 9 and 12 years.

Physiological muscle adaptation is triggered by very intense and sustained (i.e., daily) training activities when athletes push their bodies beyond their limits for normal homeostasis (see Ericsson, 2006, 2007). This intense activity produces biochemical side products that trigger the activation of dormant genes in the athletes’ DNA, which in turn initiate anatomical changes. Healthy children appear to have the prerequisite genes as part of their DNA, but few engage in the type, intensity, and duration of required practice that would achieve the desired adaptation. The only validated exceptions, at least to date, concern body size and height. Even the brain exhibits functional adaptations and anatomical changes as a function of extended training (Ericsson, 2007).

More generally, Ericsson, Krampe, and Tesch-Römer (1993) found that the level of performance attained by expert musicians was related to the amount of time accumulated in solitary practice—wherein musicians worked on specific, teacher-directed practice goals using methods purposely designed to improve specific aspects of their performance, including problem solving and feedback (deliberate practice). In some domains, it is possible for individuals to change aspects of their performance based on immediate feedback—for example, by watching one’s ballet movements in a mirror or by listening to the music that one is making. However, in other domains, objective feedback about one’s behavior is rarely available, at least not immediately. During chess games, players may not know if the move just played is the best possible move for that position.

Fig. 2. The development of expert performance (measured by adult standards) as related to age. Elite performers typically reach their peak career performance in the middle to late 20s for many vigorous sports, and one or two decades later (i.e., one or more decades past physical maturation) for less vigorous sports such as chess and billiards, as well as for the arts and sciences. All performers, including the most “gifted” or “talented,” need a minimum of approximately 10 years of intense involvement in the domain before they can win at an international level in highly competitive domains of expertise.
Similarly, physicians diagnose a patient or interpret an X-ray without getting immediate feedback about the accuracy of their decisions. To improve their performance, individuals must therefore seek out training situations with immediate valid feedback and design training activities with tasks that have validated actions. For example, radiologists can make diagnoses of old X-rays with outcomes validated by surgery or subsequent medical history. Chess players can buy chess books and then replay games between chess masters to see if they can select the same moves. For a wide range of domains, such as typing, interpreting, chess, medicine, and sports, it has been possible to identify specifically designed deliberate-practice activities that enable performers to refine mediating mechanisms, which in turn improves their performance (Ericsson, 2006; Ward, Hodges, Williams, & Starkes, 2004).

During development, elite performers often engage in more than 10,000 hours of deliberate practice. This accumulated practice frequently accounts for as much as half of the total variance in performance among skilled individuals such as regular participants in chess tournaments and full-time students at music academies. Only future research will determine whether the remaining variability in expert performance can be accounted for by more objective detailed measures of individual differences in the amount and micro-structure of practice during their extended development and/or by more basic (genetic) interindividual differences.

Deliberate practice has also been implicated as a key factor in maintaining expertise. As healthy expert performers reach older ages, their age-related performance declines result primarily from the reduction of regular deliberate practice, rather than as a direct consequence of aging per se (Krampe & Charness, 2006).

In sum, the framework offered by the expert-performance approach can explain large individual differences in performance in terms of accumulated consequences of individual differences in sustained activity and deliberate practice. Deliberate practice is a direct violation of the general rule, or perhaps even law, of least effort, which purports that the human system continuously strives to perform activities with minimal exerted effort or metabolic cost. It is clear that skilled individuals can sometimes experience highly enjoyable states (“flow” as described by Mihály Csikszentmihály, 1990) during their performance. These states are, however, incompatible with deliberate practice, in which individuals engage in a (typically planned) training activity aimed at reaching a level just beyond the currently attainable level of performance by engaging in full concentration, analysis after feedback, and repetitions with refinement. The commonly held but empirically unsupported notion that some uniquely “talented” individuals can attain superior performance in a given domain without much practice appears to be a destructive myth that could discourage people from investing the necessary efforts to reach expert levels of performance.

**FUTURE DIRECTIONS**

The scientific study of expert and superior performance will enhance our knowledge about how experts optimize the development of their performance through a high level of daily deliberate practice that is sustained from year to year. The emerging insights into effective practice methods for enhancing particular types of skill; for increasing speed, accuracy, and consistency; and for attaining the associated representations for monitoring, executing, and evaluating performance will be relevant to any motivated individual aspiring to excel in any challenging domain (Ericsson, 2006). Besides gaining understanding about how expert performers improve with deliberate practice and reach elite levels, these advances should also inform training of a wider range of professionals who aspire to improve their performance. For example, simulator training of emergency situations with air force pilots dramatically improved their crisis decision making when the same situations occurred during actual flight missions (McKinney & Davis, 2003). More generally, mere activity in the simulator does not automatically improve performance; reliable improvements have been found to show a close relation to the degree to which the training met the criteria for deliberate practice (McGaghie, Issenberg, Petrusa, & Scalese, 2006).

The research on reproducibly superior performance of experts has demonstrated that expertise development depends largely on the acquisition of complex cognitive mechanisms and physiological adaptations resulting from extended engagement in deliberate-practice activities. Further research on the detailed structure of deliberate practice that can modify physiological characteristics and alter aspects of complex cognitive mechanisms will tell us more about the necessary conditions for effective learning. To develop a complete scientific theory, biochemical research will need to specify the mechanisms by which deliberate practice can act as a catalyst for the expression of genes responsible for physiological and anatomical change. It will then be possible to determine whether the critical genes are part of any healthy individual’s DNA or are uniquely inherent to a small fraction of innately talented individuals. It will also allow us to identify potential individual differences in the ability to sustain the required type of intense training with full concentration for extended periods that characterizes deliberate practice.

We foresee a new partnership between scientists and expert performers (especially in professional domains such as medicine; Ericsson, 2004) interested in pushing their performance to higher levels by making systematic changes to their practice methods. The highest levels of expert performance and the drive for improvement will always involve searching for innovation and experimentation at the threshold of understanding, even for masters dedicated to redefining the meaning of excellence in their fields.
Recommended Reading
Ericsson, K.A. (2004). (See References). Discusses how the expert-performance approach can be applied to a professional domain of expertise, medicine, in more detail than the current article.
Feltovich, P.J., Prietula, M.J., & Ericsson, K.A. (2006). (See References). Discusses the history of the psychological study of expertise and, in particular, how traditional methods of studying expertise differ from those used to study the reproducibly superior performance of experts.

REFERENCES
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