Ericsson, K.A., & Lehman, A.C. (1996). Expert and exceptional performance: evidence of maximal adaptation to task constraints. Annual Review of Psychology, 47, 273-306.

Abstract: Expert performance in domains such as chess, dancing, sports, computer programming, music, and medicine can be accomplished only after about 10 years of intense, daily practice. This high level performance is not simply achieved through talent or by the possession of certain anatomical and physiological traits. Expert performance is moderated by cognitive and perceptual motor skills and maximal adaptations. Specific memory skills are used to expand the expert's domain further and continually improve performance.
Expert and exceptional performance are shown to be mediated by cognitive and perceptual-motor skills and by domain-specific physiological and anatomical adaptations. The highest levels of human performance in different domains can only be attained after around ten years of extended, daily amounts of deliberate practice activities. Laboratory analyses of expert performance in many domains such as chess, medicine, auditing, computer programming, bridge, physics, sports, typing, juggling, dance, and music reveal maximal adaptations of experts to domain-specific constraints. For example, acquired anticipatory skills circumvent general limits on reaction time, and distinctive memory skills allow a domain-specific expansion of working memory capacity to support planning, reasoning, and evaluation. Many of the mechanisms of superior expert performance serve the dual purpose of mediating experts' current performance and of allowing continued improvement of this performance in response to informative feedback during practice activities.

INTRODUCTION

Human behavior is enormously adaptive to environmental demands. In psychology, the most important changes in behavior are attributed to learning, as are changes in cognition, brain function, and many other modifications of the human body. Some adaptive changes, such as increase in muscle volume in response to exercise, are commonly observed and are accepted as a natural result of training activities. However, recent research in developmental biology shows that physical adaptation is more far-reaching than is commonly believed. For example, the shape of the eye is affected by an individual's visual activity; the increased incidence of near-sightedness in Western cultures appears to be an adaptive reaction to watching TV, reading, and other activities requiring sustained focus on nearby objects (Wallman 1994).

The adaptability of human behavior presents a challenge to scientists who seek to identify invariant characteristics and to propose general laws that describe all forms of behavior. We suggest that the most promising approach to finding invariants and exceptions to them is to study cases of maximal adaptation and learning, such as the behavior of experts. Expert performers devote most of their lives to attaining the highest levels of performance in a highly constrained activity (Ericsson & Charness 1994, Ericsson et al 1993). They often start training at very young ages, and the duration and intensity of their sustained training far exceed the range for other activities pursued by individuals in the normal population.

VIEWS OF EXPERT PERFORMANCE

It is generally assumed that outstanding human achievements reflect some varying balance between training and experience (nurture) on one hand and innate differences in capacities and talents (nature) on the other. One view, typically associated with Galton's work (1869/1979), holds that individual differences reflect innate basic capacities that cannot be modified by training and practice. The second and more recent view, typically associated with de Groot (1946/1978) and with Chase & Simon (1973), is that experts' knowledge and task-specific reactions must have been acquired through experience. These two views define mutually exclusive domains corresponding roughly to the popular distinction between hardware and software in computer-based metaphors for human information processing.

In the view of expert performance as talent, instruction and practice are necessary but not sufficient to attain expert levels of performance. Performance increases monotonically as a function of practice toward an asymptote representing a fixed upper bound on performance. Contemporary researchers who hold this view generally assume that training can affect some of the components mediating performance but not others, and that stable, genetically determined factors constrain the ultimate level of performance. Consequently, empirical research has focused on identifying and measuring talent relevant to particular types of activity. A practical extension of this view is that, by testing individuals at a young age, one can select the most talented children and provide them with the resources for the best training. Later in this chapter we briefly review the evidence, or rather the lack of firm evidence, for the talent-based view of expert performance.

At the time de Groot (1946/1978) started his research on chess expertise, the prevailing view was that chess experts achieved their superior performance by greater than normal intellectual capacity for extensive search of alternative chess moves. However, de Groot (1946/1978) found that world-class chess players accessed the best chess moves during their initial perception of the chess position, rather than after an extensive search. This finding implied pattern-based retrieval from memory and is fundamental to Chase & Simon's (1973) and Simon & Chase's (1973) theory of expertise. Chase & Simon showed that pattern-based retrieval can account for superior selection of chess moves and exceptional memory for chess positions without violating general limits to human information processing (Newell & Simon 1972), including the limited capacity of short-term memory.

Chase & Simon (1973) proposed that the attainment by experts of many other forms of expertise, in fact "any skilled activity (e.g. football, music)" (p. 279), was the result of acquiring, during many years of experience in their domain, vast amounts of knowledge and the ability to perform pattern-based retrieval. This assertion was borne out by subsequent research on solving textbook problems in physics (Larkin et al 1980, Simon & Simon 1978). Novices, who possessed all the necessary knowledge, struggled with physics problems and retrieved formulas and computed results by working backward from the question, whereas physics experts retrieved a solution plan as part of their normal comprehension of problems. Chi et al (1982) showed that physics experts not only had more knowledge than novices but also organized it better. Experts could therefore represent physics problems in terms of the relevant theoretical principles, whereas novices' representations were based on salient surface elements. Voss et al (1983) showed that expert reasoning is specific to a domain. Their subjects, experts in domains such as chemistry and social science, lacked the special knowledge and strategies to successfully analyze a problem in political science. More recently, researchers have designed methods to elicit experts' knowledge (Cooke 1994; Hoffman 1987, 1995) and to describe its structure and organization in specific domains (Hoffman 1992, Olson & Biolsi 1991). Glaser & Chi (1988) and, more recently, Bedard & Chi (1992) and