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Limits on the Predictive Power of Domain-Specific Experience and Knowledge in Skilled Performance

David Z. Hambrick[1] and Elizabeth J. Meinz[2]
[1]Michigan State University and [2]Southern Illinois University Edwardsville

Abstract

It is clear from decades of research that, to a very large degree, success in music, games, sports, science, and other complex domains reflects knowledge and skills acquired through experience. However, it is equally clear that basic abilities, which are known to be substantially heritable, also contribute to performance differences in many domains, even among highly skilled performers. As we discuss here, our research shows that *working memory capacity* predicts performance in complex tasks even in individuals with high levels of domain-specific experience and knowledge. We discuss implications of our findings for the understanding of individual differences in skill and identify challenges for future research.

Keywords

expertise, individual differences, working-memory capacity

The question of how people achieve high levels of skill in music, games, sports, and other complex domains has been a topic of debate in psychology for more than a century. One view is that experts are "born." According to this *talent view*, innate abilities limit the ultimate level of performance that a person can achieve in a domain. Upon discovering that "eminence" in music, literature, poetry, science, government, and many other fields tends to run in families, Francis Galton (1869) articulated the extreme version of this view when he proclaimed, "if the 'eminent' men of any period, had been changelings when babies, a very fair proportion of those who survived and retained their health up to fifty years of age, would, notwithstanding their altered circumstances, have equally risen to eminence" (p. 38). A more moderate, contemporary version of this view is that innate factors contribute to development of skill in domains that require specialized training (Simonton, 1999). The opposing view is, of course, that experts are "made"—that innate abilities are ultimately, or even entirely, irrelevant to becoming highly skilled and that what matters is putting forth a great deal of effort to acquire knowledge and skills that allow the performer to adapt to the unique demands of a domain. John Watson (1930/1970) captured the essence of this *acquired characteristics view* when he commented that "practicing more intensively than others, is probably the most reasonable explanation we have today not only for success in any line, but even for genius" (p. 212).

Evidence for the Importance of Acquired Characteristics

As it stands, evidence from several decades of research in cognitive psychology, among other fields, provides undeniably strong support for the importance of acquired characteristics. Specifically, research has left no doubt that one of largest sources of individual differences in performance on complex tasks is simply what and how much people know: declarative, procedural, and strategic knowledge acquired through years of training and practice in a domain. As a classic example, Chase and Simon (1973) found a large advantage of chess expertise for recall of chess positions but not for recall of random arrangements of pieces. Chase and Simon therefore concluded that the major component of chess skill is not superior short-term memory but, rather, a "vocabulary" of game positions that automatically elicit a small number of candidate moves.

More recently, measures of domain knowledge have been found to account for large proportions of variance in various tasks. Results from our own research are illustrative. In one project (Hambrick, Salthouse, & Meinz, 1999), we had more

Corresponding Author:
David Z. Hambrick, Department of Psychology, Michigan State University, Lansing, MI 48824
E-mail: hambric3@msu.edu

than 800 participants attempt to solve crossword puzzles and complete tests both of fluid abilities (often referred to as *Gf*), including reasoning ability and perceptual speed, and of crystallized abilities (often referred to as *Gc*), including vocabulary, cultural knowledge, and *esoteric vocabulary*—that is, knowledge of words rarely encountered outside of crossword puzzles, such as *aril* (a seed covering) and *etui* (a needle case). Across four studies, there were strong effects of crystallized abilities on puzzle performance, whereas effects of fluid abilities were near zero. Indeed, in one study, the number of clues solved in a difficult *New York Times* puzzle correlated .87 (very highly) with esoteric vocabulary but near zero with reasoning ability.

In another study (Hambrick, Meinz, Pink, Pettibone, & Oswald, 2010), we investigated the impact of domain knowledge on learning. The participants were approximately 500 undergraduate students, and the study took place in two sessions. In the first session, the participants completed tests of fluid abilities and crystallized abilities, intellectual openness, and interest in and knowledge of politics. Then, after approximately 2 months—and shortly after the 2004 U.S. presidential election—they returned to the lab and took tests to assess knowledge of events surrounding the campaigns and elections that took place after the first session. The major finding was simply that preexisting knowledge of politics was far and away the strongest predictor of knowledge acquired about the campaign.

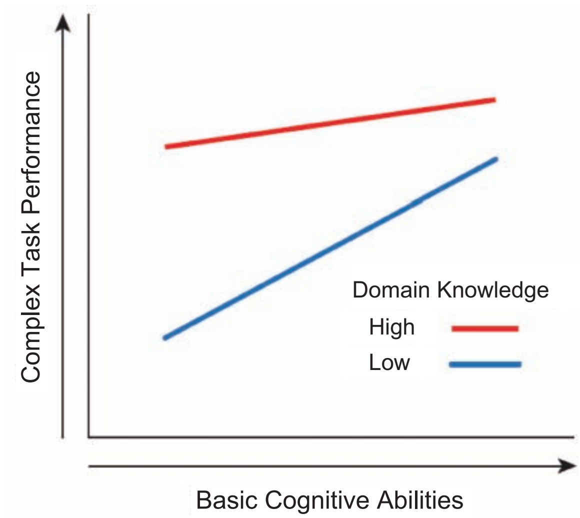

Fig. 1. The interaction between complex task performance and basic cognitive abilities at high and low levels of domain knowledge predicted by the *circumvention-of-limits hypothesis*.

Evidence for the Importance of Basic Abilities

So it is clear that domain knowledge is major source of "power" in complex tasks. However, it is just as clear that basic cognitive abilities are important. General intelligence—which is substantially heritable (Plomin, DeFries, McClearn, & McGuffin, 2008)—is widely regarded as the single best predictor of a number of real-world outcomes, including job performance (Schmidt & Hunter, 2004) and academic achievement (Kuncel & Hezlett, 2007), and correlates positively with skill in domains such as chess (Grabner, Stern, & Neubauer, 2007) and music (Ruthsatz, Detterman, Griscom, & Cirullo, 2008). Lubinski, Benbow, and colleagues (see Robertson, Smeets, Lubinski, & Benbow, 2010) have even documented that individual differences within the *top one percent* of cognitive ability predict individual differences in scientific achievement. For example, children who scored in the 99.9th percentile on the math section of the SAT by age 13 were found to be *eighteen times* more likely to go on to earn a PhD in a Science, Technology, Engineering, and Mathematics (STEM) discipline than children who "only" scored in the 99.1th percentile. In his bestselling book *Outliers*, alluding to the idea that intelligence is a "threshold" variable (Torrance, 1962), Malcolm Gladwell (2008) commented that "The relationship between success and IQ works only up to a point. Once someone has reached an IQ of somewhere around 120, having additional IQ points doesn't seem to translate into any measurable real-world advantage" (pp. 78–79). In his own bestselling book, *The Social Animal*, David Brooks (2011) expressed the same idea: "A person with a 150 IQ is in theory much smarter than a person with a 120 1Q, but those additional 30 points produce little measurable benefit when it comes to lifetime success" (p. 165). Malcolm Gladwell and David Brooks are simply wrong. At least in science, a high level of intellectual ability puts a person at a measurable advantage—and the higher the better.

Characterizing the Interplay Between Acquired Characteristics and Basic Abilities

It seems, then, that individual differences in performance on many complex tasks arise from *both* acquired characteristics and basic abilities. With this generalization as our starting point, a major goal of our collaborative research, which we began as graduate students working with Timothy Salthouse, has been to investigate the *interplay* between these two types of factors. We have been especially interested in the question of whether various forms of domain knowledge moderate the impact of basic cognitive abilities on performance. More concretely, as illustrated in Figure 1, we have asked whether relationships between basic abilities and complex task performance are weaker at high levels of domain knowledge (red line) than at lower levels (blue line), as evidenced by Ability × Knowledge interactions.

This possibility, which we refer to as the *circumvention-of-limits hypothesis*, has been mentioned by a number of theorists. Ackerman (1988) proposed that general intelligence is important in the initial stage of skill acquisition, when it is necessary to hold steps of executing a skill in the focus of attention, but then drops out as a predictor of performance as knowledge is proceduralized. Similarly, Ericsson and colleagues have argued that the acquisition of knowledge and skills through *deliberate practice*—engagement in activities specifically designed to improve performance in a domain (Ericsson, Krampe, & Tesch-Römer, 1993)—enables circumvention of performance limitations associated with basic abilities: "The effects of extended deliberate practice are more far-reaching than is commonly believed. Performers can acquire skills that circumvent basic limits on working memory capacity. . ." (Ericsson & Charness, 1994, p. 725).

Testing the circumvention-of-limits hypothesis

Over the past decade, we have carried out a series of studies to test this hypothesis. We have focused specifically on the question of whether domain knowledge reduces the effect of working-memory capacity on performance in complex tasks. In theoretically neutral terms, working-memory capacity can be thought of as the limits on the ability to simultaneously store and process information. As measured by "complex span" tasks, which require the participant to remember some information while performing mental operations (e.g., Turner & Engle's, 1989, operation span), working-memory capacity correlates strongly with abstract reasoning, problem solving, decision making, language comprehension, and complex learning (see Hambrick, 2005, for a review)—and with the general factor of intelligence, or psychometric *g* (e.g., Kane et al., 2004; Kyllonen, 1996). Working-memory capacity is also influenced by genetic factors, with heritability estimates typically around 50 percent (e.g., Kremen et al., 2007).

In one study (Hambrick & Engle, 2002), we had participants complete tests of baseball knowledge and complex-span tasks and then perform a complex memory task in which they listened to fictitious radio broadcasts of baseball games and tried to remember both the major events of the games and information about the players. Not surprisingly, domain knowledge (of baseball) had a very strong positive effect on memory performance. However, there was also a positive effect of working-memory capacity and no evidence for a Working-Memory Capacity × Domain Knowledge interaction. Working-memory capacity was as important as a predictor of memory performance at high levels of domain knowledge as it was at low levels. Similarly, in a study of skill in Texas Hold'em poker (Meinz et al., 2011), we found positive effects of both domain knowledge (of poker) and working-memory capacity on performance of a *hand evaluation* task, in which the goal was to evaluate the likelihood of drawing a card that would enable a win, and a *game memory* task, in which the goal was to remember hands in a game of Hold'em. But once again, there was no evidence for Working-Memory Capacity × Domain Knowledge interactions. We did not have world-class poker players in our sample, but we wonder whether knowledge and skill is all that it takes to win the World Series of Poker!

In another study (Hambrick & Oswald, 2005), we took a somewhat different approach to testing the circumvention-of-limits hypothesis: We experimentally manipulated activation of domain knowledge. Again using baseball as the domain, we had participants perform a rather unusual memory task in which they attempted to remember the movements of spaceships, which unbeknownst to participants "flew" from planet to planet in a solar system in the same manner that baseball players run around a baseball diamond. Then, participants performed an isomorphic task in which a baseball diamond replaced the solar system and baseball players replaced the spaceships. There was a positive effect of working-memory capacity on memory performance in the spaceship condition, and a positive effect of baseball knowledge on memory performance emerged in the baseball condition. But still there was no Working-Memory Capacity × Domain Knowledge interaction. Activation of domain knowledge by the familiar context did not reduce, much less eliminate, the effect of working-memory capacity on performance.

Deliberate practice: Necessary and sufficient?

In a final study we will mention here (Meinz & Hambrick, 2010), we focused directly on Ericsson and colleagues' claim that skills acquired through deliberate practice can enable circumvention of limits on working-memory capacity. It seems clear that deliberate practice is *necessary* to acquire a very high level of skill in a domain. For example, in a study of pianists, Ericsson et al. (1993) found that professional pianists had accumulated an average of 10,000 hours of deliberate practice (i.e., practice alone) by the age of 20, whereas amateurs had accumulated only about 2,000 hours. However, we have wondered whether deliberate practice is *sufficient* to account for individual differences in skilled performance—or just necessary. In other words, if two people accumulate the same amount of deliberate practice, will they reach the same level of performance?

To answer this question, we designed a study to find out whether working-memory capacity would predict piano sight-reading ability (i.e., the ability to play pieces with no preparation) even among individuals with thousands of hours of deliberate practice. Fifty-seven pianists representing a wide range of cumulative deliberate practice—from 260 to more than 31,000 hours—performed a battery of complex-span tasks to assess working-memory capacity along with a sight-reading task. Not surprisingly, we found that deliberate practice was a powerful predictor of sight-reading performance. In fact, it accounted for nearly 50% of the variance. However, we also found that working-memory capacity was a positive predictor of performance above and beyond deliberate practice. Furthermore, as illustrated in Figure 2, there was no evidence for a Deliberate Practice × Working-Memory Capacity interaction—and thus no evidence that high levels of deliberate practice reduced the effect of working-memory capacity on performance. This was true even when we used deliberate practice *devoted specifically to sight-reading* as a predictor variable.

We speculated that working-memory capacity limits the number of notes the player can look ahead in the piece of

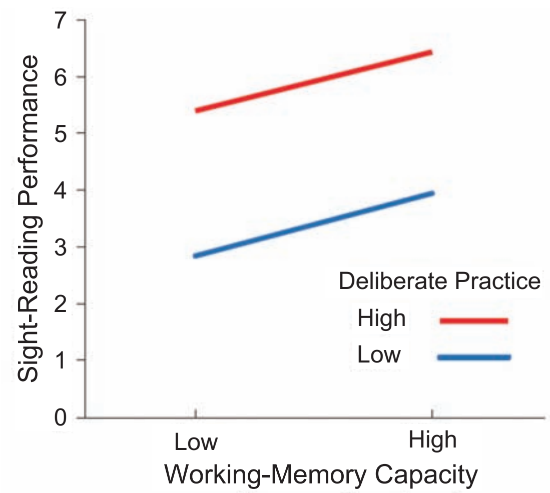

Fig. 2. Relationship between working-memory capacity and expert-rated sight-reading performance for low versus high levels of deliberate practice. (Graph plotted using values predicted from full regression equation; low and high values of the predictors correspond to values of −1 standard deviation and +1 standard deviation from the mean, respectively). Data from Meinz and Hambrick (2010).

music he or she is playing—a factor that has been shown to correlate very strongly with sight-reading skill. More generally, we argued that although deliberate practice may well be necessary to reach a very high level of skill, it is not always sufficient. Campitelli and Gobet (2011, this issue) summarize evidence from their own research that leads to this same conclusion. The general conclusion that we draw from this and the other studies reviewed here is that a high level of domain knowledge doesn't *guarantee* circumvention of limits associated with basic abilities. Basic abilities matter for novice performance, and sometimes they matter for *expert* performance.

Conclusions

High levels of skill in music, games, science, and other complex domains reflect knowledge and skills that enable the performer to adapt the unique demands of a domain. This point is amply demonstrated by Ericsson and colleagues' research (see Ericsson & Ward, 2007). However, the available evidence *does not* justify the claim that basic abilities are always unimportant for skilled performance: There is now good evidence that basic abilities predict success in a wide range of complex tasks, from chess to music, even among highly skilled performers.

The evidence we have discussed here is inconsistent with what we have termed the circumvention-of-limits hypothesis, but of course it doesn't rule out the possibility that there are conditions under which this hypothesis holds true. In fact, in a recent study, Hambrick et al. (2011) found evidence for an interaction between visuospatial ability and domain knowledge on performance in a geological *bedrock mapping* task, in which the goal was to infer the geological structure of a mountainous area. Visuospatial ability positively predicted performance at low, but not high, levels of geological knowledge. A challenge for future research is to identify task and situational factors that moderate the interplay between acquired characteristics and basic abilities. For example, in piano, it could be that working-memory capacity is important for sight-reading in performers of all levels of skill. However, working-memory capacity may become less important as the piece is practiced and then become entirely unimportant once mastered. Or perhaps working-memory capacity predicts performance in playing music in an unfamiliar genre but not a familiar genre.

We believe that research aimed at investigating these sorts of possibilities will increase scientific understanding of the underpinnings of skilled performance. We also believe that popular writers such as Malcolm Gladwell and David Brooks will do a great service to the public by accurately portraying this understanding in future books.

Recommended Reading

Ericsson, K.A., & Charness, N. (1994). (See References). Presents the *deliberate practice view* of expert performance.

Meinz, E.J., & Hambrick, D.Z. (2010). (See References). Presents evidence that deliberate practice does not reduce the effect of working-memory capacity on skilled piano sight-reading.

Declaration of Conflicting Interests

The authors declare that they have no conflicts of interest with respect to their authorship or the publication of this article.

References

Ackerman, P.L. (1988). Determinants of individual differences during skill acquisition: Cognitive abilities and information processing. *Journal of Experimental Psychology: General, 117*, 288–318.

Brooks, D. (2011). *The social animal. The hidden sources of love, character, and achievement*. New York, NY: Random House.

Campitelli, G., & Gobet, F. (2011). Deliberate practice: Necessary but not sufficient. *Current Directions in Psychological Science, 20*, 280–285.

Chase, W.G., & Simon, H.A. (1973). Perception in chess. *Cognitive Psychology, 4*, 55–81.

Ericsson, K.A., & Charness, N. (1994). Expert performance: Its structure and acquisition. *American Psychologist, 49*, 725–747.

Ericsson, K.A., Krampe, R.T., & Tesch-Römer, C. (1993). The role of deliberate practice in the acquisition of expert performance. *Psychological Review, 100*, 363–406.

Ericsson, K.A., & Ward, P. (2007). Capturing the naturally occurring superior performance of experts in the laboratory: Toward a science of expert and exceptional performance. *Current Directions in Psychological Science, 16*, 346–350.

Galton, F. (1869). *Hereditary genius*. London, England: Macmillan.

Gladwell, M. (2008). *Outliers: The story of success.* New York, NY: Little, Brown, and Co.

Grabner, R.H., Stern, E., & Neubauer, A.C. (2007). Individual differences in chess expertise: A psychometric investigation. *Acta Psychologica, 124*, 398–420.

Hambrick, D.Z. (2005). The role of domain knowledge in complex cognition. In O. Wilhelm & R.W. Engle (Eds.), *Handbook of understanding and measuring intelligence.* Thousand Oaks, CA: Sage.

Hambrick, D.Z., & Engle, R.W. (2002). Effects of domain knowledge, working memory capacity and age on cognitive performance: An investigation of the knowledge-is-power hypothesis. *Cognitive Psychology, 44*, 339–387.

Hambrick, D.Z., Libarkin, J.C., Petcovic, H.L., Baker, K.M., Elkins, J., Callahan, C., et al. (2011). *A test of the circumvention-of-limits hypothesis in geological bedrock mapping*. Manuscript submitted for publication.

Hambrick, D.Z., Meinz, E.J., Pink, J.E., Pettibone, J.C., & Oswald, F.L. (2010). Learning outside the laboratory: Ability and non-ability influences on acquiring political knowledge. *Learning and Individual Differences, 20*, 40–45.

Hambrick, D.Z., & Oswald, F.L. (2005). Does domain knowledge moderate involvement of working memory capacity in higher-level cognition? A test of three models. *Journal of Memory and Language, 52*, 377–397.

Hambrick, D.Z., Salthouse, T.A. & Meinz, E.J. (1999). Predictors of crossword puzzle proficiency and moderators of age-cognition relations. *Journal of Experimental Psychology: General, 128*, 131–164.

Kane, M.J., Hambrick, D.Z., Wilhelm, O., Payne, T., Tuholski, S., & Engle, R.W. (2004). The generality of working memory capacity: A latent variable approach to verbal and visuo-spatial memory span and reasoning. *Journal of Experimental Psychology: General, 133*, 189–217.

Kremen, W.S., Jacobsen, K.C., Xian, H., Eisen, S.A., Eaves, L.J., Tsuang, M.T., et al. (2007). Genetics of verbal working memory processes: A twin study of middle-aged men. *Neuropsychology, 21*, 569–580.

Kuncel, N.R., & Hezlett, S.A. (2007). Standardized tests predict graduate student's success. *Science, 315*, 1080–1081.

Kyllonen, P.C. (1996). Is working memory capacity Spearman's *g*? In I. Dennis & P. Tapsfield (Eds.), *Human abilities: Their nature and measurement* (pp. 49–75). Mahwah, NJ: Lawrence Erlbaum.

Meinz, E.J., & Hambrick, D.Z. (2010). Deliberate practice is necessary but not sufficient to explain individual differences in piano sight-reading skill: The role of working memory capacity. *Psychological Science, 21*, 914–919.

Meinz, E.J., Hambrick, D.Z., Hawkins, C.B., Gillings, A.K., Meyer, B.E., & Schneider, J.L. (2011). *Domain knowledge and working memory capacity as predictors of components of skill in Texas Hold'em poker*. Manuscript submitted for publication.

Plomin, R., DeFries, J.C., McClearn, G.E., & McGuffin, P. (2008). *Behavioral Genetics* (5th ed.). New York, NY: Worth Publishers.

Robertson, K., Smeets, S., Lubinski, D., & Benbow, C.P. (2010). Beyond the threshold hypothesis: Even among the gifted and top math/science graduate students, cognitive abilities, vocational interests, and lifestyle preferences matter for career choice, performance, and persistence. *Current Directions in Psychological Science, 19*, 346–351.

Ruthsatz, J., Detterman, D., Griscom, W.S., & Cirullo, B.A. (2008). Becoming an expert in the musical domain: It takes more than just practice. *Intelligence, 36*, 330–338.

Schmidt, F.L., & Hunter, J. (2004). General mental ability in the world of work: Occupational attainment and job performance. *Journal of Personality and Social Psychology, 86*, 162–173.

Simonton, D.K. (1999). Talent and its development: An emergenic and epigenetic model. *Psychological Review, 106*, 435–457.

Torrance, E.P. (1962). *Guiding creative talent*. Englewood Cliffs, NJ: Prentice Hall.

Turner, M.L. & Engle, R.W. (1989). Is working memory capacity task dependent? *Journal of Memory and Language, 28*, 127–154.

Watson, J. B. (1970). *Behaviorism*. New York, NY: Norton. (Original work published 1930)