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Toward a multifactorial model of expertise: beyond born versus made

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The debate over the origins of individual differences in expertise has raged for over a century in psychology. The "nature" view holds that expertise reflects "innate talent"—that is, genetically determined abilities. The "nurture" view counters that, if talent even exists, its effects on ultimate performance are negligible. While no scientist takes seriously a strict nature-only view of expertise, the nurture view has gained tremendous popularity over the past several decades. This environmentalist view holds that individual differences in expertise reflect training history, with no important contribution to ultimate performance by innate ability ("talent"). Here, we argue that, despite its popularity, this view is inadequate to account for the evidence concerning the origins of expertise that has accumulated since the view was first proposed. More generally, we argue that the nature versus nurture debate in research on expertise is over—or certainly should be, as it has been in other areas of psychological research for decades. We describe a multifactorial model for research on the nature and nurture of expertise, which we believe will provide a progressive direction for future research on expertise.

Keywords: music; talent; expertise; genetics; deliberate practice

Introduction

Obviously, some people reach a much higher level of skill in complex domains than other people. Music is a prime example. Consider the jazz bassist and vocalist Esperanza Spalding. At age 4, after seeing Yo-Yo Ma play cello on *Mister Rogers' Neighborhood*, Spalding took up violin and a year later earned a spot in the Chamber Music Society of Oregon. At 16, Spalding received a full scholarship to Berklee College of Music, where after graduation she became one of the conservatory's youngest instructors ever.[1] Spalding has since won four Grammy Awards.

Historically, the debate about what underlies individual differences in expertise has been framed as one of "nature versus nurture." The nature view holds that expertise reflects "innate talent." Nearly, 150 years ago, Galton[2] argued for this view based on his finding that eminence in music, science, art, and other professions runs in families. The nurture view counters that, if talent exists at all, its effects on ultimate performance are negligible. As Watson[3] stated, "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).

Today, no scientist takes seriously a strict nature view of expertise—which is to say that no one believes people are literally born experts, innately endowed with skill. Even Galton[2] recognized that one "must have an adequate power of doing a great deal of very laborious work" (p. 37) to achieve eminence. On the other hand, especially as championed by Anders Ericsson and colleagues, the nurture view has gained tremendous popularity in recent decades. Twenty-five years ago, in a pivotal article, Ericsson *et al.*[4] argued that "individuals acquire virtually all of the distinguishing characteristics of expert performers through relevant activities (deliberate practice)" (p. 397)—that is, engaging in activities specially designed to improve performance. They further claimed that, although genetic factors may influence a person's willingness to practice, they "have

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little direct impact on ultimate adult performance" (p. 365), except for height and body size. They added "we reject any important role for innate ability" (p. 399). Ericsson[5] reiterated this view, arguing "it is possible to account for the development of elite performance among healthy children without recourse to unique talent (genetic endowment)—excepting the innate determinants of body size" (p. 4).

Ericsson's view has inspired a great deal of research, as well as popular books, such as *Talent is Overrated: What* Really *Separates World-Class Performers from Everybody Else*[6] and *The Talent Code: Greatness Isn't Born, It's Grown. Here's How.*[7] Here, however, we argue that Ericsson's view is inadequate as a theoretical account of expertise, both in terms of its ability to account for relevant findings and its specification of key concepts. More generally, we argue that the nature versus nurture debate in research on expertise is over—or certainly should be, as it has been for decades in other areas of research.[8] We end by describing a multifactorial framework for research on expertise.

The deliberate practice view

Two major claims of the deliberate practice view have recently been the subjects of intensive research. The first claim concerns the magnitude of the relationship between deliberate practice and expertise (i.e., domain-relevant performance). Ericsson *et al.*[4] had musicians provide retrospective estimates of their engagement in deliberate practice across their musical careers and found a correspondence between skill level and deliberate practice: the higher the skill level, the higher the average amount of deliberate practice. Extending their framework to several domains of expertise, Ericsson *et al.* concluded that "individual differences in ultimate performance can *largely be accounted for* by differential amounts of past and current levels of practice" (p. 392, emphasis added).

In any straightforward sense of the term "largely," this claim leads to the prediction that deliberate practice should, at a minimum, explain most (the majority) of the variance in expertise. This prediction is not supported by evidence, as the results of recent meta-analyses of music studies illustrate. Hambrick *et al.*[9] reanalyzed the results of eight studies of music, each of which reported a correlation between a measure of a training activity interpretable as deliberate practice and a measure of music performance. After correcting the correlations for attenuation due to the unreliability of the measures, deliberate practice explained an average of 29.9% of the variance in music performance (Fig. 1A). Identifying several more relevant studies, Platz *et al.*[10] found that the average corrected correlation between deliberate practice and music performance was 0.61, indicating that deliberate practice explained 37% of the variance (Fig. 1B). A subsequent meta-analysis[11] included 19 music studies (as well as studies in other domains). Individual correlations were not corrected for unreliability, because many of the studies did not report reliability estimates. However, deliberate practice explained less than half of the variance in music performance under a range of reliability assumptions—for example, 42% assuming "acceptable" reliability of 0.70 for both measures (Fig. 1C). Results are similar for other domains, including games and sports.[11] Thus, deliberate practice is an important predictor of expertise, though not as important as Ericsson and colleagues have argued. That is, factors *other than deliberate practice* (and factors, such as motivation, that influence performance through deliberate practice) explain most of the variance in expertise. In practical terms, this indicates that people vary widely in the amount of training they require to reach a given level of expertise.

It also appears that deliberate practice may lose its predictive power at elite levels of performance, contrary to the claim that "[i]ndividual differences, even among elite performers, are closely related to assessed amounts of deliberate practice"[4] (p. 363). A recent meta-analysis of sports studies found that, overall, deliberate practice explained 18% of the variance in expertise, but explained only 1% of the variance in studies that compared elite performers to "sub-elite" performers (e.g., international- to national-level athletes[12]). As more direct evidence, Güllich[13] compared 83 international medalists (Olympic/World championship) to 83 nonmedalists matched on sport, age, and gender. As shown in Figure 2, across their careers, the medalists had accumulated fewer—not more—hours of organized training/practice in their main sport than the nonmedalists.

The second major claim of the deliberate practice view is that, if genetically influenced abilities matter at all for domain-relevant performance, it is only early in training. As Ericsson[14] explained, "[f]or

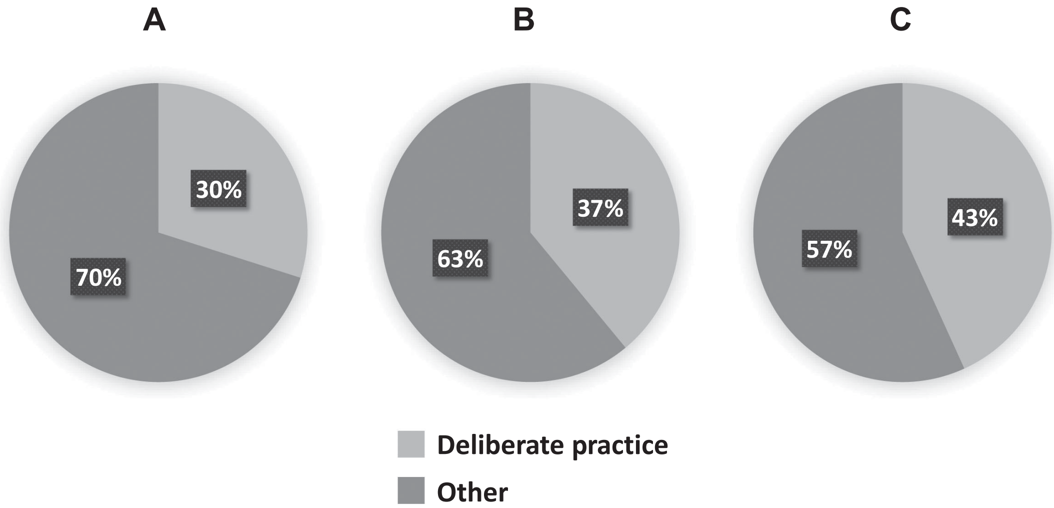

Figure 1. Average percentage of interindividual variability in musical expertise explained by deliberate practice in three meta-analyses: (A) Hambrick *et al.*,[9] (B) Platz *et al.*,[10] and (C) Macnamara *et al.*[11] Percentage values are rounded to nearest whole number.

individuals who have acquired cognitive structures that support a high level of performance the expert performance framework predicts that these acquired cognitive structures will directly mediate superior performance and thus diminishing correlations between general cognitive ability and domain-specific performance" (p. 84). Hambrick *et al.*[15] reviewed evidence from 15 studies directly relevant to this *circumvention-of-limits hypothesis*[16] and found that in only three were the findings supportive. Moreover, for some tasks, there was evidence that cognitive ability factors remained predictive of performance at higher levels of skill. For example, in a study of pianists, Meinz and Hambrick[17] found that working memory capacity significantly predicted sight-reading performance, even at high levels of deliberate practice. Similarly, cognitive ability has been found to remain a significant predictor of job performance in employees with high levels of job experience, even when the ability–performance relationship drops early in employment (e.g., see Ref. 18, Fig. 8.1; for reviews, see Refs. 15 and 19).

The deliberate practice view makes a number of other claims. One is that at least 10 years of deliberate practice is required to achieve expertise. As Ericsson[20] explained, "This ten-year rule of required engagement in domain-related activities is the most compelling evidence for the necessity of experience to attain high levels of performance" (p. S72). And as Ericsson *et al.*[21] advised, "It will take you at least a decade to achieve expertise, and you will need to invest that time wisely, by engaging in 'deliberate' practice" (p. 116). Engagement in domain-related activities is, of course, necessary to develop expertise, but there is evidence to contradict the 10-year rule. For example, the chess great Magnus Carlsen achieved grandmaster status after 5.4 years of serious chess study, or 8.4 years after learning the rules of chess.[22] As another example, Lombardo and Deaner[23] documented that eight of the 12 fastest sprinters in American history reached world class status in fewer than 10 years ($M = 8.7$, $SD = 3.8$). Ericsson[24] granted that "people are able to reach world-class levels in fewer than ten years in activities that lack a history of organized international competition" (p. 692), but chess and running are among the oldest and most organized competitive activities. In sum, the 10-year rule may serve as a useful reminder to the layperson that expertise is acquired gradually, but, as a scientific proposition, it appears to be false.

Another claim is that deliberate practice is a stronger predictor of performance than other forms of experience. As Boot and Ericsson[25] explained, "Ericsson and colleagues . . . make a critical distinction between domain-related activities of work, play, and deliberate practice, and claim that the amount of accumulated time engaged in deliberate practice activities is the primary predictor of exceptional performance" (p. 146).

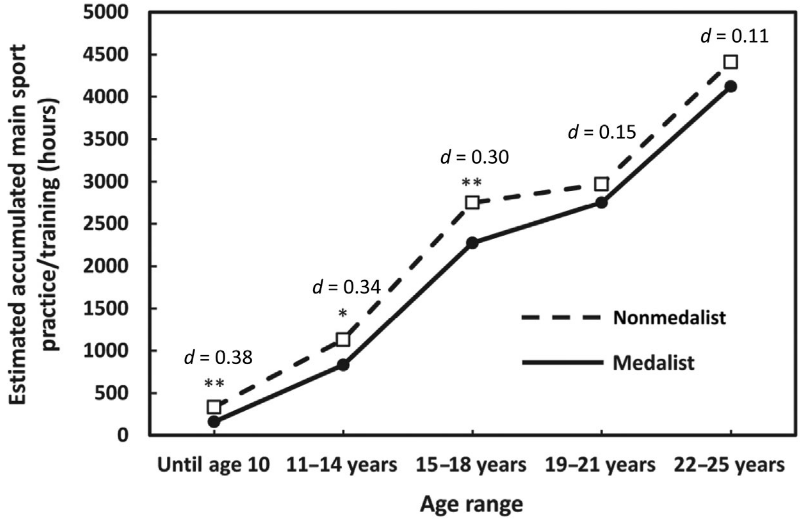

Figure 2. Estimated accumulated number of hours of practice/training in main sport for international medalists and nonmedalists matched on age, gender, and sport. Values are from Table 4 in Güllich.[13]

This is not always true. For example, what Côté and colleagues termed *deliberate play*—engaging in intrinsically motivating activities designed to maximize enjoyment[26]—is sometimes more predictive of elite performance than deliberate practice (e.g., Ref. 27; see Ref. 28 for a review). The same may sometimes be true for work activities. For example, in a study of insurance salespeople, Sonnentag and Kleine[29] found that the number of cases handled correlated more strongly with sales performance ($r = 0.37$) than did measures of both current and accumulated deliberate practice ($r = 0.21$ and 0.13, respectively). Thus, although deliberate practice is consistently found to be a significant predictor of expertise, it is not always the strongest predictor.

The deliberate practice view further claims that "the higher the level of attained elite performance, the earlier the age of first exposure as well as the age of starting deliberate practice"[4] (p. 389). Although Ericsson *et al.* presented evidence (mean starting ages for groups representing different levels of skill in music, chess, and sports) in the direction predicted by this hypothesis (but without statistical significance tests and/or effect sizes for the mean differences), the aforementioned meta-analysis of sports found no difference in average starting age for higher- and lower skill athletes.[12] Moreover, in his matched-pairs study, Güllich[13] found that the medalists started training in their main sport significantly later, not earlier, than nonmedalists ($M_{medalist} =$ 11.8 years versus $M_{nonmedalist} =$ 10.3 years) and participated significantly more in other-sport training before the start of their main sport than the nonmedalists. Thus, except for domains, such as gymnastics, where elite performance is achieved before physical maturity, it is not clear that early specialization is the best recommendation for developing expertise. Later specialization may be more optimal.

To sum up, key claims of the deliberate practice view are not well supported by the available evidence (Table 1). We further note that the concept of deliberate practice is underspecified in ways that leave open the possibility of *post hoc* explanations of results. In particular, if the correlation between deliberate practice and expertise is weaker than expected, one can always argue that the practice was not *sufficiently* deliberate, or that the teacher (if one is involved) did not use the correct method or was unqualified. This wiggle room makes any claims about the importance of deliberate practice difficult to falsify.

Ericsson's response

In the face of challenge, Ericsson has vigorously defended the deliberate practice view. However, as we have noted elsewhere, this defense is undermined by major inconsistencies and contradictions in his arguments (see Refs. 30 and 31). Most significantly, although Ericsson has criticized other researchers

Table 1. Summary of evidence for key claims of the deliberate practice view

Claim by Ericsson and colleagues	Consistent support?	Summary of evidence
"[I]ndividual differences in ultimate performance can largely be accounted for by differential amounts of past and current levels of practice." (**Ref.** 4**, p. 392**)	No	Multiple studies and meta-analyses demonstrate that deliberate practice does not largely account for individual differences in expertise; the amount of reliable variance explained by deliberate practice is consistently smaller than the amount not explained by it.
"Individual differences, even among elite performers, are closely related to assessed amounts of deliberate practice." (**Ref.** 4**, p. 363**)	No	Research on sports suggests that deliberate practice may lose its predictive validity at elite levels of performance.
"For individuals who have acquired cognitive structures that support a high level of performance the expert performance framework predicts that these acquired cognitive structures will directly mediate superior performance and thus diminishing correlations between general cognitive ability and domain-specific performance." (**Ref.** 14**, p. 84**)	No	There is little evidence to support this claim; in some tasks, cognitive ability factors are predictive of performance differences even at relatively high levels of skill. Cognitive ability significantly predicts job performance even after extensive job experience.
"It will take you at least a decade to achieve expertise, and you will need to invest that time wisely, by engaging in 'deliberate' practice." (**Ref.** 21**, p. 116**)	No	Expertise is acquired gradually in any complex domain, but there is a large amount of variability in the amount of training that it takes an individual to reach a given level of skill. Elite performance is sometimes reached in less than a decade.
"Ericsson and colleagues . . . make a critical distinction between domain-related activities of work, play, and deliberate practice, and claim that the amount of accumulated time engaged in deliberate practice activities is the primary predictor of exceptional performance." (**Ref.** 25**, p. 146**)	No	In samples representing wide ranges of skill, deliberate practice is usually found to be a significant positive predictor of individual differences in expertise, but other forms of domain-relevant experience are sometimes found to be more predictive.
"[T]he higher the level of attained elite performance, the earlier the age of first exposure as well as the age of starting deliberate practice." (**Ref.** 4**, p. 389**)	No	Research indicates that, in domains where ultimate performance is achieved after maturity, higher skill individuals may start around the same age as, or later than, lower skill individuals.

for deviating from his definition of deliberate practice in their attempts to test the deliberate practice view (see Ref. 32), he has defined the term in multiple ways—sometimes arguing that a teacher must be involved, other times arguing that a teacher need not be involved, and still other times arguing that a teacher is usually involved (Table 2). Ericsson[32] has also recently rejected studies for violating his criteria for deliberate practice—including, oddly, some of his own studies—even though he has repeatedly used the same studies to argue for the importance of deliberate practice (see Table 3 for examples).

Consequently, there is now a cloud of confusion around the deliberate practice view that makes it difficult to empirically evaluate. Adding to the confusion, Ericsson and colleagues appear to be reinterpreting studies they previously used to argue for the importance of deliberate practice as studies of a less effective form of practice that Ericsson and Pool[33] termed "purposeful practice" (i.e., self-directed practice). Consider Moxley *et al.*'s[34] portrayal of a study of spelling bee contestants by Duckworth *et al.*[35] The explicit focus of that study was deliberate practice: Along with appearing in the title, "deliberate practice" appears 72 times in the study report, and Ericsson[36] himself once stated: "In that study we (as I was also one of the co-authors) collected data on 'deliberate practice'"

Table 2. **Definitions of deliberate practice in Ericsson's writings**

Deliberate practice *must* involve a teacher:
"In distinction from leisurely or normal job-related experience, Ericsson *et al.* defined *deliberate practice* as a very specific activity designed for an individual by a skilled teacher explicitly to improve performance." (**Ref.** 57**, p. 333**)
"Ericsson *et al.* (1993) used the term '*deliberate practice* for the individualized training activities specially designed by a coach or teacher to improve specific aspects of an individual's performance through repetition and successive refinement.'"[58] (**Ref.** 32**, p. 3**)[a]
Deliberate practice *typically or often* involves a teacher:
"When individuals engage in a practice activity (typically designed by their teachers), with full concentration on improving some aspect of their performance, we call that activity deliberate practice." (**Ref.** 5**, p. 14**)
"Expert performance can . . . be traced to active engagement in deliberate practice (DP), where training (often designed and arranged by their teachers and coaches) is focused on improving particular tasks." (**Ref.** 59**, p. 988**)
Deliberate practice *need not* involve a teacher:
"Ericsson *et al.* (1993) proposed the term deliberate practice to refer to those training activities that were designed solely for the purpose of improving individuals' performance by a teacher or the performers themselves." (**Ref.** 60**, p. 84**)
"Ericsson *et al.* (1993) introduced the term *deliberate practice* to describe focused and effortful practice activities that are pursued with the explicit goal of performance improvement. Deliberate practice implies that well-defined tasks are practiced at an appropriate level of difficulty and that informative feedback is given to monitor improvement. These activities can be designed by external agents, such as teachers or trainers, or by the performers themselves." (**Ref.** 61**, p. 136**)

[a]Ericsson[32] misquotes Ericsson and Lehmann:[58] "specially designed by a coach or teacher" should be "especially designed by a coach or teacher."

(p. 6). Nonetheless, Moxley *et al.* recently stated that the spelling bee study had found certain measures "to be related to *purposeful practice* in preparation for competitions in spelling" (p. 12, emphasis added), making no mention in their discussion that the explicit focus of the study was actually *deliberate practice.* The distinction between deliberate practice and purposeful practice is potentially useful; the problem here is the switch of terms. Moxley *et al.* further claim that because SCRABBLE lacks professional coaches "SCRABBLE players cannot engage in deliberate practice, but only purposeful practice and other types of practice" (p. 4). Yet, citing one of Ericsson's own studies, Ericsson *et al.*[37] once stated that "[s]everal researchers have reported a consistent association between the amount and quality of solitary activities meeting the criteria of deliberate practice and performance in different domains of expertise, such as . . . Scrabble"[38] (p. 9). So, it appears that the criteria of deliberate practice have changed.

It is, of course, appropriate to revise a theory as evidence accumulates. This is part and parcel of what the philosopher of science Lakatos termed a "progressive" program of research.[39] It should go without saying, however, that for a scientific field to progress, revisions to a theory must be explicitly acknowledged and clearly explained. Otherwise, in Lakatos' terminology, a theory can be endlessly adjusted and readjusted through "auxiliary hypotheses" that form a "protective belt" around its "hard core"—the central theses of the theory that are essentially irrefutable.[40] The program of research then becomes degenerative rather than progressive. On that note, we now describe a framework for guiding what we believe will be a progressive program of research on expertise.

Toward a multifactorial model of expertise

To sum up, research suggests that both basic psychological traits and training—nature and nurture—contribute to individual differences in expertise. Expanding on existing theory (e.g., Ref. 41), the multifactorial gene–environment interaction model (MGIM) of expertise provides

Table 3. Examples of shifting standards for evidence concerning deliberate practice

Study rejected by Ericsson[32] for violating his criteria for deliberate practice	Previous use of the same study in Ericsson's writings to argue for the importance of deliberate practice
Hodges and Starkes[62,a]	"Several studies and reviews have since found a consistent relation between performance and amount and quality of **deliberate practice** . . . in sports (. . . Hodges & Starkes, 1996 . . .)." **(Ref.** 60**, p. 87)**
Helsen *et al.*[63,a]	"Research conducted in several domains such as . . . sports (Helsen, Starkes & Hodges, 1998 . . .) suggests that the amount of accumulated **deliberate practice** is closely related to an individual's attained level of performance." **(Ref.** 61**, p. 136)**
Duffy *et al.*[64,b]	"The engagement of the dart-related activities differed between groups for three types, namely playing in league darts, solitary practice and total **deliberate practice.** The latter two findings were in line with prior expectations namely; the more an individual engages in **deliberate practice** (particularly solitary practice) the more proficient their performance is likely to be. This finding supports one of the main tenets of Ericsson *et al.*'s (1993) theory whereby expertise is acquired through a vast number of hours spent engaging in activities purely designed to improve performance, i.e., **deliberate practice**." **(Ref.** 64**, pp. 242–243)**
Charness *et al.*[65,b]	"The paper by Charness, Tuffiash, Krampe, Reingold, and Vasyukova extends an earlier classic chapter by Charness, Krampe, and Mayr (1996) and examines retrospective estimates by a large sample of chess players about their training during the development of their skill and expertise. This paper reports the most compelling and detailed evidence for how designed training (**deliberate practice**) is the crucial factor in developing expert chess performance." **(Ref.** 66**, p. 237)**
Tuffiash *et al.*[38,b]	"Several researchers have reported a consistent association between the amount and quality of solitary activities meeting the criteria of **deliberate practice** and performance in different domains of expertise, such as . . . Scrabble (Tuffiash et al., 2007)." **(Ref.** 37**, p. 9)**
Duckworth *et al.*[35,b]	"Our major findings in this investigation are as follows: **Deliberate practice**—operationally defined in the current investigation as the solitary study of word spellings and origins—was a better predictor of National Spelling Bee performance than either being quizzed by others or engaging in leisure reading. With each year of additional preparation, spellers devoted an increasing proportion of their preparation time to **deliberate practice** . . . .Grittier spellers engaged in **deliberate practice** more so than their less gritty counterparts, and hours of **deliberate practice** fully mediated the prospective association between grit and spelling performance." **(Ref.** 35**, p. 178)**

NOTE: In each quotation, the emphasis on "deliberate practice" is added.
[a]Rejected because article "do[es] not record assigned individualized practice tasks with immediate feedback and goals for practice" (see Ref. 67, Table 3).
[b]Rejected because article "do[es] not record a teacher or coach supervising and guiding all or most of the practice" (see Ref. 67, Table 2).
For additional examples of studies rejected/previously used by Ericsson, see Ref. 68, Table 9.1; a complete list can be found here: http://www.scienceofexpertise.com/resources in the "Notes on Review of Ericsson and Pool's Peak" presentation.

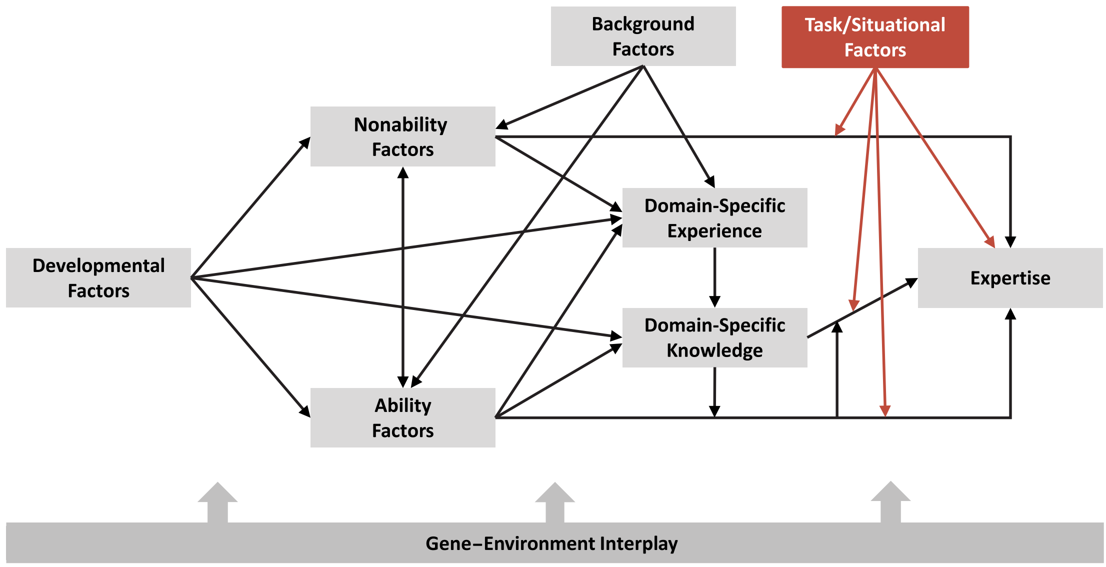

Figure 3. Multifactorial gene–environment interaction model (MGIM) of expertise. Reproduced with permission from Ref. 67.

a framework for thinking about how these factors jointly influence the development of expertise.[42,43] As shown in Figure 3, the MGIM assumes that (1) expertise arises from influences of both domain-general traits and domain-specific knowledge/skills; (2) these factors may influence expertise both indirectly and directly; and (3) genetic and environmental factors operate together to produce individual differences in expertise.

Unlike the deliberate practice view, the MGIM does not "reject any important role for innate ability" (Ref. 4, p. 392). Rather, it allows that genetically influenced abilities may predict not only initial performance but also ultimate performance. The MGIM also allows that multiple forms of experience may contribute meaningfully to the acquisition of expertise, rather than assuming the primacy of a single form of experience (i.e., deliberate practice). In short, at the core of the MGIM is the assumption that expertise is multiply determined, and thus can never be adequately understood by focusing on one factor or one class of factors.

Evidence for the MGIM

A central concept in the MGIM is *gene–environment interplay,* including both gene–environment interaction (G × E) and gene–environment correlation (*r*GE). G × E occurs when the magnitude of genetic influence on an outcome varies as a function of the type or amount of an environmental experience. *r*GE occurs when people experience different environments as a systematic function of their genetic differences rather than at random and can be *passive, active,* or *evocative*[44] (see Ref. 45 for an extension of these concepts to expertise research). Passive *r*GE occurs when a person inherits from his/her parents both their genes and an environment linked to those genes, as when a person inherits both genes underlying musical aptitude and a musically rich environment. Active *r*GE occurs when a person's genotype influences the experiences he/she creates for herself/himself, as when a person with a high music aptitude seeks out opportunities to practice music. Finally, evocative *r*GE occurs when a person's genotype elicits certain reactions in other people, as when a person with high music aptitude attracts the notice of music teachers, who take them on as a student.

There is now evidence for both gene–environment correlation and interaction in the development of expertise (see Refs. 46 and 47). Using data from the National Merit twin sample, Coon and Carey[48] found heritability estimates of 38% for males and 20% for females for music achievement. In a more recent analysis of this dataset, Hambrick and Tucker-Drob[49] found that heritability was substantial not only for musical achievement (26%) but also for a measure of music practice (38%). This finding might seem inexplicable if practice is thought of as a purely environmental variable, as it traditionally has been in the nature versus nurture debate in the expertise literature. However, as just illustrated, it is readily interpretable as an instance of *r*GE. Moreover, the genetic influence on music accomplishment remained sizeable (20%) even after controlling for music practice. This finding is consistent with the possibility that genetically influenced abilities predict expertise independent of training.

In a much larger study, Ullén *et al.*[50] had nearly 7,000 twins complete a test of musical aptitude (the Swedish Musical Discrimination Test). The heritability was 50% for rhythm discrimination, 59% for melody discrimination, and between 12% and 30% for pitch discrimination, and averaged around 50% for accumulated amount of music practice. Furthermore, using intratwin pair modeling, Mosing *et al.*[51] found that identical twins who differed massively in accumulated amount of music practice did not perform significantly differently on the tests of music aptitude. Thus, while certain types of knowledge and skill necessary to play music at a high level must be acquired (e.g., how to read music), basic sensory capacities involved in playing music may not be influenced by music practice.

There is also emerging evidence from molecular genetic research for links between specific genes and elite performance. In pioneering research, North and colleagues documented correlations between genotype for the ACTN3 gene, which codes the α-actinin-3 protein in fast-twitch muscles, and performance in various sprint events. For example, in one study,[52] compared with 18% of control subjects, only 6% of 107 elite athletes from various short-distance events had a variant of ACTN3 that made them α-actinin-3–deficient. More striking, none of the most elite athletes in the sample—the 32 Olympians—were α-actinin-3 deficient. There is also now evidence for associations between specific genes and a wide range of music-related traits, ranging from music perception to musical creativity to singing accuracy.[53]

Future directions

Multifactorial research on the "nature and nurture" of expertise is in its early stages (though well underway in some areas, especially sports science[54]). An important direction for future research is to combine the *expert performance approach* with genetically informative research designs. Developed by Ericsson and Smith,[55] the expert performance approach uses laboratory paradigms, such as chess move–choice tasks and music performance tasks, to objectively assess performance in a domain. An example of the type of question that could be addressed with this research is whether and to what degree there is overlap in genetic influences on expertise and on basic traits, such as intelligence, personality, sensorimotor ability, and motivation. This would be a way to empirically test the general claim that "expert performance is special and cannot be extrapolated from studies of performance in the general population" (Ref. 14, p. 81). Another direction for future research is to conduct candidate gene and genome-wide association studies to identify specific genes underlying variation in such objective measures of expertise, as well as its neural correlates (i.e., endophenotypes). This research will connect expertise research to the biological sciences, once and for all moving it beyond an anachronistic "nature versus nurture" perspective.

Conclusions

Twenty-five years ago, Ericsson and colleagues proposed their influential deliberate practice view of expertise. Though an influential account of expertise, this view is inadequate to explain the body of empirical evidence that has since accumulated. Moving ahead, we believe that the overarching goal of expertise research should be to develop and test theories of expertise that take into account all potentially relevant explanatory constructs. This includes different forms of experience, as well as basic human traits; it also includes task and situational factors, such as task complexity and performance pressure.[69] This research promises to increase theoretical understanding of the origins of expertise and provide scientific grounding for interventions aimed at accelerating the acquisition of expertise. For example, it may one day be possible to use information about people's genotypes to tailor musical or professional training, as is already being done in sports (e.g., Ref. 56). This type of intervention promises to help people realize their potential for acquiring expertise.

Competing interests

The authors declare no competing interests.

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