

RESPONSE TO COMMENTARIES

Misunderstandings, agreements, and disagreements: toward a cumulative science of reproducibly superior aspects of giftedness

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In our target paper we approached the issues of gifts and innate talents a little differently; in contrast to earlier reviews we turned away from definitions and global theories and focused instead on the empirical evidence for giftedness meeting the standards of laboratory science, namely that the performance associated with a gift or talent is reproducibly superior and objectively measured. We then surveyed all available domains for evidence and focused, in particular, on performance that allegedly could not be explained in terms of acquired skills and adaptations in the context of the expert performance framework. We argued that this approach would help us and other scientists make progress in identifying the verifiable, reproducible evidence for any innate gifts that may be necessary for achieving elite and expert levels of performance. Once identified, the associated phenomena could then be replicated and examined in more detail to develop complete accounts in terms of gifted individuals' unique genetic endowment, the associated unique genes, and their expression during development leading to the observable phenotypes.

We were delighted to receive so many commentaries from many of the authors that we had cited in our target paper. Several commentators (Baker, Beghetto-Kaufman, Coleman, Freeman, Kaufman, Runco, Subotnik-Jarvin-Rayhack, Ziegler) were kind enough to compliment us on our target paper's scope and depth of review, even though many expressed disagreements with some of our views and ideas. Gagné is the only commentator who feels that our target paper demonstrated little progress beyond Howe *et al.*'s (1998) target paper and the associated exchanges in

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the *Behavioral and Brain Sciences*. He states 'In spite of Ericsson's current efforts to counter and circumvent the major objections expressed then, *most* of them remain valid here' (emphasis added); however, his use of the word 'most' seems to imply at least some limited progress. The most compelling endorsement of the challenge of our target article was given by one of main theorists of giftedness, namely Ziegler. He made the case that it is the full responsibility of researchers of giftedness to support their theoretic arguments by demonstrating compelling evidence for 'innate talents, with methodologically sound investigations and studies'.

Overall, we are pleased with commentators' willingness to respond to our target article's challenge to identify observable reproducible phenomena that could be widely accepted as strong scientific evidence for innate talent. Obviously, the space constraint forced some of the commentators to cite other publications, where they have described evidence for innate talent more fully. For example, in his commentary, Baker cites issues and evidence reported in a chapter by Abernethy *et al.* (2003), where a number of criticisms against the expert performance framework in sports (Ericsson, 2003a) were voiced. However, Baker omits mentioning that the first author published a point-by-point rebuttal of those particular criticisms (Ericsson, 2003b) in the same edited volume (Starkes & Ericsson, 2003). Ideally, Baker should have commented on problems with those rebuttals rather than citing the original critique—unless the discussants address only the most recent published responses on an issue, we cannot expect progress. Ideally there should be opportunities for multiple back-and-forth exchanges to identify the core issues and evidence that captures genuine disagreements. For a rare extended transcribed exchange, see the discussion following the presentation of Ericsson *et al.* (1990) at the meeting of the Ciba symposium on 'The origins and development of high ability'. In that discussion, the first author invited 'others to tell me about research findings that we may have overlooked [as evidence for innate talent]' (p. 235). The famous behavior geneticist, Thomas Bouchard, was willing to put a wager on several bodies of evidence that would demonstrate evidence for innate talent differences in expert performance and said: 'I am ready to bet my house on that' (p. 235). There were other related bets made during the ensuing discussion, which we feel demonstrates remarkable conviction in the absence of verifiable facts from studies. To go beyond exchanges of opinion we need to reach an agreement on the reproducible phenomena that are the fundamental empirical support for theoretical claims, after which it should be possible to resolve these issues with scientific methods and future experiments.

In this reply, we have organized the ideas in the commentaries into three general categories, namely the biological foundation of giftedness and heritability, deliberate practice, and objective metrics of performance. The purpose of each section is to try to identify three different types of claims and arguments: what we believe are misunderstandings of our framework, what appear to be general agreements, and what we feel remain genuine disagreements. For each disagreement we will review relevant evidence as well as indicate where future research is needed.

Biological foundation of giftedness and heritability

Several of the commentators (Baker, Gagné, Runco, Simonton) feel that our target article selectively reviewed and overlooked evidence on heritability, genetic determination of high ability and biological mechanisms mediating elite performance. We feel these criticisms are important, and we attempt to directly address them below.

Misunderstandings

Many of the misunderstandings in the present commentaries resemble earlier misconceptions of our work, where previous authors had incorrectly depicted our framework as representing an ‘extreme environmentalism’ standpoint that rejects even the possibility of innate talent. For example, Baker describes the ‘authors’ dismissal of the possibility of innate factors explaining expert performance’. We disagree with this characterization because we do not dismiss this possibility, and this is a very important distinction. We try to adopt a scientific stance, where we state that our current review has not yet found evidence for ‘innate factors explaining expert performance’ with the exception of body size and height. However, such evidence may ultimately be uncovered, and we have even tried to anticipate how such genetic differences might potentially arise, such as with motivational factors. Baker, Runco, Gagné and Simonton point to evidence that they feel that we have not considered in our target article. In a section below we review their examples in the light of a more explicit discussion about the kind of evidence that would be necessary to show that genetic factors genuinely constrain individuals’ ability to attain expert levels of performance. Before we discuss these criteria we will first outline what we all seem to agree on regarding genetic influences on the development of human ability and performance.

Agreements

It is unquestionable that development of human embryos involves the activation of genes in an orderly manner to produce viable and healthy child, rather than any other type of organism, such as a zebra or a shrimp. Furthermore, there are chromosomal aberrations, such as Down’s syndrome, and single gene mutations that cause developmental problems and disadvantages. There is a very clear asymmetry between genetic mutations that provide advantages and those that create deficiencies. When a gene is mutated there is a very high probability that the effect will be detrimental or even lethal (Vogel & Motulsky, 1997). It is comparable to making random changes to statements in a computer program or rewiring a computer randomly: the change will almost invariably create problems rather than create an improvement in functioning.

In our target paper, we reviewed evidence for genes that impose limits on the attainment of expert performance. We argued that extended deliberate practice could activate genes all healthy children possess as part of their DNA that in turn

would cause changes in the physiological and neural activities associated with expert performance. We and the commentaries are in agreement that the activation of genes is a critical component of the skill acquisition process. The disagreement is whether individual differences in genetic makeup selectively allow only some rare individuals to attain elite levels of performance. We turn to these disagreements in the next section.

Disagreements

Several commentators took issue with our criticisms of evidence for giftedness and also identified evidence that they felt could not be explained within our current framework. These arguments are grouped according to some shared general ideas.

Definition of health. In our target article, we stated that we were interested in making generalizations concerning expert performance for 'normal, healthy individuals'. Baker criticizes our attempt to define health as way to exclude individuals with known deficits, such as brain injury, and other types of medical and genetic problems. We agree that there is no fixed definition of health and with increased knowledge of various health problems, such as cholesterol levels and obesity, what might once be considered merely an individual difference on a dimension could be changed into a criterion for disease. On the other hand, our use of term 'health' emphasized identification on the basis of known handicaps. In most cases, we doubt whether there will be controversy that individuals with known diagnosed genetic diseases will be disadvantaged in attaining elite performance. We welcome proposals that would allow us a more precise definition of the population of children who lack known deficits, but in the interim we will use the label 'healthy' to refer to them.

Overlooking 'strong favorable' evidence for innate talent. Gagné claims that we omit 'lots of strong favorable evidence' for the talent position coming from race differences in sports and cites Entin's (2000) book *Taboo: why Black athletes dominate sports and why we're afraid to talk about it*. In fact, even Entin (2000) concedes that he knows of no solid evidence for individual genes that can explain the superiority of runners with African ancestry, such as Kenyan and other runners. Rather, he merely believes that scientific evidence for such genes will eventually emerge. In contrast, more recent research on the compelling performance advantages (see Ericsson, 2007) such as the Kenyan runners' superiority in long distance events points to alternative accounts based on physiological differences induced by physical activity during childhood at high altitude (Larsen *et al.*, 2005; Onywera *et al.*, 2006).

Generalizability of heritabilities from general population to elite performance. Many of the commentaries cite heritability estimates in their arguments for the role of talent, though this ignores the important problem that heritability estimates from one population cannot be generalized to another. Several commentators (Gagné, Runco and Simonton) turn to a discussion of attributes that reveal heritabilities of psychological measures with the twin method for the general population. The

evidence for heritability in performance on tests of creativity (Runco; see Runco, 2007) and results of personality tests (Simonton) based on twin studies meets standard criteria for statistical significance. In particular, Simonton argues that if a measure is heritable and if it predicts elite performance, then this constitutes evidence for innate talent. However, in our target paper we showed that individuals who belong to a twin pair are underrepresented among expert performers. Without having twins in samples of elite individuals, we cannot use the traditional twin method to estimate the heritability of a given psychological measure *for our population of interest, namely for elite individuals*. In fact, there are many reasons why heritabilities and relations between variables among untrained individuals in the general population will probably not generalize to expert performers. Heritabilities reflect genetic correlations in populations exposed certain types of environments, and heritability estimates can dramatically change under differing environmental conditions. If extended intense training in a domain of expertise activates new genes to provide the necessary adaptations and changes, there should be little correspondence with untrained individuals who have not engaged in similar activities. More generally, research on processes mediating reproducibly superior expert performance shows that the mediating mechanisms differ fundamentally from those used by novices (Ericsson, 2006a)—during years of practice and training experts acquire elaborate mechanisms for encoding and maintaining flexible access to critical task information that bypass basic capacities, such as short-term memory capacity (Ericsson & Kintsch, 1995).

Changes in the mediating mechanisms during the extended acquisition of skill. Moreover, there is an impressive body of evidence showing that with increasing level of skill there are changes in the patterns of neural activation (Hill & Schneider, 2006), and some evidence even suggests that intense training can change functional and structural aspects of the brain (Ericsson, 2006b). In a recent review (Roring *et al.*, in press) we discuss how early and extended training has been shown to change the cortical mapping of the brain area controlling fingers of string players and that intense music practice influences the development of myelin around nerves in critical brain regions (Bengtsson *et al.*, 2005). Furthermore, regions of brain activity have been shown to change dramatically as skill increases (Grabner *et al.*, 2006; Volke *et al.*, 2002). Vandervert gives a very interesting proposal for how the cerebellum becomes increasingly involved as the skill become effortless and automatic (see also Ramnani, 2006, for a more cautious review and proposal). Although it is reasonable to assume that skilled performance may well involve the cerebellum, it is important to point out that deliberate practice cannot be automated. In fact, we argue in the target article that deliberate practice is designed to give the performer increased control over their performance. This does not mean that experts need to control actively all aspects of performance at all times, but it means that they are capable of controlling any of the relevant aspects of their performance, if so desired. However, we agree with Vandervert that further research on how the brain changes as a function of extended deliberate practice is one of

the most exciting directions for research on expert performance and its biological basis.

Involvement of invariant domain-general mechanisms. In our target paper we provided support for the neural, cognitive and physiological changes in the mechanisms mediating increasingly skilled performance. We believe that this type of evidence also addresses Kaufman's criticisms of our framework for not addressing the role of domain-general mechanisms. In general, we have not found evidence for general performance measures that correlate with objectively measured expert performance (distinguished from reputation factors). Furthermore, if the relation between IQ and performance in domains, such as chess, is not reliable this would rule out the mediation of IQ and similar domain-general mechanisms. Nor does it appear that IQ or working memory capacity is a 'bottleneck' as described by Kaufman, given that some elite individuals have below average IQ scores. Since our review we have found additional studies (Grabner *et al.*, 2006; Unterrainer *et al.*, 2006) that fail to find a relationship between performance and IQ in samples of skilled chess players with a very broad range of IQ scores.

We realize that Kaufman rejects IQ as a measure of the mechanisms to which he refers. However, until he is able to measure these mechanisms in a reproducible manner and show them to be reliably related to acquisition of expert performance, it will be impossible for us to attempt to replicate and examine the associated phenomena in the laboratory. Finding such evidence might be difficult, as reviews have discussed that domain-general measures have not been found to be predictive of elite achievement when it is objectively defined as reproducibly superior performance (Ericsson & Lehmann, 1996). Moreover, given the dramatic changes that take place over years of extended deliberate practice, the strategies and mechanisms mediating basic cognitive processes with unskilled individuals more typical of traditional psychological research may not inform research on elite achievement. For this reason we disagree with Kaufman, and we argue instead that the difficulty with the search for domain-general learning mechanisms, such as with list memory experiments is that the mediating mechanisms in these experiments are unlikely to play much of a role in specific domains of expertise. This is especially true when individuals have spent years developing new methods for improving performance.

Unique genes influencing expert performance. In our target article we argue that innate talent accounts will ultimately need to specify those genes that give talented individuals their advantage and how these genes are expressed during development and training. In his commentary, Runco suggests the possibility that genes might influence performance on creativity tests. However, given that creativity and intelligence tests have not yet been shown to relate to the acquisition of expert performance in any specific domain, heritability of performance on those tests and their associations to genes is not directly relevant to reproducibly superior performance. Nonetheless, it is interesting to assess the strength of the evidence for individual genes influencing creativity. Runco describes a recent study in his new book (Runco, 2007): Reuter *et al.* (2006) tested 92 adults on sub-tests of a German

intelligence test where the participants were asked to generate as many different combinations as possible of figural, verbal and symbolic elements and then correlated their performance to three different gene loci. A few of these relations were reliable at the 0.05 level. If, however, a Bonferroni adjustment of the p -level was made for the nine different tests ($p_{\text{crit}}=0.05/9=0.006$), then none of these relations would remain significant, which may be one of the reasons why Reuter et al. (2005) referred to their study as a pilot study in the title. In general, the research on finding individual genes related to above average intelligence has had many false alarms (Petrill *et al.*, 1997; Plomin *et al.*, 2001). It is our assessment that it will take some time until findings between regular test performance on tasks measuring superior creativity/intelligence and specific genes will be reproducible and valid.

There are, however, studies that relate unique genes directly to individual differences in elite performance, namely in sports. Baker cites research that has found specific genes that are 'possible contributors' to expert performance in sports, such as the ACE polymorphism. This evidence involves identifying elite level athletes and then testing their DNA to find differences between elite athletes in power/sprint and endurance sports. In our target paper we cited the recent review by McArthur and North (2005) which questioned the existence of evidence at the time of their review for unique genes influencing elite endurance performance. More recent studies have not settled the issue, but some have found no relation between the ACE polymorphism in Kenyan elite long distance runners (Scott *et al.*, 2005). Furthermore, there is at least one example of a world class Caucasian athlete who did not possess the supposedly beneficial genes (Lucia *et al.*, in press). Our assessment of the studies of unique genes contributing to elite performance in sport appears to us to be very similar to that of Baker, who agrees with the lack of current evidence but does not rule out the possibility that some evidence might be uncovered in the future.

As discussed above, though we are impressed with the number of commentators willing to give examples and counter-evidence to our arguments, we must point out that as scientists, we need to focus on *verifiable, reproducible* evidence that can be replicated in laboratories with different theoretical frameworks. Furthermore, without experimental proof we cannot assume that any findings after the first few hours of training will generalize to the long road toward expert performance, which requires orders of magnitude longer training periods. Indeed, we devoted much of our target article to the discussion of reliable evidence of factors affecting and contributing to the development of expert performance. In the next section, we address commentators that took issue with our conceptualization of the role of deliberate practice in the development of expertise.

Deliberate practice

A cornerstone of our framework is the notion of deliberate practice. Any misunderstanding of what deliberate practice is and how it differs from other activities, such as mere professional experience, will first be addressed. We will then try to identify the agreement about what constitutes the criteria for deliberate

practice. Finally we will discuss criticisms of the sufficiency of deliberate practice to explain giftedness and exceptional performance.

Misunderstandings

Many of the misunderstandings arise from overlooking aspects of the definition of deliberate practice. For instance, we take issue with the introductory statement by Shavinina, who describes her disappointment with a doctor having only five years of experience. As we discussed in our target article deliberate practice must be distinguished from mere experience, in that only through focusing and improving specific aspects of performance, such as the aspects in which the performer is weakest, can an aspiring individual improve. It is likely that many doctors who have more experience than this are actually *less* proficient if they have not engaged in the *appropriate* practice activities, which has actually been found in some studies of medical expertise showing how in some medical domains, performance *diminishes* with experience (Choudhry *et al.*, 2005). Experience in a domain is by no means a guarantee of superior performance and sometimes fails to predict skill entirely. A more appropriate metric of performance would be to investigate the doctors' past records of success in diagnosis and surgery with patients with similar symptoms during the last year, so as to choose the doctor with the best record. The importance of deliberate practice has been found for many domains of expert performance that researchers have investigated, including many domains that are not merely motor-based, such as chess, Scrabble, medical diagnosis and mental calculation. This contrasts with the misconceptions of some commentaries that our framework has not addressed intellectual domains.

Rate of skill acquisition. Similarly, Simonton reports evidence that some individuals reach elite levels of achievement much faster than others, but individual differences in time to attain a given performance level is consistent with our framework and need not support the notion of talent or innate learning rates as he advocates. In fact, the studies cited by Simonton treated years of experience as a practice variable—experience is not an accurate measure of deliberate practice, as we have repeatedly argued in our target article. If individuals reaching elite levels of achievement engage in deliberate practice more frequently and for longer durations than others, they will almost certainly improve at faster rates, which is exactly what Sloboda *et al.* (1996) found for 'gifted' in comparison to less 'gifted' music students. Differences in the quality of practice are also likely to explain Subotnik *et al.*'s comment that some individuals may appear to 'practice' as much as experts but perform at far lower levels; for instance, as we mention in the target article many chess players never improve over decades of experience despite consistently playing in chess tournaments. However, many chess players 'practice' by frequently playing for fun with their friends, whereas others engage in effortful study of thousands of chess positions and receive specific instruction from a trainer. In recent reviews (Ericsson, 2004, 2006b) and our target paper we show that there are differences in the level of deliberate practice that can explain differences in speed of attaining high levels of

performance as well as the attained level of performance even among highly experienced individuals. Much of this evidence is based on investigations using retrospective estimates of domain related activities; notably, Gagné rejects the use of retrospective estimates of practice, as he feels there is little difference between these retrospective estimates and anecdotal accounts of exceptional performances. In contrast to subjective reports of talents, these data have been validated by repeated measures at different times and by correlations between the performers' estimates and their parents' and coaches' independent estimates. They also have the potential for validation against actual training studies in laboratory observations.

Not everyone can become an expert. Some of our commentators incorrectly assume that we imply that *any* random individual can become an expert. We argue that attaining expert performance is clearly constrained by opportunities to engage in deliberate practice, and that this is a far from trivial constraint. Sometimes these opportunities are related to the age of the performer. In our target article, we discussed how critical periods can impose barriers, preventing random individuals from reaching elite levels of achievement in certain domains unless these individuals engage in appropriate practice activities within the associated developmental windows. Similarly an early start of training often allows access to the best teachers and training environments—most adults cannot engage in deliberate practice for practical purposes, given their busy day-to-day lives and additional responsibilities. Our framework emphasizes a number of necessary conditions that a healthy child needs to have a chance to reach the highest levels of performance in domain. Shavinina quoted a question addressed to the first author after one of his talks, where the member of the audience asked whether he could become an Olympic athlete at his mature age. We argue that this individual would at least have to follow the developmental path of the past Olympic winners and start training early, engage in years of focused deliberate practice in the best training environments, and so on. The idea that random people would be able to attain these levels of performance without matching the training history of today's elite performers reflects a fundamental misunderstanding of our ideas and our framework. It is thus incorrect to claim that there is 'no evidence for constraints on the attainment of achievement', as Runco suggested. In general, we argue that deliberate practice mediates the development of high-level performance within a series of constraints that limit individuals' opportunities to engage in it. Additionally, even if children have the optimal opportunities they need to be motivated to engage in deliberate practice and to be willing to consistently push themselves beyond their comfort zone for extended periods of time. We agree with Subotnik *et al.* that these motivational factors require more study and investigation.

Agreements

There is general agreement that training is necessary for attaining exceptional performance. Gagné even claims that practice plays 'a role no IT [innate talent]

defender denies'. Many of the commentators, such as Subotnik *et al.*, make an even clearer endorsement of the essential role of deliberate practice activities, such as 'disciplined practice guided by an outstanding teacher/mentor' for 'years' of committed practice and instruction. Freeman states that we have demonstrated 'the strong effects of deliberate solitary practice on high-level performance, quite differently from mindless drill'. However, disagreements exist between commentators in the role of deliberate practice on the acquisition of expert performance. Although we are in agreement that deliberate practice is necessary, many of our commentators would contend that it is not sufficient. We turn to these arguments in the next section.

Disagreements

In our target paper we proposed that attainment of an individual's expert performance can be viewed as a sequence of states ($S[i]$) and deliberate practice is the type of practice that allows individuals to attain change in the cognitive or physiological mechanisms that leads to a transition from one state, $S[i]$, to another state, $S[i+1]$. 'Ultimately, a complete theory must account for *all* the transitions between the different states and how some participants attain these transitions (i.e., improvements) either through practice, experience or maturation'. In our review we were unable to find evidence for any transitions blocked by innate constraints that limit healthy children from attaining expert levels of performance, with the exception of height and body size, although we acknowledge that further research is required for a full description of these transitions in many domains. Many of the commentators reject this finding by arguing that deliberate practice is *insufficient* to attain elite levels of performance. Our knowledge about the sequence of states describing the acquisition of expert performance is still limited but steadily increasing, especially during the last decade. Given that deliberate practice requires effortful concentration and problem solving to discover new methods for improving performance, improvement in a domain is a gradual process extended over a long period of time.

One or many paths to expert performance. One concern, raised by Runco, is that our method may not appreciate that there are several paths towards expertise. We may be partially responsible for this misconception of our framework. The number of different paths leading to superior performance is an empirical question that can only be fully answered by additional research. While we do not conceptualize the path towards expertise as necessarily being the same for everyone, our extensive reviews and investigations consistently reveal the importance of engagement in appropriate deliberate practice activities. Thus, although factors affecting individuals and their training environment may produce different paths, it is the importance of deliberate practice that remains constant. It may also be that future research will reveal that some changes and improvements are optimally acquired in a specific order. For instance in many domains, such as music, the curricula are remarkably similar across different countries and teachers. Furthermore, the extended process of acquiring expert levels of performance involves the building of new skills by adapting

previously acquired ones. The issue of how to describe the sequences of states will depend on the level of description. In fact, even different individuals in the same domain often acquire very different mechanisms mediating their performance, illustrating the complexity of the acquisition process as discussed by Shavinina. Perhaps the most compelling evidence for the differences in detailed structure of the mediating mechanisms has been most convincingly demonstrated for memory experts and other related types of experts (Ericsson, 1988, 2003c, 2006a). Parsimony dictates that we search for the invariant general characteristics of the sequences of states of the development, but we note that improvement in a domain may not be linear as suggested by Ziegler.

Sudden emergence of exceptional performance. In earlier reviews of exceptional abilities and giftedness Ericsson and Faivre (1989) reviewed a large body of published evidence claiming support for suddenly emerging abilities in memory, calendar calculation, and mental calculation. In this review, we demonstrated that in every case an account based on abilities acquired through practice gave the most parsimonious account for them. In his commentary Gagné now claims that no talent researcher believes in the sudden emergence of traits and concludes that such evidence for sudden achievements is obviously incorrect. Although this seems to reflect progress, at the end of his commentary he describes a prodigy named Sarah Chang who received ‘extremely laudatory judgment of her master teacher at the Julliard School of Music’ at age 5 years. It seems that the argument has changed slightly, from sudden emergence to very rapid development that is inexplicable by normal learning processes. It would be a very interesting if someone had performed a thorough documentation of Sarah Chang’s early development, particularly with a thorough review of all the music activities in which she has engaged along with a longitudinal measurement of her level of objective performance. Unfortunately, we have found no serious description of how she prepared the pieces for her first recordings or an extensive analysis of how her dramatically superior learning environment—including supportive parents (one of whom is an expert violinist) and exposure to some of the best violin instructors in the world—influenced her rapid rise in musical proficiency. Moreover, would it be possible for other children, adolescents, and adults to match her earlier performances under ‘blind listening’ conditions, where judges are naïve to the identity of the artist? Without this it is possible that some of her earlier performances might appear impressive primarily due to her young age (see our prodigy discussion). Notably, Sarah continued to improve, but was only awarded a prize for adult music performance when she was 16 years old, well over a decade after her start of training with the violin. We would like to encourage today’s parents of prodigies to cooperate with scientists to allow a scientific description of their children’s rapid development and the associated practice activities. Only then can we begin to make claims concerning the role of practice and innate talent in such precocious development.

Freeman similarly criticizes our rejection of sudden emergence of performance, but then later in her commentary she claims that ‘we know that gifts appear and

disappear at different times in a life'. In her recent review of longitudinal studies of gifted children Freeman (2006) finds that it is nearly impossible to generalize factors contributing to success of the gifted. She draws an analogy between the confluence of unique factors contributing to their success falling in love: 'It is possible to say how it feels and what happens because of it, but there is no sure recipe to apply to others' (Freeman, 2006, p. 400). We remain more optimistic that it will be possible to scientifically identify factors that lead to the acquisition of expert performance.

Explaining the acquisition of the highest levels of performance. Some of our commentators would also contend that certain aspects of exceptional performance are impossible to account for scientifically, such as extreme cases of motivation, giftedness and creativity (e.g., Freeman). We would argue that, through the objective measurement of practice activities, we should be able to explain all aspects of performance. We turn to a further discussion of this issue in our next section on objective metrics of performance.

Our main conclusion is that researchers should be encouraged to rigorously investigate the backgrounds of children exhibiting prodigious development, which would give the scientific community empirical data to support qualitatively different development from other individuals. Alternatively, these children may differ not in their learning but in their ability and motivation to engage in deliberate practice at young ages. Future longitudinal research with measurement of performance and detailed descriptions of activities related to practice is necessary to resolve these issues.

Objective metrics of performance

In this section, we address the issues raised by our commentators regarding our emphasis of objective, evidence-based metrics of performance. We first discuss misunderstandings with our laboratory-based approach. Next, we summarize general areas of agreement. We then challenge disagreements and arguments, beginning with our views on traditional talent identification methods. Finally, we discuss whether exceptional achievements can be studied scientifically.

Misunderstandings

First, as discussed in our paper, the expert performance approach examines reproducibly superior performance by designing representative tasks in order to capture this performance in the laboratory. Runco and others raise this issue that performance captured in the laboratory may not fully appreciate the intricacies of real-world performance. In our paper, we cite several reviews documenting the successful identification of superior performance in various domains that are validated against in-vivo metrics of skill. However, many of our commentators argue that there are some areas of giftedness and superior performance that cannot be accounted for adequately by our framework. Before turning to these issues, we review some areas of general consensus with respect to the objective measurement of performance.

Agreements

As scientists we can all agree that we must build the foundation based on verifiable, reproducible evidence. As we have proposed in our target article, this evidence can be offered from any scientific discipline so long as it meets the criteria outlined. We also agree on the importance of laboratory studies to find statistically significant relations under controlled conditions. To a certain extent, we agree that we need to avoid more subjective evidence (such as anecdotes) as metrics of performance. Some of our commentators, however, would contend that there are certain areas of behaviour that are scientifically impossible to explain or predict, and continue to consider subjective evidence. We address their arguments in the next subsection.

Disagreements

Problems with the criteria for reproducibility. Some of our commentators argue that there are some aspects of performance that *cannot* be replicated, such as problem discovery (Runco). While we agree that scientific discoveries are impossible to perfectly replicate, we do not agree that it is impossible to investigate the phenomena with scientific methods. As mentioned in our paper, problem discovery must occur within the context of commonly available knowledge. We gave the example of a study performed by Qin and Simon (1990), where college students were able to reproduce some of Kepler's scientific discoveries when given the appropriate background knowledge. As voiced by several of our commentators (Beghetto & Kaufman, Coleman, Freeman, Runco), this study may not have considered the unique social and cultural conditions that Kepler faced in his day. We agree that these factors should be considered to understand Kepler's achievements, but would contend that they are not critical to assess if a gift or unique cognitive capacity would be required to generate these discoveries. To assess the necessary conditions for discovery, it is most important to focus on the knowledge available to the discoverer and the processes generating the critical ideas and products. If college students can discover Kepler's laws with roughly equivalent background information, we need not assume that Kepler possessed any unique gift or capacity for this achievement. Indeed, recent reviews indicate problem discovery can be characterized by definite states of progress (Tweney, 2004).

Exclusion of creative achievements. Some of our commentators also argue that our recommendations for objective metrics of performance, particularly in domains that involve creative accomplishments, are unrealistic (e.g., Beghetto & Kaufman, Coleman, Subotnik *et al.*). We would agree that, especially in the arts and sciences, a product's success is decided by human judges and is thus influenced by cultural forces and subjective factors. However, if an individual can reproducibly generate works of arts judged technically superior (i.e., free from reputation-related biases) to those of their peers then this is evidence for reproducibly superior expert performance. This is consistent with the use of representative tasks in controlled settings as recommended by our framework.

Although we feel (and many of our commentators agree) that our review of current research in expert performance was extensive, some of our commentators claim that we have 'ignored' certain areas, such as creative domains, and have interpreted our relatively brief coverage of these topics as evidence that the expert performance framework cannot adequately account for accomplishments in such domains. It is a fact that there have been fewer investigations from an expert performance standpoint into the nature of more 'open-ended' domains, such as 'poetry, theoretical physics, architecture and painting' (Coleman). Still, we recognize both their importance as well as the increased difficulties of studying these domains. In our review, we described our approach to creative accomplishments and give several recommendations for future investigations. However, there are some investigations using an expert performance approach that examine such 'open-ended' domains (Hyllegard, 2000; Kozbelt, 2001; see also Weinberg, 2006). We look forward to further studies of these domains that assess the prospects and limits of the expert performance approach.

Exclusion of the subjective and idiosyncratic experiences. Coleman makes the case for why 'the subjective experience of exceptional performers' is more interesting and that our framework based on reproducible evidence is too limiting. However, our laboratory techniques, such as protocol analysis (Ericsson & Simon, 1993; for a review, see Ericsson, 2006a), have convinced us that many related aspects of thinking can be rigorously studied, thus leaving relatively few aspects of subjective experience of expert performance outside the reach of our proposed arsenal of data collection methods and analyses.

In the same vein, we agree with Beghetto and Kaufman that major creative contributions are infrequent and unpredictable, presenting an important challenge to investigators. In our target article, we point out the difficulty of identifying extreme creative achievement in the arts and sciences given that historically-based social judgment is often the primary metric of performance. We argue that our framework can potentially investigate these achievements when they can be equated with some form of objectively-measured reproducibly superior performance. Innovators do not, however, randomly generate their best products but they all have a long history in which they acquire the necessary skills to develop and express their ideas (Ericsson, 1999). They also must master their domain in order to seek out the boundaries of knowledge and practice. Once we have specified the conditions that are necessary for being able to make major or even minor innovations, we will have probably specified much of the development of the exceptional performers. Only after specifying what can be accounted for within our framework would one be able to identify those aspects that cannot be captured. Weinberg (2006) provides retrospective accounts for many major innovative achievements that could be produced without assuming the necessity of innate talent.

Problems with capturing the highest levels of creative achievement. Although we focused on the development of expert abilities in our paper, as we mentioned in our section on deliberate practice, we would argue that our framework can be extended to

examine and understand cases of extreme creativity, motivation and giftedness. We do not make the distinction between 'normal experts' and 'super experts'. According to some of our commentators, our framework may apply to the former, but the latter is much harder to explain. Indeed, while some of our commentators would cite hereditary factors to explain extreme cases of giftedness and creativity (e.g., Simonton), others would contend that such cases are simply inexplicable (e.g., Freeman). Our research and reviews lead us to disagree with both viewpoints. Indeed, as discussed in our target article examinations of so-called 'extreme' cases of precocity and giftedness often reveal uncommonly rigorous training regimen (see Roe, 1953; Lehmann & Ericsson, 1998; Ericsson, 2002). Specifically, these individuals engage in longer, more concentrated deliberate practice sessions than their contemporaries and consistently seek ways to improve their own performance. In fact, many of history's examples of seemingly inexplicable achievements are no longer unique. While Mozart may have been considered a prodigy in his day, many young students enrolled in Suzuki schools today undergo even more arduous training; in fact, the performance of many of these students would make Mozart seem quite average at similar ages (Lehmann & Ericsson, 1998)!

Subotnik *et al.* raise a number of interesting issues concerning talent development that focus on the development of performance in a world with limited resources of the best teachers and the best training environments. They propose that some aspects of personality, motivation, and ambition are less trainable or maybe trainable to a very limited degree. It would be fascinating to conduct longitudinal studies where music students' performance and amount and, in particular, quality of practice activities were measured, especially before and after they had been accepted to prestigious teachers and learning environments. Once we are able to accurately describe and measure practice then we will be in a much better position to assess which additional factors are predictive of future success. So far we have seen examples where dispositional factors, such as motivation, ambition and personality, may not have a direct effect on success, but an indirect effect that leads to increased amount and quality of practice (deliberate practice). The question of when the music student first reveals the 'feeling for music' and if and how it is sustained across the development is particularly interesting. It might also be interesting to explore the development of elite performance in the other dramatic arts, such as acting, dancing, and opera, where it is taken for granted that the performers are trained to project a feeling to the audience with body language and facial expressions that differ according to the role they are playing. We argue that if one can train actors to give expression of strong feelings, why it is not possible to train musicians on related factors? How often are young music students helped to develop their observable 'feelings for music', and are interventions at certain time periods more effective than others?

Concluding remarks and future directions

The purpose of this reply was never to try to force any 'IT defenders', such as Gagné, to change their basic position. Our goal was to use our framework to identify

misunderstandings (at least as we interpret our framework), to sketch the basic agreements and discuss our disagreements by reviewing evidence and asking further questions. Science progresses normally by answering one question and generating several new detailed questions that can be successfully studied with empirical methods. Hence, progress involves producing a more refined and nearly always more complex description of the phenomena and their associated causes or correlates. We have summarized the empirical support for necessary prerequisites in terms of training and practice for reaching expert levels of performance. We also hope that our distinctions of different types of experience and practice will motivate researchers to consider these type of distinctions in their future work (many of the commentators already do), especially when they collect new data on the development of elite performers in any of the variety of expert domains. We also have tried to describe what we consider are the limits of our knowledge.

In his commentary Ziegler asks questions about our basic approach and its usefulness for researchers of giftedness and high ability. The expert performance approach (Ericsson & Smith, 1991; Ericsson, 2006a, b) was designed to identify large stable performance differences in everyday life and capture them with representative tasks in the laboratory to assess the structure of the mediating mechanisms and collect information about factors linked to their development. This approach was taken to maximize our efforts to gain information about both effects of practice *and* potential innate unmodifiable capacities and mechanisms. Our approach would thus prioritize the work on measuring and describing relevant aspects of the superior performance of interest and only then search for its precursors in the form of deliberate practice, training environments, and innate prerequisites. Perhaps attempting to answer Ziegler's questions is somewhat premature until we have established consensus on how to measure the desired outcome of the educational intervention. Answers to these questions will most likely depend how the target performance is defined. According to the expert performance approach large stable differences in the target performance serve as the fixed reference points for analyzing the environment, activities and genetic factors. This is not the only approach, but it is the approach that we have adopted and thus advocate.

All of us are scientists first and foremost and, thus, we all accept the evidence that individual differences in height have a strong genetic basis (for a review, see Ericsson *et al.*, 1993). Perhaps in the future we will accumulate similar evidence for a genetic influence on other attributes related to expert performance in some domains. Until then, we can only speculate on the probability that evidence of unique or combinations of genes that determine the attainable level of performance will be uncovered. We find the arguments by biologists for the existence of unique genes causing a distinct advantages compelling, but the ultimate resolution will come when we understand the complete sequences of states associated with the acquisition of expert performance in many domains.

Most of these types of papers only allow a complete cycle of exchanges. The commentators read the target paper, write their comments and the authors of the target paper get a chance to address their comments. In order to improve on this, we

requested to have our reply sent out in draft form to all the commentators so they could point out misunderstandings, factual errors, and any other comments with the understanding. However, time did not allow this exchange, but perhaps future issues of this journal might permit such a continued discussion. Nonetheless we have tried to develop a description of the state of the art that will hopefully help future research as a reference point on the exciting journey exploring the fascinating phenomena of reproducibly superior performance and its structure and development.

References

- Abernethy, B., Farrow, D. & Berry, J. (2003) Constraints and issues in the development of a general theory of expert perceptual-motor performance: a critique of the deliberate practice framework, in: J. L. Starkes & K. A. Ericsson (Eds) *Expert performance in sports: advances in research on sport expertise* (Champaign, IL, Human Kinetics), 349–369.
- Bengtsson, S. L., Nagy, Z., Skare, S., Forsman, L., Forsberg, H. & Ullén, F. (2005) Extensive piano practicing has regionally specific effects on white matter development, *Nature Neuroscience*, 8, 1148–1150.
- Choudhry, N. K., Fletcher, R. H. & Soumerai, S. B. (2005) Systematic review: the relationship between clinical experience and quality of health care, *Annals of Internal Medicine*, 142, 260–273.
- Entine, J. (2000) *Taboo: why Black athletes dominate sports and why we're afraid to talk about it* (New York, Public Affairs).
- Ericsson, K. A. (1988) Analysis of memory performance in terms of memory skill, in: R. J. Sternberg (Ed.) *Advances in the psychology of human intelligence* (Hillsdale, NJ, Erlbaum), Volume 4, 137–179.
- Ericsson, K. A. (1999) Creative expertise as superior reproducible performance: innovative and flexible aspects of expert performance, *Psychological Inquiry*, 10(4), 329–333.
- Ericsson, K. A. (2002) Attaining excellence through deliberate practice: insights from the study of expert performance, in: M. Ferrari (Ed.) *The pursuit of excellence in education* (Hillsdale, NJ, Erlbaum), 21–55.
- Ericsson, K. A. (2003a) The development of elite performance and deliberate practice: an update from the perspective of the expert performance approach, in: J. Starkes & K. A. Ericsson (Eds) *Expert performance in sport: recent advances in research on sport expertise* (Champaign, IL, Human Kinetics), 49–81.
- Ericsson, K. A. (2003b) How the expert performance approach differs from traditional approaches to expertise in sports: in search of a shared theoretical framework for studying expert performance, in: J. Starkes & K. A. Ericsson (Eds) *Expert performance in sport: recent advances in research on sport expertise* (Champaign, IL, Human Kinetics), 371–401.
- Ericsson, K. A. (2003c) Exceptional memorizers: Made, not born, *Trends in Cognitive Sciences*, 7, 233–235.
- Ericsson, K. A. (2004) Deliberate practice and the acquisition and maintenance of expert performance in medicine and related domains, *Academic Medicine*, 79, S70–S81.
- Ericsson, K. A. (2006a) Protocol analysis and expert thought: concurrent verbalizations of thinking during experts' performance on representative task, in: K. A. Ericsson, N. Charness, P. Feltovich & R. R. Hoffman (Eds) *Cambridge handbook of expertise and expert performance* (Cambridge, Cambridge University Press), 223–242.
- Ericsson, K. A. (2006b) The influence of experience and deliberate practice on the development of superior expert performance, in: K. A. Ericsson, N. Charness, P. Feltovich & R. R. Hoffman (Eds) *Cambridge handbook of expertise and expert performance* (Cambridge, Cambridge University Press), 685–706.

- Ericsson, K. A. (2007) Deliberate practice and the modifiability of body and mind: toward a science of the structure and acquisition of expert and elite performance, *International Journal of Sport Psychology*, 38, 4–34.
- Ericsson, K. A. & Faivre, I. (1988) What's exceptional about exceptional abilities?, in: L. K. Obler & D. Fein (Eds) *The exceptional brain: neuropsychology of talent and special abilities* (New York, Guilford), 436–473.
- Ericsson, K. A. & Kintsch, W. (1995) Long-term working memory, *Psychological Review*, 102, 211–245.
- Ericsson, K. A., Krampe, R. T. h. & Tesch-Römer, C. (1993) The role of deliberate practice in the acquisition of expert performance, *Psychological Review*, 100, 363–406.
- Ericsson, K. A. & Lehmann, A. C. (1996) Expert and exceptional performance: evidence on maximal adaptations on task constraints, *Annual Review of Psychology*, 47, 273–305.
- Ericsson, K. A. & Simon, H. A. (1993) *Protocol analysis: verbal reports as data* (rev. edn.) (Cambridge, MA, The MIT Press).
- Ericsson, K. A. & Smith, J. (1991) Prospects and limits in the empirical study of expertise: an introduction, in: K. A. Ericsson & J. Smith (Eds) *Toward a general theory of expertise: prospects and limits* (Cambridge, Cambridge University Press), 1–38.
- Ericsson, K. A., Tesch-Römer, C. & Krampe, R. (1990) A general theoretical framework for studying the acquisition of expert-level performance, in: M. J. A. Howe (Ed.) *Encouraging the development of exceptional abilities and talents in young people* (Leicester, The British Psychological Society), 109–130.
- Freeman, J. (2006) Giftedness in the long term, *Journal for the Education of the Gifted*, 29, 394–403.
- Grabner, R. H., Neubauer, A. C. & Stern, E. (2006) Superior performance and neural efficiency: The impact of intelligence and expertise, *Brain Research Bulletin*, 69, 422–439.
- Hill, N. M. & Schneider, W. (2006) Brain changes in the development of expertise: neuroanatomical and neurophysiological evidence about skill-based adaptations, in: K. A. Ericsson, N. Charness, P. Feltovich & R. R. Hoffman (Eds) *Cambridge handbook of expertise and expert performance* (Cambridge, Cambridge University Press), 223–242.
- Howe, M. J. A., Davidson, J. W. & Sloboda, J. A. (1998) Innate talents: reality or myth?, *Behavioral and Brain Sciences*, 21, 399–442.
- Hyllegard, R. (2000) Parental attribution of artistic ability in talented children, *Perceptual and Motor Skills*, 91, 1134–1144.
- Kozbelt, A. (2001) Artists as experts in visual cognition, *Visual Cognition*, 8, 705–723.
- Larsen, H. B., Nolan, T., Borch, C. & Sondrgaard, H. (2005) Training response of adolescent Kenyan town and village boys to endurance running, *Scandinavian Journal of Medicine and Science in Sports*, 15, 48–57.
- Lehmann, A. C. & Ericsson, K. A. (1998) The historical development of domains of expertise: performance standards and innovations in music, in: A. Steptoe (Ed.) *Genius and the mind: studies of creativity and temperament in the historical record* (Oxford, Oxford University Press), 7–94.
- Lucia, A., Oliván, J., Gomez-Gallego, F., Santiago, C., Montil, M. & Foster, C. (in press) Citius and longius (faster and longer) with no alpha-actinin-3 in skeletal muscles?, *British Journal of Sports Medicine*.
- McArthur, D. G. & North, K. N. (2005) Genes and human elite athletic performance, *Human Genetics*, 116, 331–339.
- Onywera, V. O., Scott, R. A., Boit, M. K. & Pitsiladis, Y. P. (2006) Demographic characteristics of elite Kenyan endurance runners, *Journal of Sport Sciences*, 24, 415–422.
- Petrill, S. A., Ball, D., Elev, T., Hill, L., Plomin, R., McClearn, G. E., Smith, D. L., Chorney, K., Chorney, M., Hirshz, M. S., Detterman, D. K., Thompson, L. A., Benbow, C., Lubinski, D., Daniels, J., Owen, M. J. & McGuffin, P. (1997) Failure to replicate a QTL

- association between a DNA marker identified by EST00083 and IQ, *Intelligence*, 25, 179–184.
- Plomin, R., Hill, L., Carig, I. W., McGuffin, P., Purcell, S., Sham, P., Lubinski, D., Thompson, L. A., Fisher, P. J., Turic, D. & Owen, M. J. (2001) A genome-wide scan of 1842 DNA markers for allelic associations with general cognitive ability: a five-stage design using DNA pooling and extreme selected groups, *Intelligence*, 31, 489–495.
- Qin, Y. & Simon, H. A. (1990) Laboratory replication of scientific discovery processes, *Cognitive Science*, 14, 281–312.
- Ramnani, N. (2006) The primate cortico-cerebellar system: anatomy and function, *Nature Reviews Neuroscience*, 7, 511–522.
- Reuter, M., Roth, S., Holve, K. & Henning, J. (2006) Identification of first gene for creativity: a pilot study, *Brain Research*, 1069, 190–197.
- Roe, A. (1953) *The making of a scientist* (New York, Dodd, Mead, & Co).
- Roring, R. W., Nandagopal, K. & Ericsson, K. A. (in press) Can parieto-frontal integration theory be extended to account for individual differences in skilled and expert performance in everyday life?, *Behaviour and Brain Sciences*.
- Runco, M. A. (2007) *Creativity: theories and themes: research, development, and practice* (San Diego, CA, Academic Press).
- Scott, R. A., Moran, C., Wilson, R. H., Onywera, V., Boit, M. K., Goodwin, W. H., Gohlke, P., Payne, J., Montgomery, H. & Pitsiladis, Y. P. (2005) No association between Angiotensin Converting Enzyme (ACE) gene variation and endurance athlete status in Kenyans, *Comparative and Biochemical Physiology. Part A: Molecular and Integrative Physiology*, 141, 169–175.
- Sloboda, J. A., Davidson, J. W., Howe, M. J. A. & Moore, D. G. (1996) The role of practice in the development of performing musicians, *British Journal of Psychology*, 87, 287–309.
- Starkes, J. & Ericsson, K. A. (Eds) (2003) *Expert performance in sport: recent advances in research on sport expertise* (Champaign, IL, Human Kinetics).
- Tweney, R. D. (2004) Replication and the experimental ethnography of science, *Journal of Cognition and Culture*, 3/4, 731–758.
- Unterrainer, J. M., Kaller, C. M., Halsband, U. & Rahm, B. (2006) Planning abilities and chess: a comparison of chess and non-chess players on the Tower of London task, *British Journal of Psychology*, 97, 299–311.
- Vogel, F. & Motulsky, A. G. (1997) *Human genetics: problems and approaches* (3rd edn) (Berlin, Springer Verlag).
- Volke, H. J., Dettmar, P., Richter, P., Rudolf, M. & Buhss, U. (2002) On-coupling and off-coupling of neocortical areas in chess experts and novices as revealed by evoked EEG coherence measures and factor-based topological analysis—a pilot study, *Journal of Psychophysiology*, 16, 23–36.
- Weinberg, R. W. (2006) *Creativity: understanding innovation in problem solving, science, invention, and the arts* (Hoboken, NJ, Wiley).