The Nature and Nurture of Talent: A Bioecological Perspective on the Ontogeny of Exceptional Abilities

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Despite extensive research, questions underlying the nature and nurture of talent remain both numerous and diverse. In the current paper, we present an account that addresses 2 of the primary questions inspired by this debate: (a) the very existence of innate talents and (b) how exceptional abilities are developed. The development of exceptional performance is addressed through a synthesis of recent models that invoke multiplier effects to explain how differences in initial conditions (e.g., different levels of innate abilities), coupled with gene-environment interactions, determine ranges of phenotypic outcomes.

Introduction

In 1924, John B. Watson, the renowned behaviorist, proclaimed,

> Give me a dozen healthy infants, well-formed, and my own specified world to bring them up in and I'll guarantee to take any one at random and train him to become any type of specialist I might select—doctor, lawyer, artist, merchant chief, and yes, even beggar-man thief, regardless of his talents, penchants, tendencies, abilities, vocations, and race of his ancestors. (p. 128)

Watson's behaviorist views stood in stark contrast to those of Sir Francis Galton (1869), who, some 55 years earlier, had advocated for the genetic underpinnings of human abilities in his nativistic *Hereditary Genius*. Until the mid-20th century, these opposing views were at the heart of one of psychology's most controversial debates: the roles of nature versus nurture in human behavioral and psychological development.

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For the past half century, however, the nature-nurture debate has taken on a new form. Inspired by Anastasi (1958) in her 1957 presidential address to the American Psychological Association, psychologists have moved beyond queries regarding "which or how much," of nature or nurture was responsible for a given trait and, instead, have focused on an exploration of precisely *how* genetics and environment interact to produce a phenotypic outcome, such as high ability and talent (Bronfenbrenner & Ceci, 1993, 1994). Accordingly, research has emerged investigating the interactions between genes and environment that are responsible for producing various facets of human behavioral and psychological outcomes, including intelligence, antisocial behaviors, musical ability, and personality, to name but a few. For example, recent research shows why some children who are maltreated grow up to develop antisocial behavior, whereas others do not: a functional polymorphism in the gene encoding the neurotransmitter-metabolizing enzyme monoamine oxidase A (MAOA) moderates the effect of environmental maltreatment. Maltreated children with a genotype conferring high levels of MAOA expression are less likely to develop antisocial problems (Caspi et al., 2002).

Alongside studies that attempt to explain the entire spectrum of phenotypic outcomes in a given domain, a considerable body of research has focused on individuals whose abilities place them at one extreme of a phenotype's distribution (i.e., the so-called talented and gifted). Interestingly, in spite of researchers' shift toward a gene-environment interaction model to explain more universal developmental outcomes, the study of talent and giftedness remains, for the most part, orthogonal to this trend, with some camps still advocating what are essentially environmental or genetic "main effects" positions. At the core of the debate are two pressing questions concerning (a) the explication of the mechanisms through which exceptional ability is manifested and (b) the very existence of innate talents and gifts from which exceptional ability presumably derives.[1] We present here our own theoretical position regarding both the existence of talent and how genes and environment interact to yield exceptional abilities. We have purposely chosen not to limit our discussion to one class of phenomena because the mechanisms that we discuss, and the goals we present for future research, would seem to be applicable to investigations of talent and expertise in all domains. We conclude with a discussion of where we feel research should proceed to further elucidate our understanding of talent and the mechanisms underlying its ontogeny.

A Synergistic Perspective on Expertise

We begin our analysis by addressing the first question: What is the mechanism through which exceptional competencies are manifested? Recently, Ceci, Barnett, and Kanaya (2003) underscored the importance of a "multiplier effect" as a generalized mechanism for the development of childhood abilities into adult attainments. Here we take Ceci et al.'s analysis of this mechanism, including various models that incorporate the notion of a multiplier effect, and focus on its specific application to the development of high ability.

A multiplier effect occurs when a single impetus that may be small in magnitude sets into motion a chain reaction of events that can result in amplified growth of a measurable outcome. Multiplier effects are not new; they have been invoked in various domains, most notably economics, to explain a wide range of phenomena. For example, based on Keynesian economic theory, multiplier effects have been used to explain how small fluctuations in government spending can result in much larger changes in total output (e.g., Harrod, 1936; Samuelson, 1939). In the context of human psychological and behavioral development, multiplier effects are used to explain how small changes in an individual or in a society—whether genetically or environmentally induced—can be the impetus for a series of reciprocal interactions between individuals and their environments that ultimately results in huge differences. Under the right conditions, these interactions may result in more highly developed phenotypic outcomes than were present at the introduction of the initial small change. In short, the message of multiplier effects is that a small input may yield substantial outputs.

IQ Analyses by Dickens and Flynn. A recent application of multiplier effects in human development may be found in Dickens and Flynn's (2001) insightful analysis of IQ variance and changes in IQ over time. Based on the cascading power of multiplier effects, Dickens and Flynn presented a set of mathematical models that illustrated the previously underappreciated potency of environmental effects on IQ. Although the goal of Dickens and Flynn's argument was to demonstrate how correlations between genes and environment can mask the potency of environmental effects despite high heritability estimates for IQ, most relevant to the current discussion is the mechanism by which these correlations are produced. Dickens and Flynn posited that, at the individual level, a multiplier effect results when reciprocal causality between genotype and environment results in a positive feedback loop wherein higher IQ leads to the selection of better environments that, in turn, stimulate further intellectual growth.

As an example of a multiplier effect, Dickens and Flynn (2001) presented an analogy of a young boy who had some genetic predisposition for playing basketball. Following recognition of his son's predisposition, the boy's father played basketball with his son with a higher frequency than would have occurred otherwise. As a result, the son's abilities improved beyond those of his peers, causing team captains to choose him earlier when picking teams at school. Being chosen early fueled the boy's interest in basketball even more and spawned increased practice that led to membership on a school team that, in turn, exposed him to expert coaching and helped him develop an even higher level of ability. As this example shows, the development of the boy's competence relied both on his initial genetically based gift and his practice as a result of multiple environmental opportunities and influences.

Seemingly small environmental shifts may also explain societal-level rises in IQ. Dickens and Flynn (2001) referred to a *social multiplier* whereby an increase in the IQ of one group may cause their environments and, consequently, those of other groups with whom they come into contact to improve. This, in turn, can trigger a rise in IQ of the latter individuals who are exposed to that better environment. Using a similar analogy, Dickens and Flynn proposed that the increase in popularity of basketball over the past 60 years in the United States can be traced back to increased viewing of basketball in the home following the introduction of television in the 1950s. This increased viewing, in turn, motivated interest in the sport, which stimulated increasingly larger numbers of people to play. As more people played, and consequently improved their basketball skills, the mean level of basketball-playing ability in the population rose, subsequently affecting how players and coaches interacted, which further served to improve the game and the abilities of its participants. The point of this and the previous example is that, as Dickens and Flynn emphasized, some initial impetus, although seemingly insignificant in the larger picture, was capable of stimulating a series of reciprocal gene-environment effects that resulted in substantial changes at individual and societal levels.

The Bioecological Model. As Dickens and Flynn (2001) acknowledged, previous models had recognized the importance of gene-environment reciprocal causality and correlation. For example, the bioecological model of human development (Bronfenbrenner & Ceci, 1993; 1994; Ceci, 1996) proposed a set of hypotheses that, collectively, forms a theoretical model for predicting the actualization of genetic potential into effective psychological functioning. Central to the model is the notion that the mechanism of translation of genetic potential (e.g., intellectual skills) into actual phenotype occurs by means of what the authors term *proximal processes.* These are defined as complex, reciprocal interactions between individuals and their immediate environment. Among the defining properties of these proximal processes are that they occur on a regular basis over an extended period of time; they are reciprocal in nature (i.e., not merely instruction provided by a teacher or computer, but some form of interactivity that builds on itself); and, in the course of actualizing genetic potential, their direction and power, as well as their form and content, are determined by attributes of the developing individual, the environments in which that individual develops, and the nature of the particular developmental outcome in question (Bronfenbrenner & Ceci, 1994). As an example of how these properties operate, Bronfenbrenner and Ceci gave the example of the longitudinal work of Drillien (1964), who showed that mother-infant interactions over time (i.e., proximal processes) predicted developmental outcomes. More specifically, the power of these interactions to predict children's outcomes were directly influenced by characteristics of the developing child (i.e., age, birth weight) and the context in which that development took place (i.e., social class).

Just as Dickens and Flynn (2001) proposed that multiplier effects will be most potent when genotypes are most highly correlated with environments, and under conditions in which reciprocal causation between the two persist, the bioecological model hypothesizes that penchants will be most fully actualized under conditions of enduring, highly interactive proximal processes. Thus, based on the concept of a multiplier effect and the reciprocal interactions between an individual and his or her environment, we can see how the bioecological paradigm and Dickens and Flynn's models provide a means to explain the mechanisms underlying phenotypic outcomes within the full spectrum of human abilities.

Multiplier Effects, the Bioecological Model, and Pathways to High Ability. Although useful for explaining development across the full range of ability, how can these models explain the development of exceptional competencies? To answer this question we must focus on a central principle of the multiplier effect, namely, its reliance on initial conditions. In the bioecological model, Bronfenbrenner and Ceci (1994) promoted the role of genetic material as representing "active dispositions expressed in selective patterns of attention, action, and response" (p. 572), implying that genes set proximal processes into motion. Likewise, Dickens and Flynn (2001) acknowledged the role of genetic differences as a causal agent for a multiplier effect, although they allow for instigation of the effect to be environmental in nature, suggesting that "the process by which the ability of an individual and the environment of an individual are matched can increase the influence of any initial difference in ability—whether its source is genetic or environmental" (p. 350). Putting aside issues of whether or not the initial impetus is genetic or environmental in nature (we return to this point when we address the second question that we posed in our introduction), a key point in mapping these theories onto the development of exceptional abilities is the consideration of Dickens and Flynn's suggestion that differences in initial conditions *may be of degree, rather than kind*. That is, we must consider that individuals are not only born with different proclivities, but that, within particular traits, a wide range of variability may exist that produces both qualitative (e.g., eye color) and quantitative (e.g., height) diversity. As a result, although underlying mechanisms thus far described can apply to pathways of development at all levels of ability, the trajectories may differ, depending on where on the pathway one begins. In short, given similar conditions in which to thrive, initial quantitative variation may be a starting point to differentiate ordinary from extraordinary developmental outcomes. So, the exceptional violinist may simply have begun with superior conditions at the start.

Lastly, to fully understand how the bioecological paradigm and the Dickens and Flynn models can help to explain the development of high ability, we must consider one final aspect of a multiplier effect encompassed in what has been called the Matthew Effect. Essentially, the idea behind the Matthew Effect is that initial advantage begets future advantage (i.e., "the rich get richer and the poor get poorer"). Stanovich (1986) discussed the concept in terms of the principle of "organism-environment correlation" to show that disparity increases when children with different genotypes or from different backgrounds are selectively exposed to different types of environments. In the case of achieving expertise at reading, for example:

> The very children who are reading well and who have good vocabularies will read more, learn more word meanings, and hence read even better. Children with inadequate vocabularies—who read slowly and without enjoyment—read less, and

> as a result have slower development of vocabulary knowledge, which inhibits further growth in reading ability (p. 381)....Children who become better readers have selected (e.g., by choosing friends who read or choosing reading as a leisure activity rather than sports or video games), shaped (e.g., by asking for books as presents when young), and evoked (e.g., the child's parents noticed that looking at books was enjoyed or perhaps just that it kept the child quiet) an environment that will be conducive to further growth in reading. Children who lag in reading achievement do not construct such an environment. (p. 382)

Above and beyond the properties of a multiplier effect described above, a central aspect of the Matthew Effect models is that the gain achieved by the initially advantaged is *disproportionate* to that of the initially disadvantaged. This is an important point because it explains the mathematical inevitability of a multiplicative model; in other words, linear initial differences that precede a multiplier effect do not result in linearly differential outcomes. These points are illustrated in Figure 1, which shows the theoretical development of ability within a single domain.

As can be seen in Figure 1, groups A_i through D_i begin their developmental trajectories for a particular competency possessing different initial levels of potential for that skill. Over time, individuals within and across these groups will experience varying levels of proximal processes (some greater than others) that, via a multiplier effect, will lead them to a final level of outcome, as seen in the ranges on the right side of Figure 1 (A_o through D_o). Because of the varying levels of proximal processes within each group, the outcome levels within each group will vary between what could be expected, given minimal positive gene-environment interactions ($Min_{A, B, C, D}$) versus what we would expect following optimal interactions (Max_A through Max_D). Consequently, although individuals who begin their trajectory at the lower end of the range of initial conditions (Group A) will not be able to attain the same high levels of ability as those who begin at much higher levels, even individuals who are most advantaged in terms of the initial potential for some talent or skill (Group D) may end up with the worst possible outcome (i.e., if they experience zero or negative proximal processes related to that domain of skill). It therefore follows that individuals starting off with the most conducive initial conditions, who, as we later discuss, represent the smallest proportion of the total population, have the widest range of possible outcomes. This is the theoretical equivalent of the aphorism that, given a less opti-

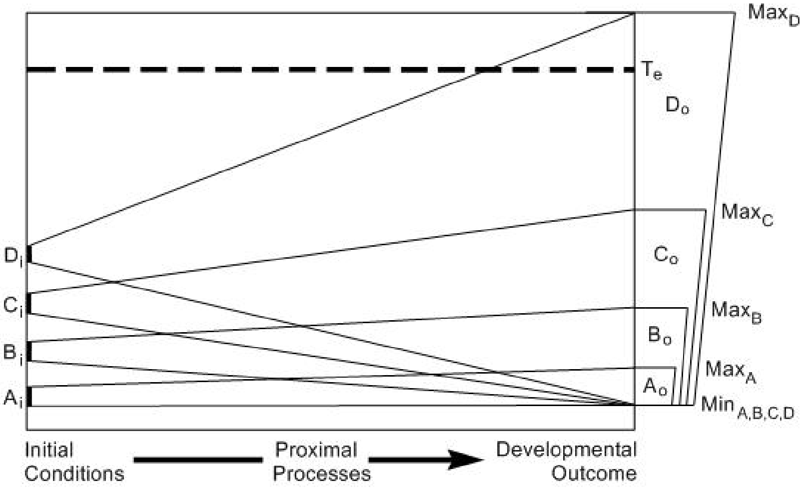

Figure 1. Theoretical development of ability within a single domain.

mal environment, the same person who ended up as CEO of a major corporation might have ended up as a ruthless criminal.

Figure 1 also shows that, although differences in initial conditions may be linear, the maximum possible outcomes (Max_A through Max_D), given optimal gene-environment interactions, grow disproportionately. With each added level of initial potential, the slope of maximum attainment increases. As we mentioned earlier, this is a mathematical inevitability of a multiplicative model and a Matthew Effect. It bears noting that this is a distinction between our model and those of Dickens and Flynn (2001), whose models of reciprocal causality are linear in both genetic endowment and environment (W. T. Dickens, personal communication, August 31, 2004). Although Dickens and Flynn posited reciprocal causality in the absence of gene-environment interaction, we put forth that, in fact, the effects of proximal processes differ as a function of initial conditions.[2] Accordingly, individuals who begin life with "better" initial conditions will benefit more from environmental stimuli that draw on those particular traits (Ceci & Papierno, 2005). For example, two individuals may begin life with the required traits to become an expert dancer (e.g., flexibility, muscle strength, balance, rhythm), with the exception that the agility of one individual (Group C) is markedly inferior to that of her counterpart (Group D). Given identical proximal processes that would teach a particular skill set that required all of the "expert dancer" initial conditions, including agility, the individual in Group D would benefit disproportionately more from that exogenous stimulus than would the individual in Group C. A similar effect would be seen between two individuals who start their trajectory with the same qualitative initial conditions (i.e., both start in Group D), but for whom one's set of skills is quantitatively superior to the other. Hence, we see a Matthew Effect both within and across groups.

One last component of Figure 1 is the dotted line, T_e, which represents a threshold for expertise. It is only those whose performance exceeds this threshold who would be considered exceptional in that domain. This threshold will be different within every domain, may be variable across time, and will be defined by the current societal distribution of skills in that domain. For example, in what they described as the evolution of domains of expertise, Ericsson and Charness (1999) pointed to Platt's (1966) illustration that today's musicians consider as their normal repertoire pieces of music that accomplished musicians over a century ago deemed unplayable. The point is that, although the mechanisms to achieve exceptional levels of competence may be constant over time and across individuals, we must be mindful of what is necessary to achieve those levels, given current societal abilities and standards.

Finally, Figure 1 depicts a situation that many parents of large families appreciate, at least implicitly; namely, that some children are more responsive to the environment than are others. Some children have far greater ranges of reaction than others. Variations in proximal processes may propel one child to the stratosphere or the floor, depending on the direction of the processes, while for another child, the difference that results is far less pronounced. One could imagine siblings within the same family who begin with different initial conditions and who also experience different, or react differently to, proximal processes within the same environment. Under very low levels of proximal processes, one child may not only fail to capitalize on a high initial level of competence (e.g., Group D), but be outperformed by another sibling who began his or her developmental trajectory with less potential talent in Group A, B, or C. Doubtless some extraordinary potential is never actualized, and, conversely, some families squeeze the maximum performance out of relatively modest levels of potential in their offspring.

In sum, we propose that the ontogeny of exceptional abilities is based on reciprocal gene-environment interactions that act as multiplier effects to transform initial conditions into fully developed skills. As gene-environment interactions improve, so too will the level of outcome. Importantly, the initial conditions from which this causal pathway is initiated will affect the maximum potential within and across individuals. Because of the nature of multiplier effects, given the same level of proximal processes, those who start out at the most advantaged level will develop skills at a disproportionately higher level that those who start out disadvantaged. Finally, among those who start off with sufficiently high initial conditions, only a portion will surpass some level of performance considered by society at that particular point in time to be considered exceptional in that domain. The remaining unanswered question to which we now turn is: What precisely underlies the differential initial conditions on which multiplier effects act?

Precursors for Expertise

As we mentioned in our introduction, within the literature on talent and giftedness a sizeable body of research argues for either a noninteractional model of high-ability development or an implicitly weak interactional model. At one end of the spectrum are those who argue that there exists no evidentiary basis for innate talent and that expertise in any domain can be explained by such environmental effects as intense practice and coaching. In fact, one of the core tenets of this environmentalist position is the assertion that deliberate practice for extended periods of time is the driving force behind expert performance. As evidence for this fact, researchers cite studies that demonstrate that within any domain, attainment of expertise requires extended periods of practice and that following extreme levels of practice, "ordinary" individuals (e.g., Groups B and C in Figure 1) can perform at levels that are indistinguishable from those of so-called gifted individuals (for extensive reviews, see Ericsson, Krampe, & Heizmann, 1993; Howe, Davidson, & Sloboda, 1998). Ericsson, in particular, has argued for the "10,000 hours" threshold, stating that logs of practice time of experts reveal the importance of years of practice (Ericsson, 1996; Ericsson, Krampe, & Heizmann, 1993; Ericsson, Krampe, & Tesch-Römer, 1993). For example, Ericsson and Charness (1994) pointed out the well-known findings of Simon and Chase (1973), who determined that the attainment of the level of international chess master required approximately 10 years of intense training. Ericsson and Chase put forth that the highest levels of achievement in sports, arts, and science require similar preparation, underscoring that people tend to underestimate the extensive amount of practice time invested by great performers, relying instead on a conception that the performers were simply born with their demonstrated level of ability.

A problem with these conclusions, at least when discussing the existence of innate talent, is that such claims equate developed expertise with talent. Clearly, both talent and expertise suggest very high levels of ability relative to conventional levels of skill in a domain, but they should not be thought of as the same. More precisely, although talent (when expressed) entails expertise, expertise does not necessarily imply talent. This is because expertise as a status merely reflects a high level of competency resulting from extended training, experience in a domain, or both. Talent, on the other hand, refers to innate potential that may or may not get actualized into expertise: Someone with innate potential for acquiring a foreign language, such as Russian, may only have this potential actualized if his or her school or parents provide exposure to Russian. At the same time, someone with no innate talent for foreign language acquisition may, given enough practice, achieve a level of fluency indistinguishable from his talented counterpart. Thus, expertise says little about the origins of initial conditions that led to that high level of ability. Even proponents of a genetic basis for talent agree that the attainment of expertise necessitates extended periods of training, but this is a different argument than suggesting that talent is required in order to attain expertise (e.g., Ericsson & Charness, 1994). Consequently, the argument that talent is not innate because expertise can be acquired does not seem to hold much water. What this evidence does show, however, is that high levels of ultimate attainment in a given domain may be achieved via multiple developmental pathways. For some people and for some domains, this pathway may rely more heavily on innate talent. For other people and for other domains, initial potential may not be as variable and differences in ultimate levels of actualization may depend more heavily on the level of proximal processes in the environment.

An interesting example of the important influence on the relationship between talent and expertise that is exerted by *the domain itself* comes from the work of Simonton (1999a). Simonton's study of people's creative accomplishments examined the ages at which people in different academic disciplines made their greatest intellectual contributions. He showed that mathematicians and physicists tend to make their most significant contributions very early in their careers (by their late 20s), that psychologists make their mark in midlife, and that historians take until their later years—their 60s, or even later—to produce their greatest works. One of the many fascinating conclusions Simonton's analyses raise concerns the roles of innate gifts versus developed expertise in these different academic domains. A mathematician of 25 simply has not been alive the number of hours needed to amass the proficiency and insights of an historian of 70. Innate gifts may play a role in success in both disciplines, but clearly the data suggest that hours of practice play a more important role in history than mathematics; the latter may depend more on the capacity of working memory, which peaks in young adulthood. The moral of the story is that whenever we speak about talent, expertise, or related issues, we should bear in mind that the domain in which the abilities are manifested brings its own characteristics to the "equation for success."

It is presumably rare that an environmental influence is so strong as to overcome what may be a complete lack of genetic potential for a particular developmental outcome, though such cases undoubtedly exist. What of the situation, though, in which innate talent—what Ceci et al. (2003) described as "a genetic superiority for a specific task" (pg. 84)—initiates gene-environment interactions? Here the problem arises that, at least for now, our evidence of innate talent is purely theoretical. Even still, we concur with the notion that innate talent, when it exists for a particular domain, comprises a rare combination of genes that come together to bring about the necessary penchants to self-select the appropriate environmental cue that will actualize that potential via proximal processes. Proponents of similar so-called emergenic models have argued that such polygenic systems are *requisite* for the attainment of expert levels of performance (e.g., Jensen, 1997; Simonton, 1999b, 2001). Although we agree with the possibility of emergenic systems, we disagree that expertise is limited to those who begin life with such rare combinations of genes. To argue otherwise would lead to the conclusion that an optimal environment can never compensate for less than optimal genes. This seems unlikely when one considers the evidence described earlier that shows that, in extreme circumstances, individuals with seemingly no genetic potential for a particular skill can, nevertheless, achieve expertise in that domain.

Equations for success, therefore, may play their most important role with respect to initial conditions. In Figure 1, we purposely labeled the left axis "initial conditions" because we do not believe that the attainment of expert levels of performance always requires genetic precursors. Just as we accept Dickens and Flynn's (2001) position that the stimulus that initiates a multiplier effect may be either endogenous or exogenous, we posit that the differences between levels A_i through D_i can be thought of as being derived from genetic *or* environmental origins, or some combination of the two.

Figure 2 represents a hypothetical distribution for traits within a particular domain. As depicted in this figure, as the number of traits that are required for a competency increases, an individual moves to a higher group (i.e., A through D) corresponding to different initial conditions in Figure 1. Several points are worth noting about Figure 2. First, differences between groups across the distribution (i.e., from Group A to Group D) represent not only differences in number of traits, but also a progression from basic abilities required to merely *perform* within a domain to those necessary to *excel* within that domain. Thus, traits possessed by individuals in Group A in Figure 2 will be relevant, albeit less specialized, than those possessed by individuals in Group D for a particular domain. These latter, nonessential traits that are the basis for individual differences within the range of competency in that domain are represented in Figure 1 as varying levels of developmental outcome within and across groups.

Second, although the range of potential developmental outcomes in Figure 1 is greatest for Group D, Figure 2 shows that because of the rarity of an individual possessing all requisite traits, these individuals actually represent only a small proportion of the total population. This is consistent with Simonton's (1999b) emergenic view of talent. Note that the same is true for individuals possessing hardly any, or none, of the requisite traits to perform in a particular domain. Finally, Figure 2 shows that initial conditions within each group may consist of traits with genetic (i.e., inherited) or environmental (i.e., noninherited) origins. Thus, what is important when considering the catalyst for proximal processes that may lead to exceptional abilities is not whether they are genetic or environmental, but rather their degree; the ontogeny of exceptional ability within an individual depends on the right combination of traits onto which gene-environment interactions can act, regardless of the origins of those traits. However, only those individuals who possess the entire set of requisite traits (i.e., Group D) even have the chance to cross the threshold of expertise, T_e in Figure 1, given optimal proximal processes to actualize and develop those traits.

A striking example of how our model would operate would be an individual who possesses all of the rare genetic proclivities to become a master painter with the exception of the fact that she is born with some deficiency that affects expression of particular genes to photoreceptor cells in the eye (see Blackshaw, Fraioli, Furukawa, & Cepko, 2001, for evidence of the identification of genes important in the development of photoreceptor cells). In this example, the potential to be a master painter is diminished by this

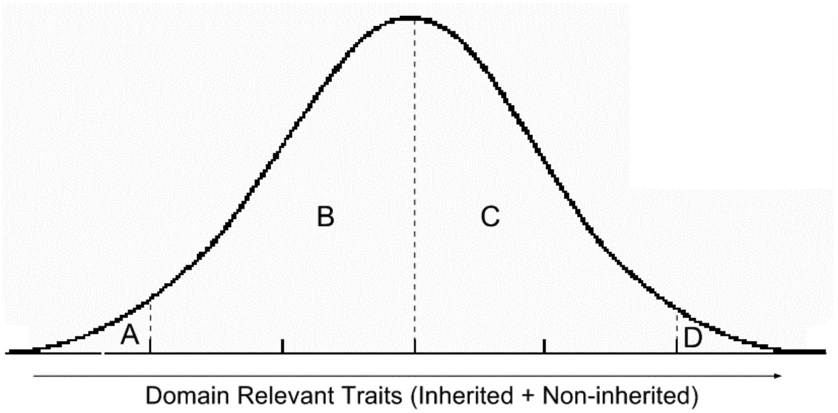

Figure 2. Hypothetical distribution for traits within a single domain.

particular genetic defect because it is requisite for the attainment of expertise in this domain. If the polygenic systems for talent are truly random, as such authors as Simonton (1999b) have proposed, then this example is plausible. However, one could imagine a point in the not-too-distant future when such treatments as retinal implants may be able to correct this individual's sight, thus completing the recipe for traits required to initiate the proximal processes that would lead to the actualization of exceptional skill. That is, although this individual was not born with all of the traits required to become a master painter, some environmental intervention could elevate her beyond the limitations of her genes to compensate for the "hereditary gap," thus promoting her from Group C to Group D. Without this environmental intervention to fill in the gap left by heredity, she could never become a master painter. Likewise, any other combination of traits, genetically or environmentally derived, could lead to low to moderate levels of painting ability, but they would never produce a master painter. A similar example in the domain of music might be the individual who possesses the potential to be a concert violinist, but who inherited a nonsyndromic hearing impairment affecting pitch perception. Here, the use of cochlear implants might provide a means for compensating for this deficiency in individuals with all of the other innate precursors, thus providing the means to become expert musicians.

Of course, at the other end of the spectrum, one can imagine individuals for whom noninherited traits represent the majority of traits that provide the initial conditions necessary to begin their developmental trajectory from Group D (see, e.g., Ericsson, 1996; Ericsson, Krampe, & Heizmann, 1993; Ericsson, Krampe, & Tesch-Römer, 1993). Either way, we emphasize, again, that although innate talent, in the form of genetic predispositions for domain-relevant skills, may be one initial condition for expertise, it is not the only one for a pathway to exceptional ability.

Conclusions

In this paper we have presented a bioecological perspective on talent and the ontogeny of exceptional competencies based on two primary assumptions: (a) that multiplier effects acting through reciprocal interactions between individuals and their environments pave developmental pathways to high ability and (b) that initial conditions, derived from combinations of inherited and noninherited traits, determine one's maximum potential outcome. Investigations of innate talent should continue to address the goal of understanding the mechanisms through which genotypes and proximal processes can, under the right conditions, coalesce into expertise.

For example, previous research related to the Matthew Effect has shown that, in general, the rich get richer, but are there particular processes associated with specific talent domains? In other words, are there general proximal processes that best facilitate achieving expertise as a dancer or a chess player, or does the abundance of varying initial conditions, coupled with the lengthy arm of multiplier effects, create such a vast array of potential pathways that no specific set of proximal processes (beyond deliberate practice) is consistently related to achieving expertise within a given talent domain? An expert chess player would require proximal processes that strengthen domain-relevant skills, including memory, logical reasoning, and visualization skills, whereas an expert dancer would require proximal processes to enhance such characteristics as agility, coordination, and rhythm. The set of proximal processes that foster these abilities in different individuals will assuredly differ. But, due to individual differences in experience, proximal processes within a domain will often not be identical. This raises the question of whether a common factors analysis could reveal a set of proximal processes (or at least core proximal processes that are supplemented with individual variation) that must be present in some form to achieve a particular expertise. Moreover, can we assume that the interactions that give rise to exceptional ability are the same as those in the rest of the range of ability? If proximal processes are highly influenced by characteristics of the developing individual, can we determine if or how differences in initial conditions moderate proximal pathways, particularly those that lead to expertise?

As Bronfenbrenner and Ceci (1994) lamented, previous research has rarely, if ever, simultaneously manipulated multiple proximal processes. In order to even begin fathoming the myriad outcomes multiplier effects can generate with even the slightest alteration, future research would benefit from a systematic comparison of how varying multiple proximal processes can influence the development of exceptional ability. Hence, Bronfenbrenner and Ceci emphasized

> the importance of using research designs that permit the assessment of the joint synergistic effects of two or more processes involving different agents and activities (e.g., solo as well as joint activities, fathers as well as mothers, peers as well as adults, and activities at school as well as at home). (p. 582)

Yet, we must also look within groups to investigate what properties of proximal processes underlie differences in developmental outcomes within the accessible range, given an individual's initial conditions. For example, what are the differences in proximal processes in situations wherein two individuals begin their developmental trajectories with all of the requisite conditions for a given domain (i.e., Group D), but only very few surpass the threshold of expertise? We can also ask whether or not proximal processes and developmental trajectories are different for individuals who end up with the same phenotypic outcome, in this case exceptional ability, but who start off with different combinations of inherited and noninherited conditions. Using our example from above, we can imagine two individuals in virtually any domain who have all of the conditions necessary to develop exceptional ability; but, for one of them, the conditions are all innate, whereas the other requires some form of exogenous intervention to elevate her to the same starting point as the first individual. If these two individuals eventually reach the same level of expertise, can we assume that their pathways were the same? Along the same lines, is an individual whose proximal processes are initiated by an exogenous, rather than endogenous, stimulus more likely to suffer negative consequences if the environmental stimulation that began their path to expertise is later compromised? Relatedly, is it possible his or her differences in proximal processes, or the consequences of the scenario just presented, are a systematic function of the relative proportion of inherited and noninherited traits that comprise the full combination of conditions required for expertise? Conversely, can problems arising from differences in the proportion of inherited and noninherited traits, if they exist, be resolved by manipulating levels of proximal processes?

Simonton (1999b) theorized that there are specific components required to achieve expertise—a sentiment with which we agree. This raises the question of how to determine precisely which traits are requisite for particular domains of expertise. Recent breakthroughs in trait segregation analysis to identify quantitative trait loci (QTL) afford new possibilities for empirical investigations of this question. For example, analyses of QTL are permitting researchers to identify regions of the genome that make contributions to the variance of specific phenotypic traits (see Ginsburg & Livshits, 1999; Plomin, DeFries, Craig, & McGuffin, 2003, for reviews of these analytic procedures). Thus, rather than relying on theoretical suppositions, it may soon be feasible to take populations of individuals who all demonstrate the same developmental outcome and compare their environments, as well as their genetic makeup, for similarities and differences to determine common factors underlying varying levels of ability. Theoretically, this information would be useful for confirming whether or not particular combinations of inherited and noninherited traits underlie expertise and whether or not strengths in the latter can, in fact, compensate for the deficits in the former.

Practically, such findings could lay groundwork for investigations into how interventions can best capitalize on multiplier effects (e.g., Dickens & Flynn, 2001) through the use of individualized compensation for gaps in heredity or unactualized genotypes. An individual may have the requisite potential to be an excellent cellist or a skilled linguist, but that individual must, at the very least, be exposed to, and perhaps even prodded toward, expertise in these domains. The bioecological model refers to this as *opportunity structures* (Bronfenbrenner & Ceci, 1994). Returning to the earlier basketball analogy, had the father never played basketball with his son, he would have never been able to recognize his son's natural ability and offer the opportunities for experience and practice that enabled the son to realize his talent. If an individual is found to possess the requisite skills for expertise, but is never exposed to a potential talent domain, that person's range of potential developmental outcomes will be unnecessarily limited. Research into how to foster opportunity structures, coupled with information about an individual's genetic makeup, may facilitate the degree to which potential is actualized (e.g., through earlier introduction into talent domains). Additionally, investigations for genes related to talent need not be limited to searches within a domain. Perhaps there are transdomainal genes associated with talent where proximal processes dictate the potential area of expertise (e.g., a "general talent" gene that can be channeled in myriad directions, depending on the nature of the proximal processes).

Finally, current methods only allow for a measure of the proportion of variance in an observable trait that is heritable. This tells us little about how much of an individual's absolute potential is expressed in his or her actualized performance. Is variation in performance a reflection of difference in actualized potential or a reflection of differences in absolute potential? For example, was Einstein successful because he actualized a greater proportion of his absolute potential or because his absolute potential was so high that actualizing even a portion of it elevated him above his peers?

In sum, future research on talent and the ontogeny of exceptional abilities should have two distinct, but intertwining, primary roots. One primary root would be the exploration of specific combinations of traits that are associated with particular abilities, with the second being the search for how proximal processes influence the development of expertise. Each of these roots motivates fundamental questions in its own right, but only through exploration of their interface will we be better able to unravel the puzzle of talent and its manifestation into exceptional ability.

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Endnotes

1. For the sake of convenience, throughout this article we use the term *talent* to refer to both talents and gifts. We recognize that the literature has differentiated between the two constructs, the former referring to more general abilities with the latter signifying domain specific competencies (e.g., Gagné, 1991; but see, e.g., Detterman, 1993), however, this distinction is not germane to our evaluation.

2. In their models Dickens and Flynn represent reciprocal effects as $A = aG + vE$ and $E = bA + e$, where A is ability, G is genetic endowment, E is ability-relevant environment, and e is initial exogenous environment. This set of equations produces $A = (aG + ve)/(1-bv)$. In our proposed model with interaction, $A = GEe$ (Dickens, 2004).