## **Functional Neural Anatomy of Talent**

M. LAYNE KALBFLEISCH

The terms *gifted*, *talented*, and *intelligent* all have meanings that suggest an individual's highly proficient or exceptional performance in one or more specific areas of strength. Other than Spearman's g, which theorizes about a general elevated level of potential or ability, more contemporary theories of intelligence are based on theoretical models that define ability or intelligence according to a priori categories of specific performance. Recent studies in cognitive neuroscience report on the neural basis of g from various perspectives such as the neural speed theory and the efficiency of prefrontal function. Exceptional talent is the result of interactions between goal-directed behavior and nonvolitional perceptual processes in the brain that have yet to be fully characterized and understood by the fields of psychology and cognitive neuroscience. Some developmental studies report differences in region-specific neural activation, recruitment patterns, and reaction times in subjects who are identified with high IQ scores according to traditional scales of assessment such as the WISC-III or Stanford-Binet. Although as cases of savants and prodigies illustrate, talent is not synonymous with high IQ. This review synthesizes information from the fields of psychometrics and gifted education, with findings from the neurosciences on the neural basis of intelligence, creativity, profiles of expert performers, cognitive function, and plasticity to suggest a paradigm for investigating talent as the maximal and productive use of either or both of one's high level of general intelligence or domain-specific ability. *Anat Rec (Part B: New Anat) 277B:21–36, 2004.* 0204 Wiley-Liss, Inc.

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## TALENT: GENOTYPE OR PHENOTYPE?

Someone exhibits "talent" when they perform in a certain capacity above the norm. Someone possesses "intelligence" when they respond to a cir-

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motivation, applying their knowledge and skill when it is a relevant contribution [e.g., the premise of Sternberg's "practical intelligence" (Sternberg, 1985)]. Someone is "creative" when they provide a solution for or interpretation of a problem or product that is significant and novel. From a developmental perspective, a child is cognitively "gifted" when their aptitude/IQ measures approximately two standard deviations above the norm  $(\sim 130)$  on psychometric measures of intelligence and when they display certain behaviors or traits such as creativity, exceptional memory, rapid processing speed, high motivation, an affinity for learning, and optimal cognitive performance in one or more domains. These attributes are the basis of the expression of talent. Yet relying solely on a psychometric assessment of IQ limits how we identify talent, particularly creative talent (Amabile, 1996). People with measured high IQs tend to display certain exceptional cognitive traits and abilities. Why the use of the word talent? Because tal*ented* is a word often used to describe someone who performs optimally according to definitions of intelligence and/or creativity.

Recent evidence suggests that certain aspects of cognition underlying the potential for talent exist by means of a heritable code (Posthuma et al., 2001, 2002; de Geus and Boomsma, 2002; Thompson et al., 2002). Emerging methods in the fields of structural and functional neuroimaging and genetics have made it possible to detect patterns that suggest the heritability of temperament (Eley and Plomin, 1997; Schwartz, et al., 2003) and cognitive abilities (Thompson et al., 2002) determined by genetic influence over the development of certain parts of the brain. In contrast, other brain structures required for learning, such as the hippocampus, have been shown to be more open to environmental influence and experience (Foy et al., 1987; Gunnar, 1998; Maguire et al., 2000, 2003). Heritability studies have demonstrated conflicting ideas that environmental effects influence cognitive differences later in life (McClearn

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et al., 1997), that maternal effects are the underlying factor in heritability (Devlin et al., 1997), and that heritability is lowered when analyses include data from a greater number of relatives in addition to the twin (Feldman and Otto, 1997). While these relationships continue to be explored as computational, genetic, and neuroscientific methods advance and converge (Thompson et al., 2002), it is not uncommon to read about studies that have made rudimentary determinations about the genetic heritability of diseases such as Alzheimer's (Saunders et al., 2003) and schizophrenia (Cannon et al., 1998). Understanding more about the predisposition for disease and disability will allow science to develop early interventions and effective treatments. Understanding more about the predisposition for ability will shed light on processes of neurological and psychological development and allow science and technology to design heuristics based on biological principles of optimal performance.

This review argues that talent can be attributed to two things: measured high intelligence that results in consistent domain-general optimal cognitive performance, and/or extraordinary ability in a domain-specific area that is not particularly related to a general measure of IQ, but a reflection of individual plasticity and neurobiological predisposition. These two attributes can be dually present or mutually exclusive in an individual. Practically speaking, talent is the possession and development of a skill, and the expression of a natural aptitude in one or more domains. A domain is a "culturally structured pattern of sensorimotor and cognitive skills in a symbolic system such as music, mathematics, or athletics" (Csikszentmihalyi and Robinson. 1986). It involves interaction between biological, psychological, familial, societal, cultural, and historical factors (Feldman, 1986). Is talent dependent on a general level of high ability, characterized in the literature as Spearman's g (1927)?

The notion of talent alludes simple description. This review argues that the methodologies of cognitive neuroscience are an appropriate way to begin to consider talent as a concept that supercedes both intelligence and creativity. This anticipates the utility of future research to inform endeavors focused on education, intervention, and the modeling of general high-level cognitive expertise and context-specific optimal performance. This review will examine those findings from the literatures on intelligence, creativity, gifted education, and expertise which are supported by experimental evidence from cognitive neuroscience and neurobiology. Therefore, theories and experimental results addressed in this article suggest evidence for a specific neural circuitry that is recruited

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for optimal performance on an array of higher level cognitive tasks and more automatically activated for general cognitive use in people with high ability. Further, we suggest a new paradigm for investigating the relationship between cognitive and emotional development and certain types of expertise. Finally, the review will expand the talent paradigm by including a point of view on domain-specific expertise in the context of neural plasticity. The overall goal is to present a paradigm of thinking about the nature of expertise that supercedes separate literatures and has the potential to lead to new insight about the nature of exceptional ability and human development. This review is written assuming a broad audience; therefore, definitions of key vocabulary and concepts are provided, and not all fields of evidence incorporated into the discussion are covered with equal depth.

### MEASUREMENT, HERITABILITY, AND CAPTURE OF G

Based on traditional psychometric instruments such as the Stanford-Binet IV (Thorndike et al., 1986) and the WISC-III (Wechsler, 1991), IQ is comprised of abilities on modular subtests that assess a combination of natural skill and information gleaned from experience to measure verbal IQ (crystallized knowledge) and performance IQ (fluid intelligence) comprising the full-scale IQ score. This score predicts an individual's likelihood for success in a formal educational environment and is accepted as a psychometric measure of Spearman's theoretical composite, g. These measures, however, have been shown to correlate significantly with achievement (Brody, 1992) and are intrinsically biased against individuals made vulnerable in the learning process by factors such as second-language issues (Naglieri and Yazzie, 1983), poverty (Zurcher, 1998), learning disabilities (Kavale and Forness, 1984), or a combination of exceptionally high abilities in one or more domains with a disability affecting others (Silverman, 1989). The interaction of these factors with natural skill makes a measure of full-scale IO hard to interpret or generalize when attempting to account for individual differences in performance.

To assess ability more fairly across many populations of children and adults, clinicians and researchers have employed progressive matrices tests, such as Raven's Progressive Matrices (Raven, 1947), which consist of the visual completion of geometric designs that free them of potential achievement, cultural, language, and enrichment biases (Figure 1). Raven's has been criticized for its lack of normative data. but it has well-documented use in assessing various skills associated with problem-solving across cultures, languages, and representative of domain-specific problem-solving (Das, 1973; Labouvie-Vief et al., 1975; Harber and Hartley, 1983; Riding and Powell, 1987; Horgan and Morgan, 1990). Studies in cognitive neuroscience have utilized Raven's to explore reasoning ability (Table 1), to

suggest a specific cortical anatomy employed during these tasks, which includes subareas of the prefrontal cortex (PFC) (Prabhakaran et al., 1997; Christoff et al., 2001; Kroger et al., 2002). Measures from Raven's have been shown to correlate with measures of general intelligence (Gray et al., 2003). One of the first studies of reasoning in cognitive neuroscience did not use matrix stimuli (Rao et al., 1997) but provided evidence for a circuit that encompassed not only higher-level cortical areas, but deep structures such as the basal ganglia, thalamus, and cerebellum. Recent functional imaging studies make the case that intelligence tests, and matrices tests in particular, predict brain response to demanding task events (Duncan, 2003; Gray et al., 2003).

In sum, matrices tests appear to engage a neural circuitry common to reasoning paradigms that involve other domain-specific stimuli such as mathematical and verbal reasoning. For instance, bilateral damage to the caudate nucleus and putamen (basal ganglia nuclei shown to be recruited during matrix reasoning tasks) cause deficits in speech production, sentence comprehension, and abstract reasoning while lexical access and memory remain intact (Pickett et al., 1998). During syllogistic reasoning, dissociable domain-specific circuits are recruited depending on the type of content (language vs. visual-spatial), but the general circuitry recruited involves the bilateral basal ganglia nuclei, right cerebellum, bilateral fusiform gyri, and lateral PFC (Goel et al., 2000; Goel and Dolan, 2001). Finally, during tasks of mathematical reasoning, the bilateral PFC activates as reasoning demands become more complex (Prabakharan et al., 2001).

There appears to be some contributory innate base that marks an individual's potential for cognitive strength that is not fully appreciated within the current discussion on the nature of intelligence. Genetics studies suggest the heritability of general cognitive ability, characterized by Spearman's g factor (Table 2). Several of these studies employ the use of identical twins because they share all of their genes, have brains that are more similar than randomly picked



**Figure 1.** Matrix reasoning problem (Christoff et al., 2001). This is an adapted item from Raven's Progressive Matrices. The goal is to select the item that correctly completes the pattern in the picture.

pairs, and serve as controls for environmental influence on development. Although some challenge the validity of interpreting data from twin studies (Kamin and Goldberger, 2002), findings from several independent studies suggest genetic influence over brain structures that are believed to facilitate the subcomponent cognitive processes of general intelligence such as working memory, processing speed, and implicit memory (Table 2). Interestingly, these processes are thought to be the main sources of variance which account for individual performance differences on cognitive tasks

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(Kyllonen and Christal, 1990). These regions, the corpus callosum, frontalparietal cortices, bilateral temporal cortices, insular cortex, and the dorsolateral PFC, participate in the cortical architecture that facilitates functions such as interhemispheric communication, spatial navigation, attention, memory, emotion, language, and reasoning. Further, these regions have afferent and efferent connections that incorporate input from deep structures of the brain such as the basal ganglia, thalamus, and cerebellum. These regions are also candidate areas recruited during matrix reasoning tasks (Table 1). Genetics studies and experiments from cognitive neuroscience provide evidence to suggest that these cortical areas

provide the structural basis of optimal cognitive performance, or intellectual talent.

Other neuroscientific studies that suggest evidence for a specific neural circuit characterize g based on the functional efficiency of the PFC (Duncan et al., 2000; Fuster, 2002; Duncan, 2003) and the neural speed theory of intelligence (Posthuma et al., 2002). A phenomenon missing from the discussion on talent or optimal performance is neural binding as the mechanism that may be shown to facilitates cognitive fluency seen in high-ability individuals (Engel et al., 1999; Newman and Grace, 1999). While the expression of talent is not dependent on high g, as will be illustrated later in this discussion, it is necessary to consider the role of g in the expression of intellectual talent. Part of that expression is dependent on neural circuits involving the PFC.

From an evolutionary point of view, the PFC is of particular interest in the discussion of ability or talent. Largest relative to body size in the human brain when compared with other species, it facilitates sophisticated cognitive abilities such as fluid intelligence, problem-solving, planning, the ability to delay gratification, the ability to anticipate consequences to actions, and reasoning ability (Fuster, 2003). It may be more advantageous, however, to explore the PFC from the standpoint of functional connectivity rather than relative size, as many of these cognitive abilities have also been attributed to birds in studies documenting their cognitive abilities to change behavior in response to experience and social context (Clayton and Dickinson, 1998, 1999; Emery and Clayton, 2001), to deceive (Lanza et al., 1982; Emery and Clayton, 2001), to reason formally (von Fersen et al., 1990, 1991), and to problem-solve (Weir et al., 2002). Structural neurobiological techniques document prefrontal cortical connections to limbic structures and the dopaminergic circuits of the basal ganglia (Groenewegen et al., 1997; Behrens et al., 2003). Connections between limbic structures and the PFC are thought to modulate cognition based on context, emotion, and reward expectancy (Newman and Grace, 1999). Connections between the PFC and basal gan-

Study	Regions of Interest	Proposed Function
Prabhakaran et al., 1997	RPFC, Bilateral Parietal	Figural Processing
	Bi PFC, L Parietal, Temporal, Occipital	Analytical Processing
Duncan et al., 2000	Lateral PFC in one or both hemispheres	Areas specifically recruited during high `g' tasks
Christoff et al., 2001	Bi RLPFC (lateral area 10)	Left activation of RLPFC as complexity increases
	R DLPFC (BA 9/46)	Working memory, spatial processing
Kroger et al., 2002	Parietal, DLPFC	Fluid reasoning, working memory
-	Anterior LPFC	Activity increases as complexity increases

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	s reasoning brain				

glia are thought to enable memory consolidation, insight, and problemsolving, the seed processes of creativity (Gluck and Myers, 1998). Elaborating on cognitive functions associated with the PFC, Duncan and Owen (2000) illustrate that similar regions of frontal cortex are recruited during a variety of cognitive processes that have been associated with the psychological and neuroscientific characterization of g such as response selection, executive function, working memory, episodic memory, problemsolving, and aspects of perception. Some of these frontal regions are under tighter genetic control than others (Table 3).

The domain-general processes underlying g are ultimately expressed based on the goal-directed behaviors facilitated by the frontal cortices (Duncan et al., 1996), but also appear to be genetically linked by subtle nonvolitional perceptual processes. The neural speed theory of intelligence purports that response reaction time is associated with intelligence on both phenotypic and genetic levels (Eysenck, 1986; Vernon, 1987). This relationship is called an endophenotype, a measure of brain function that correlates with cognitive ability through shared genetic factors (de Geus and Boomsma, 2002). Reaction time is the behavioral result of a series of subcomponent processes: stimulus detection, stimulus evaluation, response selection, response activation, and response initiation (Posthuma et al., 2002). This is important to the idea of talent because this is a process that is representative of perceptual nonvolitional speed and may contribute to the cognitive fluency associated with talent or optimal performance. Performance measures on the Eriksen flanker task assess reaction time (Figure 2). The flanker task is used to assess cognitive control, a perceptual subcomponent of attention that indicates an ability to direct attentional resources efficiently and appropriately to determine relevant from irrel-

Genetically Influenced	Measure to Determine		
Structure	Heritability	Associated Cognitive Process	Genetics Studies
Corpus Callosum	Volume, Gray Matter Density	Communicates information between hemispheres, processing speed	Oppenheim et al., 1989; Pfefferbaum et al., 2001; Thompson et al., 2001
Frontal- Parietal Cortices	Shape	Executive function, cognitive control, response inhibition, reasoning, sensorimotor integration, implicit memory, manage representations of abstract information	Wright et al., 2002
Bilateral Temporal Cortex	Shape; Behavioral Genetics; Gray Matter Density	Language function, memory encoding and retrieval	Thompson et al., 2002; Wright et al., 2002; Alarcon et al., 1998
Insula	Shape	Supports high cognitive load demands on working memory	Wright et al., 2002
Middle Frontal BA 9 and 46 (DLPFC)	Behavioral genetics; Gray Matter Density	Working memory, perceptual speed, response selection, top down management of attention resources, manipulation of spatial information, processing speed	Alarcon et al., 1998; Thompson et al., 2002

Definitions of Measurement Techniques: Shape Studies: measures anatomical shape parameters of certain brain structures and analyzes variability using factor or principle component analysis (Thompson et al., 2002). Volume Studies: measures the overall volume of the brain in relation to cognitive ability (Thompson et al., 2002). Gray Matter Density Studies: compares the spatial distribution of gray matter across subjects in a study. Differences in frontal gray matter correlate with differences in intellectual function. Differences in regional gray matter volume significantly correlate with differences in IQ (Thompson et al., 2001).

Frontal Cortex Sub-region	Associated Cognitive Process	References
Mid-DLPFC (BA9/46)	Manipulation and monitoring of (spatial) information in working memory; manage stimulus complexity	Milham et al., 2003; Veltman et al., 2003; Glahn et al., 2002; Petrides, 2002; Kroger et al., 2003; Postle et al., 2000; D'Esposito et al., 1999; Owen et al., 1999
Mid-ventrolateral PFC (BA 47)	Maintenance of working memory, execution of organizational and strategic processes during high loads on working memory, memory retrieval	Bunge et al., 2003; Ferrandez et al., 2003; Kostopoulos and Petrides, 2003; Rypma and D'Esposito, 2003; Veltman et al., 2003; Glahn et al., 2002; Petrides, 2002
Bilateral lateral PFC	Formation, maintenance and manipulation of internal representations; temporal organization of goal-directed action, reasoning, manage task complexity, differentiating emotional response	Fuster, 2002; Ullsperger et al., 2002; Vuilleumier et al., 2002
Dorsal anterior cingulate	Conflict detection and monitoring, cognitive control	Milham et al., 2003; Stephan et al., 2003; Fan et al., 2002; Dreher and Berman, 2002; Fossella et al., 2002; Braver et al., 2001; MacDonald et al., 2000
Medial frontal cortex	Facilitate emotional behavior, inhibition of prepotent motor response	Goel and Dolan, 2003; Pelletier et al., 2003; Sylvester et al., 2003; Fuster, 2002

TABLE 3. Cognitive processes of heritably influenced sub-regions of the fro
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evant information. Trials are usually administered so quickly on the flanker task ( $\sim 500$  ms per trial) that subject response (measured by reaction time) is more detection than the type of formal decision made during a task involving explicit complex-problemsolving.

The brain regions associated with successful performance on the flanker task are primarily the dorsolateral prefrontal cortex (DLPFC) and anterior cingulate gyrus (Bunge et al., 2002b; Fan et al., 2003). First, the DLPFC, implicated as a brain region under heritable influence (Table 2), is thought to govern a domain-specific ability to manipulate information in spatial working memory (D'Esposito et al., 1999; Owen et al., 1999; Postle et al., 2000), and to be involved in other key aspects of cognition that are domain-general: maintain top-down control of attention, manipulate information in working memory, and facilitate response selection (Glahn et al., 2002: Milham et al., 2003). Second, the anterior cingulate gyrus, another subregion of the frontal cortex, is central to the subcomponent attentional processes of cognitive and inhibitory control as it is the region that detects conflicting or coinciding stimuli (Braver et al., 2001). Further, its activation appears to be context-specific. If the task is lateralized on either the right or left side of the brain, the anterior cingulate appears to activate in tandem (Stephan et al., 2003). This has consequences for the types of information conflict mediated by this region, verbal versus spatial or cognitive versus emotional and its capability to respond to various types of information processing in various places in the cortex.

There is a subcomponent process in reaction time that appears to account for its correlation with genetics and ability. Electrophysiological data illustrate that although genetic effects accounted for 40% of the variability in the onset and peak of the lateralized readiness potential (LRP), a measure associated with response time and choice selection, in young and old cohorts neither were associated with verbal or performance IQ or corre-

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Figure 2. Flanker task (Eriksen and Eriksen, 1974). This task is designed to assess cognitive control. The participant is asked to press a button, "left" or "right," that corresponds to the direction of the central target arrow (underlined). Reaction times will vary at statistically significant levels between congruent and incongruent trials despite concentration and volitional effort.

lated with genetics (Posthuma et al., 2002). However, in an earlier study of younger individuals, the perceptual speed of early detection of the stimulus was correlated with IQ linked to a common genetic influence. This suggests that nonvolitional processes are under tighter genetic influence than goal-directed behavior and that specific perceptual subprocesses account for the relationship between ability and genetics (Posthuma et al., 2001). cognitive Developmental neuroscience also stands to contribute to our understanding of the relationship between g and reaction time. The flanker task ferreted out an interesting finding in a developmental study, which illustrates the functional anatomy at work in the developing brain of age-appropriate performing children versus those who are of the same age with high cognitive ability.

### DEVELOPMENT OF G

Preliminary evidence from two developmental studies shows differential patterns of neural recruitment in regions of the PFC in high-ability children when compared with their sameage peers with average ability. Data suggest that physical and functional aspects of brain development appear to be accelerated in certain children, resulting in access to or the ability to recruit regions of neural function usu-

ally reserved for late adolescence and adulthood (Alexander et al., 1996; Bunge et al., 2002a). First, in a study that investigated the development of attention assessing cognitive control and response inhibition using an interleaved flanker/go-no-go design (Figure 3), children who performed better (who made 2-8% errors of commission) than their peers (who made 9–26% errors of commission) exhibited similar no-go error rates to the adult group (Bunge, et al., 2002a). While the flanker measures cognitive control, the go-no-go tests a subject's ability to inhibit a prepotent response. During performance, adults activated the right ventrolateral prefrontal cortex (VLPFC) and the bilateral superior and inferior parietal lobules during performance on this task. Better-performing children activated the bilateral inferior parietal lobule while worse-performing children activated the left VLPFC and the bilateral DLPFC. It has been suggested that the parietal cortices manage representations of abstract information (Rickard et al., 2000), which would suggest that the better-performing children had access to more sophisticated nonvolitional cognitive processes while performing this task, recruiting a subset of the adult response inhibition circuitry. Further, the worse performers, having activated the VLPFC and DLPFC, would appear to be using greater working memory and object recognition mechanisms to perform the task, suggesting reliance on more literal cognitive processes.

Analysis of the flanker portion of the task to assess cognitive control demonstrated that better-performing children did not show similar activation patterns to adults, but showed greater activations (in intensity and bilaterality) of similar regions to worse responders. This suggests they had greater neural power available to them to perform well on the task. Thus, a possible interpretation of this study is that children who displayed expertise during this task exhibit developmental trajectories that differ from their average performing peers.

Second, an EEG study investigated the performance of children with high IQs ages 8–12 years old compared with the performance of young adults ages 18–21 years old and 8- to 12Congruent Trial<</th><</th><</th><</th>Incongruent Trial<</td><</td><</td><</td>Neutral Trial\*\*\*No-Go Trialxxx

Figure 3. Interleaved flanker/go-no-go task (Bunge et al., 2002a). This task is designed to assess cognitive control and response inhibition. The participant is asked to press a button that corresponds to the direction of the central target arrow (underlined). Press "left," "right," or withhold response when the central target is flanked by "x." Reaction times will vary at statistically significant levels between congruent and incongruent trials despite concentration and volitional effort. (This figure is a modified version of a figure from Bunge et al., 2002a).

year-old peers of average ability during tasks of mathematical word problem-solving. Results showed that the high-ability children ages 8-12 years exhibited enhanced alpha activity in the right hemisphere during performance, similar to the 18- to 21-yearold young adult group, whereas their peers of average aptitude showed lower levels of alpha activity in the left hemisphere only (Alexander et al., 1996). These data are particularly interesting in the context of the dynamic development taking place in the PFC throughout childhood and into adulthood documented by diffusion tensor imaging studies (Giedd et al., 1999; Sowell et al., 1999, 2001). Normally functioning children at young ages tend to recruit left hemisphere regions to perform cognitive tasks relating to attention and spatial working memory, gaining access to right hemisphere areas to support the growing efficiency of their cognition as they mature. Data from children with high IQ, or those that display expertise on specific cognitive tasks, suggest that they recruit portions of the prefrontal and parietal cortices from both the right and left hemispheres or show greater activations in developmentally appropriate regions. These are both factors that may contribute to the efficiency of cognitive processing at younger ages that translates into optimal performance.

In sum, a high IQ or high g gives great potential for the possession and expression of talent or cognitive ex-

pertise. While talent should be considered in this context, it cannot be completely characterized by it. Assuming that g or a high-IQ are synonymous or at least both necessary and sufficient for talent to exist and be expressed fails to incorporate influences from the natural environment and individual experience. While the development of talent may involve natural disposition, early skill acquisition, motivation, and persistent effort and involvement over the course of many years, the existence of child prodigies violates the assumption that one must invest years in developing talent in a particular area and suggests a way to explore not only the underlying functional anatomy or anatomies of exceptional ability but also issues important to developmental cognitive neuroscience such as the relationship between cognitive and emotional development.

### CHALLENGING ASSUMPTIONS: SOMATIC MARKER, GIFTED CHILDREN, AND PRODIGIES

Damasio (1996) formulated the somatic marker hypothesis from observations of people who have suffered damage to areas of the PFC, primarily the ventromedial prefrontal cortex. This damage causes persons to show severe impairments in personal and social decision-making in spite of preserved intellectual abilities. Their intellect remains normal as reported by a conventional IQ test, as does rote memory, their ability to perform academic logic problems, and language function. This loss of "practical sense" cannot be explained according to defects in IQ, knowledge, language, short-term memory, or the basic ability to pay attention. Damasio (1996) postulates that part of what is lost is the ability to connect to the emotional part of memory. Therefore, while a person can recall information and function in a rote intellectual sense, they are unable to link to emotional memory in order to make intelligent choices appropriate to their own context.

How does this relate to talent? There is a natural phenomenon in gifted children that illustrates a dissociation between intellect and emotion without injury, insult, or lesion that

Characteristic	Prodigies	Savants
IQ	Normal IQ	Impaired IQ
Definition	Adult competency in a specific area prior to age 10	Exceptional domain specific talent at an early age
Emotion	Problems with emotional adjustment	Show lack of emotion
Development	Talked and read at much earlier ages than normal toddlers	Reliance on literal and concrete patterns of thinking and performance
Higher Level Cognition	Understand and communicate using logical thought and language far beyond peers	Minimal or no abstract reasoning or metacognitive ability
Idiosyncracy	Age-appropriate reasoning, logic, and moral development	Intuitive perception of underlying rule structures in a particular domain where they display talent
Memory	Exceptional declarative and procedural memory capacity in area of expertise	Exceptional declarative and procedural memory capacity in area of expertise

### TABLE 4. Cognitive and affective characteristics of prodigies and savants

could lend important insight into how these mechanisms develop and interact. Many gifted children experience developmental asynchrony, which means that their emotional development lags far behind their intellectual prowess (Catheline-Antipoff and Poinso, 1994; Winner, 2001). They may be capable of solving calculus equations at the age of 9, but still be an emotionally aged 9-year-old or less mature. Emotional adjustment issues are prevalent in many gifted children. While investigations involving children with high-IQs are criticized for their lack of generalizability, there is untapped potential in what could be discovered as the neural and environmental basis for the expression of exceptional talent in various forms and the role that emotion and reward play in that process. Dabrowski (1991) characterizes these proclivities in the theory of overexcitabilities, which asserts that gifted children absorb, respond to, and utilize all types of sensory information with unusual intensity because of their heightened abilities, which leads to an inability to assimilate equitably this awareness emotionally and intellectually.

Prodigies are an extreme example of this dissociation because they refute traditionally held definitions of development from psychology and neuroscience (Table 4). Prodigies are children who perform at adult levels of competency in a cognitively demanding field prior to the age of 10 (Feldman, 1986). Their talents defy Piagetian definitions of development dependent on sequential stages that define thinking capabilities at any given time during developmental years. Also, their temperaments and abilities violate the view that neural mechanisms of attention and executive function assist in emotional development and precede advanced cognitive processing in the developing brain (Posner and Rothbart, 1998).

To illustrate, the study by Hollingworth (1942), based on 12 children (8 boys and 4 girls) with IQ scores of 180 or above, identified three main char-

### Many gifted children experience developmental asynchrony, which means that their emotional development lags far behind their intellectual prowess.

acteristics of prodigies: they talked and read at much earlier ages than normal toddlers; they were highly skilled at understanding and communicating using logical thought and language well beyond children their own ages; and they experienced difficulties with emotional adjustment, attributed to their intellectual capacity to perceive complex issues and absorb life events without the advanced emotional skill to manage and adjust properly. Their abilities to talk, read, and communicate at much earlier ages support the idea of heritable influence over the neural structures that

govern these processes as these children have abilities that exceed their education and life experience (Table 2).

Another study of two 8-year-old chess players and one 10-year-old musical composer found that even though these children performed at exceptional levels in these specific domains, they performed at age-appropriate levels on tests of spatial reasoning, role-taking, moral judgment, and logic (Colangelo, 1991). Therefore, while they had exceptional domainspecific talent, abilities related to emotional development and general intellectual ability appeared normal. The dual role of the PFC in facilitating higher-level cognition (van den Heuvel et al., 2003) and the perception and regulation of emotion (Phillips et al., 2003) suggests fertile ground for future explorations of prefrontal function in adult and developing populations. In contrast, studies of savants offer another perspective on the relationship between IQ and g. Their talent negatively correlates with their intelligence quotient.

### SAVANTS: LITTLE RELATIONSHIP BETWEEN TALENT AND G

Studies of savants illustrate that talent is not necessarily based on the psychometric indication of g (Table 4). Savants possess minimal or no abstract reasoning or metacognitive capability and rely heavily on literal and concrete patterns of thinking and performance (Treffert, 1989). Treffert (1989) characterized a savant named Leslie Lempke who illustrates the unusual capacities and characteristics of a savant. Leslie was born premature,



**Figure 4. A-D:** The interhemispheric asymmetry of the human temporal cortex may help explain how compensatory mechanisms develop in the brain when normal function is impaired. Data suggest that greater functionally distinct columnar systems per surface unit comprise left BA22 in contrast to right BA22. Cluster diameters shown are 20 percent larger in the left hemisphere (Galuske et al., 2000). 4A and B: Camera lucida drawings of the patchy patterns of long-range intrinsic connections through area 22 after simultaneous injection of carbocyanine dyes, Dil and DiA. Dark grey, Dil; light gray, DiA; asterisks, implantation sites; m, medial; a, anterior; d, dorsal. (A) Pattern with interdigitating patches (arrows). (B) Pattern with two double-label patches (arrows). 4C: Estimation of the number of different subsystems of interconnected columns in left and right area 22. The error bars on the top of each column give the standard error of the mean. Interhemispheric differences were significant (Mann-Whitney U, P = 0.01). 4D: Cytoarchitectonic subdivision of the upper portion of the temporal lobe (see shaded area) according to the classification of Brodmann. Area 22 is elaborated in Figures 4A-4C.

palsied, mentally handicapped, and affected by a disease that leads to permanent blindness. Around age 7, his adopted mother introduced him to the piano by running his fingers across the keys and singing and playing for him. By age 8 Leslie was playing the bongo drums, concertina, ukulele, xylophone, and accordion and had learned to play the chord organ at age 9. At age 14, Leslie overheard Tchaikovsky's Piano Concerto No. 1 during a television movie and awoke his family early the next morning by playing a perfect rendition. Having acquired an extensive classical repertoire, he performs for audiences worldwide. Leslie's measured IQ is 58.

Though savants have many difficulties with normal intellectual function, their strengths demonstrate an intuitive perception of underlying rule structures in a particular domain where they display talent (i.e., musical or calculation ability). It has been suggested that the capacity for rule-learning is facilitated by the frontopolar cortex (Strange et al., 2001). Savants who are able to utilize strategies based on these rule structures have higher IQs than their peers and are sometimes called prodigious savants (Morelock and Feldman, 1991). The anatomy-IQ relationship in this instance is intriguing in light of the proposed heritability of frontal cortical function. Savants also tend to have limited access to emotion, such that their performances and behavior are mechanical, repetitive, or imitative, as opposed to prodigies who experience disynchrony between intellectual and emotional capacity.

In addition, savants rely on exceptional memory capacity for specific domain information. Treffert (1989) proposed two possible alternatives to explain this ability. The first, based on research from Geschwind and Galaburda (1987) on lateralization of

brain function, suggests that injury sustained to the brain's left hemisphere causes the right hemisphere to compensate by developing heightened domain-specific capabilities. A study on the lateralization of language-relevant auditory input in normal adults illustrates patterns of connectivity between the left and right hemispheres (Galuske et al., 2000). Specifically, there is a functional lateralization in the left posterior part of Brodmann area 22 in conjunction with processing of auditory sounds related to language (Figure 4). This study illustrates that both hemispheres are constructed to facilitate auditory stimuli, but that the left hemisphere has more architecture dedicated to the process. The authors analogize this functional organization to the cortical columnar organization of the visual system and hypothesize that these differences may result from experience-dependent influences during early development. Potentially, in relation to the potential basis of savant musical capabilities or even compensatory strategies in people with less severe disability, in the face of loss of left hemisphere function, the right hemisphere is primed to compensate and develop other strengths. While the right hemisphere is non-dominant for language, it specializes in the discrimination of melody, pitch, and sound discrimination (Galuske et al., 2000).

Treffert's second hypothesis for savant ability suggests that savant memory is the result of compensation of the corticostriatal system, which has been shown to display increased connectivity and plasticity in comparison to other cortical-temporal and cortical-parietal circuits during visuomotor learning (Toni et al., 2002). This cortical-striatal circuit is thought to facilitate procedural, habitual, nonassociative memory (Middleton and Strick, 1994; Poldrack and Gabrieli, 1997). To extend Treffert's original hvpothesis, certain types of information are stored and utilized from procedural memory, resulting in obsessive repetitive behaviors or the abilities to play complex musical compositions after hearing the piece one time or to display extraordinary numerical calculation ability. These abilities and behaviors coupled with the lack of emotion suggest atypicality in orbito-

frontal regions known to play a role in memory encoding, obsessive-compulsive behavior, and emotion processing (Northoff et al., 2000; Frey and Petrides, 2002; Neel et al., 2002). There are several examples of plasticity and compensation in the face of injury such as preserved intellectual function in children who undergo hemispherectomy for epilepsy (Vining et al., 1997) and the amelioration of symptoms related to phantom limb syndrome (Knecht et al., 1998). Thus, it is entirely possible that the savant brain represents a specific type of plasticity not yet fully characterized or understood.

Another provocative question raised by the existence of savants is why the domains of music and mathematics are particularly accessible to them. Perhaps because these domains are not as dependent on skills of language or social interaction and rely on more primary sensory domains such as motor, audition, and vision, closer to wavs the brain forms memories. Or perhaps they are recruiting areas of the brain that have been suggested to have a dual role in certain types of language processing and mathematical cognition, but some endogenous mechanism predisposes these resources for domain-specific use and exceptional competency (Simon et al., 2002). The studies of Wynn (1992, 2000) on the presence of numerical abilities in infants demonstrate that the brain in the very beginning of life is primed with some sort of computational skill. Whether this ability is dependent on areas of the brain that use visuospatial skill or the early use of Broca's area for nonlinguistic purposes is not currently known. This mechanism could be altered in the savant brain.

Another characteristic that appears to undergird all exceptionally performing populations is the ability to understand intuitively formal rule structures of activities or skills where exceptional talent exists. For example, music and mathematics are two domains that have regular and well-established symbolic rule structures which vary much less than grammatical structures of specific languages. Creative talent in art is also more highly based on symbol. A recent article by Conard (2003) provides evi-

dence of human capability to think and produce cave art on a symbolic. figurative level as far back as the early Upper Palaeolithic period, suggesting that this type of talent has not evolved over time, but has existed in human cognition for over 30,000 years. There is evidence of talent when a pathological deficit is accompanied by a high IQ: creative talent in the mentally ill (Jamison, 1995), superior declarative or episodic memory and perfect pitch in high-functioning autism (Bonnel et al., 2003), and proposed divergent thinking abilities in attention-deficit hyperactivity disorder (ADHD) (Kaufman et al., 2000). This may provide a potential domain-specific cognitive benefit or prophylaxis when it coexists in an individual with a learning disability or attention disorder (Kaufman, et al., 2000; Winner et al., 2001; Chae et al., 2003), or it may create a hindrance due to increased susceptibility to emotional adjustment and behavioral problems (Shaywitz et al., 2001; Winner, 2001). Whatever the neural basis, the end result is a specific intellectual or creative cognitive fluency that supports a focal talent.

Another provocative question raised by the existence of savants is why the domains of music and mathematics are particularly accessible to them.

What do the developing populations of gifted children, prodigies, and savants have the potential to tell us about the neural nature of expertise? They provide natural examples of specific kinds of expertise. As we begin to understand more about the normally developing brain, these are populations outside of the norm that provide juxtaposition for certain kinds of function. In addition to the pattern of early recruitment of brain areas normally reserved for adult function, it is important to ask what is special about the function of those areas. If we agree that there is a central circuitry that predetermines a certain level of cognitive function, we can document where function is happening. Knowing this, the next important question is how this function occurs.

### TALENT AND PLASTICITY

Research on plasticity, the brain's ability to respond to environmental influence and individual experience, has focused on changes at the levels of the synapse and individual neuron, with theories articulating the relationship between environmental input and cellular response (Greenough et al., 1987; Quartz and Sejnowski, 1997). Anatomical studies of cell assemblies nested in brain regions involved in sensation and cognition may reveal signs of endogenous enrichment or atypical development that influence their anatomical organization and functional algorithm (Elston, 2000; Passingham et al., 2002; Dityatev and Schachner, 2003). Some argue, however, that current definitions of plasticity do not account for the range of response the brain has to experience (Grossman et al., 2002). The perceptual phenomenon synesthesia is an example of an endogenous form of perception and plasticity that is not fully understood (Mattingley et al., 2001). Synesthesia, the ability to see specific shapes and sounds in certain colors, is proposedly the result of cross-wiring between the "color center" (area V4 or V8) and the "number area," both located in the fusiform gyrus. It has been reported that synesthesia has a higher incidence among artists and poets (Ramachandran and Hubbard, 2001).

In contrast, learning is a form of plasticity that is better understood. In general, learning is the interaction between natural factors and environmental support and opportunity. It is an associative process dependent upon multiple forms of memory and the functional connectivity of systems in the brain. When these factors interact in a way that allow an individual to perform at an extraordinary level. we observe talent. Cognitive neuroscientific data on the brains of expert musicians and mathematicians provides an example of domain-specific expertise. Changes in the brains of expert musicians attest to the changes in the brain that occur from practice and

development. A review on the characteristics of the brains of expert musicians by Munte et al. (2002) summarizes three functional differences in expert musicians when compared with nonmusicians. First, cortical representations of digits on the left hand (used for fingering a stringed instrument) are greater in musicians who started training at an early age. Second, expert musicians elicit mismatched negativity (MMN) at faster rates than nonmusicians and in listening to harmonic subtleties not detected by an untrained ear. The MMN is a frontal negative wave in the eventrelated potential (ERP) that indicates preattentive nonvolitional detection of changes and arises from the supratemporal plain of the temporal lobe along with connections from the frontal cortex. Third, the N1, another component of the ERP arising from primary auditory cortex, is enhanced in musicians in response to consonant versus dissonant chords.

Further, the structure and size of the planum temporale, the anterior corpus callosum, and the cerebellum differ in expert musicians. Specifically, a larger left planum temporale correlates with perfect pitch regardless of handedness. The size of the anterior midsagittal corpus callosum increases the earlier the age musical training began, distinguishing those who began their training prior to age 7. Its size is a good indicator of the number of axons that cross the midline, indicating enhanced interhemispheric communication.

The execution of music requires precision of movement and male musicians have been found to have greater mean-relative cerebellar volume than male nonmusicians. A voxel-based morphometry analysis method revealed increased gray matter volume in bilateral sensorimotor regions, left basal ganglia, bilateral cerebellum, and the left posterior perisylvian region (Ashburner and Friston, 2002). Since these studies have been completed in adults, it remains unclear whether these areas are different due to practice or innate talent, although the MMN measure is of particular interest within the context of the neural speed theory and the fact that it is measured at a prefrontal connection.

The structural and functional differences in temporal, parietal, and frontal cortical areas may reflect the influence of genetics as a basis for individual musical talent. Changes in connectivity may involve the striatum, making it a structure that has greater plastic capability responding to learning and to practice. Genetics have not been shown to influence the striatum to the degree that it appears to affect temporal and frontal structures of the brain. Thus, the involvement of the striatum in these neural circuitries juxtaposes the potential of endowed capability with experience-based connectivity.

Another nonverbal domain similar to instrumental music in its spatial structure and nonverbal lexicon, but different in its neural circuitry, is mathematical cognition. Findings from one experiment debunk the conclusion that mathematics is solely a left-lateralized activity (Rickard et al., 2000). A simple arithmetic condition

One way of looking at creativity within the paradigm of talent is to reexamine the juxtaposition between the function of the brain during waking hours versus sleep.

(e.g.,  $5 \times 6 = 30$ ) showed significant bilateral activations across all eight subjects in Brodmann's area (BA) 44, DLPFC, inferior and superior parietal areas, lingual gyri, and fusiform gyri. There were stronger left activations in BA 44 and parietal cortices. In contrast, magnitude judgment condition (e.g., which is larger, 24 or 27?) showed activation of the bilateral inferior parietal cortex in five of eight subjects. The authors suggest that the role of this area is to represent abstract magnitude information utilized in this task and potentially in the arithmetic task to compensate for weaker rote memory. This study was performed with adults. Remember that children ages 8-12 with high IQs

tested with EEG while solving mathematical word problems also showed bilateral activations and increased alpha activity as compared with their average-ability peers who showed left hemisphere activations during problem-solving (Alexander et al., 1996). The study did not specify the spatial localization of the bilateral signal, but this provides support for the idea that high-ability children access adult-like neural circuits at earlier-than-expected ages.

Studies of a calculating prodigy named Rudiger Gamm provide specific evidence for the prodigious profile of the calculating brain. One PET study of his abilities revealed that he used different brain areas than nonexperts to solve calculations (Pesenti et al., 2001). Specifically, they found that he could switch between short-term storage strategies and goal-directed processes and highly efficient episodic memory encoding and retrieval, processes supported by right prefrontal and medial temporal areas. Another PET study expanded these findings, reporting activations in the right medial frontal and parahippocampal gyri in correlation with episodic memory processes (Houde and Tzourio-Mazoyer, 2003). The authors suggest that experts may have a strategy for utilizing long-term memory capacity in order to retain task-specific information required to solve complex problems and to support working memory. It is unknown whether this functional anatomy is specific to mathematical ability or domain general. Insight into this question may come from future studies on the functional anatomies of other domains such as chess and reading. One of the bases for identifying gifted children or a hallmark for early potential is that a child learned to read at a very early age. Developmental cognitive neuroscience is poised to document the functional anatomy of reading expertise within the context of developmental studies of reading and dyslexia (Turkeltaub et al., 2002). There are several memory theories about the basis of chess expertise based on mnemonic chunking, visual imagery, or spatial skills, but cognitive neuroscience has yet to establish their neural basis (DeGroot, 1965; Schneider et al., 1993; Gobet and Simon, 1998; Waters et al., 2002). Cre-



Stimulus Inputs

Figure 5. Functional and anatomical relationship between declarative and nondeclarative memory systems (Gluck and Myers, 1998).

ative production is yet another domain to consider in the functional anatomy of talent.

# COGNITION, CREATIVITY, AND TALENT

The human capacity for creativity, insight, and innovation demonstrates the dynamic complexity of the brain (Singer, 1995). The creative process signals the system's ability to add a layer of fresh structure to a skill or endeavor. Creativity is a novel response to a problem or a need, or a transformation of the known to fit the novel. But what are the optimal ways to examine neurobiologically the notions of complexity, insight, and novel performance associated with creative output? One way of looking at creativity within the paradigm of talent is to reexamine the juxtaposition between the function of the brain during waking hours versus sleep. In part, creativity is the result of processes that take place in the making and storage of memory (Feldman, 1988). Specifically, nondeclarative memory houses all capacities for skill building, language priming, behavioral conditioning, and consolidated information (White, 1997; Gluck and Meyers, 1998). Figure 5 shows the transformation of information as it enters the brain, is stored in declarative memory and then some processed into implicit stores, making information available for insight problem-solving, and creative production (Gluck and Myers, 1998). Allers et al. (2002) provide electrophysiological evidence for functional connectivity between the hippocampus and the neocortex by correlating theta activity in the hippocampus and the rate of firing oscillations in the globus pallidus of the basal ganglia.

Consolidation is believed to be facilitated by these circuits in two ways: first, on the conscious level when someone engages in the repetition of a movement or a piece of knowledge (Murre, 1996), and second, on the nonconscious level during sleep (Crick and Mitchison, 1983; Buzsaki, 1989; Alvarez and Squire, 1994; Karni et al., 1994), when the body, isolated and at rest from external stimuli, permits the brain to process information more quickly. This phenomenontemporal compression—occurs in the hippocampus during slow-wave sleep (Shen and McNaughton, 1996; August and Levy, 1999). Additional evidence for the contributions of consolidation processes to creativity are suggested by studies that illustrate that brain regions serve different functions during sleep stages (Figure 6). During rapid eye movement sleep, the basal ganglia, hippocampus, and motivationreward systems in limbic areas of the brain interact independently of orbitofrontal and dorsolateral prefrontal regions that facilitate function in these areas during waking moments (Hobson et al., 2000). This seems plausible in light of evidence that many individuals attribute inspirations for their theories, models, and creative products to dreams (Feldman, 1988). The author is not assuming that cognitive processing during sleep guarantees creativity, but anecdotal evidence has suggested it is a rich time for information to be combined in myriad ways. If one considers the argument that temporal binding (John et al., 1997; Engel et al.,

1999; Newman and Grace, 1999) facilitates consciousness and one might even argue the potential awake cognitive state associated with creative production, called flow (Csikszentmihalvi and Csikszentmihalyi, 1988), while temporal compression assists cognition during sleep, one has a way of thinking about continuous cognitive processing that makes room for not only the ideas of intellect and creativity but talent as well. One ERP study reported that more working memory is required to perform analytical tasks versus creative tasks (Lavric et al., 2000). Principles of cognitive binding and cross-modal interactive processing in the brain may eventually lead us to a greater understanding of individual differences in the fluency and speed of cognitive performance in areas of general or specific talent (Treisman, 1996; Fuster et al., 2000; Bushara et al., 2003; Laurienti et al., 2003). Cognition is not only subject to perceptual facilitation and conscious direction, but also to more autonomic-like processing that occurs during sleep. It is through these mechanisms that various neural systems converge disparate sensory information into coherent awareness and cognition, leading to performance and production.

### SKETCHING NEURAL ARCHITECTURES OF TALENT

The book How People Learn: Brain, Mind, Experience, and School (Bransford et al., 1999) lists six key characteristics of experts: experts notice features and meaningful patterns of information that are not noticed by novices; experts have a depth of content knowledge organized in ways that reflect a deep understanding of the domain; expert knowledge reflects applicability and cannot be reduced to isolated sets of facts; experts are able to retrieve important aspects of their knowledge flexibly, with little attentional effort; experts may know their domain thoroughly but still be unable to teach others; and experts have varying levels of flexibility in their approach to new situations. These principles illustrate that the expert mind has a way of centrally organizing and easily retrieving relevant skill and content knowledge. This review has

### FOREBRAIN PROCESSES IN NORMAL DREAMING - INTEGRATED MODEL



Figure 6. Forebrain processes during normal dreaming (Hobson et al., 2000). Regions of the brain facilitating physiological homeostasis, perception, cognition, and action during waking hours take on different roles during sleep. This type of plasticity may contribute to cognition which supports creativity and problem solving.

attempted to sketch the neural land-scapes that make this possible.

In the case of general reasoning related to the concept of g, a circuitry involving connections between the PFC, striatum, and the cerebellum appear to engage regardless of the domain specificity of the task. Particularly, the striatum appears to play a large role in how the brain responds to experience. Areas under heritable influence watermark brain function at a certain level of individual capacity, which is perhaps why we see differences in the functional neuroanatomy of high-ability children. In music, the temporal lobes and primary sensory and auditory motor cortices are involved as well as the corpus callosum. In mathematics, the DLPFC, parietal areas, and lingual and fusiform gyri appear to facilitate performance. Special circumstances of expertise that exist in prodigies and savants offer an opportunity to explore the basis of certain types of talent and ability without the ambiguity created when we study adults with lesions. Children with high IQs offer the opportunity to explore the relationship between cognition and emotion in a dissociation that is natural and common in this population. Of course, the trade-off is a markedly shifting physiological baseline, changing as children mature. Once a normed atlas can be formed based on developmental data acquired with diffusion tensor imaging, the way will be paved to explore the profiles of special populations of children with more certainty.

Matrices tests appear to be useful tools for more fairly assessing core natural cognitive ability. The cognitive neuroscience literature documenting performance on Raven's Progressive Matrices and other tasks of conceptual reasoning and problemsolving is based on findings from studies with adults (Prabhakaran et al., 1997; Christoff et al., 2001; Kroger et al., 2002). The limited findings from the developmental literature suggest an opportunity for investigating the neural bases of optimal performance on perceptual and cognitive levels. Studies that characterize reasoning ability utilizing this paradigm in the developing brain are still needed and could add important functional knowledge to complement findings about developmental trajectories of the prefrontal cortices throughout late childhood and adolescence.

Mechanisms of temporal and cognitive binding and cross-modal interaction may later explain individual differences associated with talent or disability as a way of understanding the physiology underneath functional areas of activation detected in imaging studies. Neurochemical support for the structural and functional architectures suggested here is the neurotransmitter dopamine. It fuels the reward region, the nucleus accumbens, and the direct and indirect striatal pathways of the basal ganglia that are implicated in aspects of neural circuitries previously discussed. It is modulated by experiments that manipulate reward and motivation (White, 1989; Ullsperger and von Cramon, 2003), as well as implicit memory (White, 1997; Braver and Barch, 2002) and reasoning (Cools et al., 2002). In addition, it provides neuromodulatory assistance in cognitive and emotional contexts (Hariri et al., 2002; Mattay et al., 2003). The neural

basis of these abilities is a convergence of goal-directed and nonvolitional cognitive processes.

The goal of this review was to synthesize findings from across psychology, gifted education, and neuroscience to present a contemporary view of talent, the optimal and productive use of either or both of one's high level of general intelligence or domain-specific ability. As such, it is a concept that supercedes separate literatures on the nature of intelligence and creativity to suggest a more neurobiologically elegant way of thinking about optimal performance. With growing technological and methodological advances in the neurosciences, various fields working interdependently are poised to answer some of nature's most complex and compelling questions regarding human cognition and its remarkable consequences.

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