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Shatz, M. (1977). On the development of communicative understandings: An early strategy for interpreting and responding to messages. In J. Glick & A. Clarke-Stewart (Eds.), *Studies in social and communicative development* (pp. 24–65). New York: Gardner.

Tomasello, M., & Farrar, J. (1986). Joint attention and early language. *Child Development, 57,* 1454–1463.

Volpe, J. J. (1981). Neonatal intraventricular hemorrhage. *New England Journal of Medicine, 304,* 886–891.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Welsch, M. C., & Pennington, B. F. (1988). Assessing frontal lobe functioning in children: Views from developmental psychology. *Developmental Neuropsychology, 4*(3), 199–230.

Wertsch, J. V. (1979). From social interaction to higher psychological processes. *Human Development, 22,* 1–22.

CHAPTER FIVE

Individual Differences in the Development of Executive Function in Children: Lessons From the Delayed Response and A-not-B Tasks

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An explosion of research activity in the area of attention, memory, and executive function has been noted since the mid-1980s (Lyon & Krasnegor, 1996). The bulk of this activity, however, has focused on the examination of group differences in executive skills, with less attention devoted to the manner by which individual children differ in executive skills from their peers. This chapter explores individual differences from a developmental perspective, that is, by returning to the emergence of basic executive functions and tracing the subsequent manifestations by examining the individual patterns of change. Therefore, it first reviews the history of executive function through critical case study descriptions and then discusses the current conceptualizations of executive functions. Traditional frameworks for understanding individual differences are described with emphasis on quasi-experimental designs commonly used in developmental neuropsychology. Finally, investigations concerning the performance of infants and young children on a particular executive function paradigm are reviewed because, according to the position herein, executive behavior is readily observable early in development.

WHERE DID THE CONCEPT OF EXECUTIVE FUNCTIONS DEVELOP? A CASE STUDY REVIEW

Historically, case study has been a useful approach to investigate individual differences in adult and child populations. The strength of this approach lies in its sensitivity to individual variation and its breadth of qualitative descriptions. Many authors identify the unique clinical presentation of Phineas Gage, an otherwise unremarkable railroad worker, as the dawning of modern interest in the brain–behavior relations associated with executive functions (Harlow, 1848, 1868). Gage made history when an accidental explosion sent a large tamping iron traversing through his left frontal lobe, causing focal, yet extensive damage. Harlow's behavioral observations are the only record of the psychological changes characterized by reduced inhibition and altered personality:

> The equilibrium or balance, so to speak, between his intellectual faculties and his animal propensities, seems to have been destroyed. He is fitful, irreverent, indulging at times in the grossest profanity (which was not previously his custom), manifesting but little deference for his fellows, impatient of restraint or advice when it conflicts with his desires, at times pertinaciously obstinate, yet capricious and vacillating, devising many plans for future operations, which are no sooner arranged than they are abandoned in turn for others appearing more feasible. (Harlow, 1868, p. 344).

Soon after the injury, Harlow (1848) concluded that Gage's memory was unimpaired. However, extended observations noted that Gage would entertain his nieces and nephews with fabulous stories of "his wonderful feats and hairbreadth escapes, without any foundation except in his fancy" (Harlow, 1868, p. 334).

Using a formal, psychometric approach, Eslinger and Damasio (1985) investigated patient EVR, whose orbital frontal surface and the frontal pole were excised bilaterally, due to a large orbitofrontal meningioma. Traditional neuropsychological batteries, which included measures of executive functions, such as the Wisconsin Card Sorting Test (WCST; Heaton, 1981), demonstrated little, if any, evidence of disturbed higher cortical functions following recovery from surgery. Protocols from repeated follow-up examinations are noteworthy in that EVR's performance was strategic, sophisticated, and almost flawless. However, information provided by family members, along with observations of EVR's decision making in everyday life, clearly demonstrated a significant disability associated with his frontal lobe tumor and excision, which A. R. Damasio, Tranel, and H. Damasio (1990) labeled acquired sociopathy.

In children, the investigation of executive skills has a much shorter history. Until the 1980s, many neuropsychologists believed that executive skills did not "turn on" or become functional until puberty (Golden, 1981). However, recent studies with various methods and measurement tools have demonstrated repeatedly that children possess executive functions (Chelune & Baer, 1986; Levin et al., 1991; Welsh, Pennington, & Groisser, 1991). In addition, lesions to the prefrontal cortex early in life may be less likely to mimic impairments observed acutely following prefrontal lesions in adulthood (Eslinger, Biddle, & Grattan, 1997). This

observation is not surprising, considering that the children's behavior and intact central nervous systems differ from those of adults. It is well established that brain–behavior relations from adult neuropsychology do not generalize well to children (Fletcher & Taylor, 1984).

Eslinger and colleagues (1997) reviewed several cases of early prefrontal cortex lesions in children, including JC. JC, a 7-year-old right-handed boy, had an unremarkable medical, developmental, and early academic history when he suddenly developed severe headache, vomiting, seizures, and subsequent loss of consciousness. He underwent emergency surgery, resulting in right middle frontal gyrus topectomy and excision of an arteriovenous malformation located just superior and lateral to the head of the caudate (see Eslinger et al., 1997, for specific MRI localization). Neuropsychological evaluation 6 months after surgery revealed specific dissociations in cognitive, memory, and executive functions similar to that observed in Gage and EVR. Unlike these cases, JC's damage was localized to right frontal cortex, therefore, specific difficulties in spatial planning, sequencing, constructional praxis, and monitoring during multistep tasks were prominent, in addition to a classic "adult-like" left hemi-spatial neglect. Measured intelligence was in the High Average Range and consistent with premorbid expectations (Wechsler Intelligence Scale for Children–Revised, WISC–R Full Scale IQ = 111; VIQ = 113, PIQ = 106). Patterns of distracted, impulsive, and disinhibited behavior, with tangential speech, were noted. One of the more idiosyncratic behaviors displayed by JC was an obsessive propensity to sniff everything.

Follow-up neuropsychological evaluation of JC, 4 years after surgery, revealed greatly diminished—yet residual evidence of—spatial planning and spatial attention deficits. Interestingly, these mild persisting deficits were not apparent when external organizational strategies were provided. Performance on an executive function battery indicated executive function impairments on many measures, but noteworthy exceptions included age-appropriate performance on the WCST and the Tower of Hanoi (TOH; Simon, 1975). Socially, JC denied any behavioral problems and commented "I'm nice. I'm a good friend, I'm nice to other people." However, reports from his parents and teachers revealed persisting difficulties with concentration, restlessness, and carelessness in his work. Social problems and aggressive behavior were noted, with JC showing poor appreciation or compliance with age-appropriate nuance and finesse in social situations. His parents reported that, "JC doesn't seem to understand a lot of the dynamics of his peer groups. He takes things very literally and personally," but described him as a happy, loving boy, who was sociable, outgoing, and responsive to his family life (Eslinger et al., 1997).

These cases share several commonalties. First, general intellectual and other neuropsychological functions, such as language, sensory abilities, and visuospatial skills were not impaired. In contrast, deficits in inhibition, maintaining information over time, judgment, planning, and social skills were prominent. Furthermore, performance on tasks considered to "measure" executive and frontal lobe function was in the normal range. Comparing the findings from these cases suggests that the nature of executive processes may be elusive (i.e., not easily captured or quantified), at least on traditional psychometric measures.

WHAT ARE EXECUTIVE FUNCTIONS? A CONSTRUCT REVIEW

The study of executive function in children is comprised of a patchwork of tasks and in various populations, with some investigations focusing on neuropathological correlates and others on cognitive or behavioral interrelations (Pennington, 1997). Many of the tasks purported to measure executive function have been linked speculatively to frontal lobe function without direct measurement of the brain. Pennington labeled this inferred brain–behavior relation as the "frontal metaphor." He noted the indiscriminant use of this metaphor to explain a wide range of normal developmental phenomena and clinical presentations. The power of the frontal metaphor is in the application of neuroscience to integrate an understanding of normal developmental progression, developmental disabilities, and outcome following acquired frontal lobe lesions. The unique patterns of behavioral disturbance associated with frontal lobe lesions in both adults and children markedly reduce daily living skills and are frequently the source of distress to patient's family members seeking clinical services. However, discussions of global psychological constructs, like executive functions, rapidly deteriorate into vague analogies without the elucidation of component processes and corresponding operational definitions.

There is no universally accepted operational definition of executive functions. Luria (1973) originally proposed a "functional brain unit for programming, regulation, and verification of activity," in which "man not only reacts passively to incoming information but creates intentions, forms plans and programs of his actions, inspects their performance, regulates his behavior so that it conforms to these plans and programs, finally he verifies his conscious activity comparing the effects of his actions with the original intentions and correcting any mistakes that he has made" (pp. 79–80). More recently, theorists from different traditions have emphasized diverse aspects of cognition in order to define executive functions (Eslinger, 1996). For example, in Lyon and Krasnegor (1996), Borkowski and Burke (1996) took an information-processing approach, emphasizing

that executive functions are comprised of three main components: task analysis, strategy control, and strategy monitoring. Pennington, Bennetto, McAleer, and Roberts (1996) focused on planning, maintaining such plans online, and inhibiting other actions in order to problem solve to achieve a future goal. Executive functions have been defined behaviorally by Hayes, Gifford, and Ruckstahl (1996) to include the complex control of stimuli, responses, and derived properties in a given context. In contrast, Graham and Harris (1996) focused on the self-regulatory strategies, including metacognition, goal-setting, monitoring, strategy deployment, and action plans. Barkley (1996) proposed that executive functions overlap heavily with attention mechanisms. He identified four criteria that must be present for a given behavior to be "executive": behavior–behavior response chains, relation to the probability of a subsequent response, a delay between events and actions, and finally, inhibition of other responses.

All of these cognitive theories included at least semi-independent component processes of executive skills. The validity of these processes has been investigated either by manipulating task demands or by examining patterns of associations among various tasks (Embretson, 1983). Problems arise because neuropsychologists, both in clinical practice and research investigations, interpret patterns of task performance on the basis of face validity, where isolated deficits represent distinct component process impairments (Taylor, 1996). In fact, the underlying measurement characteristics of many executive function tasks have not been well studied and may not reflect distinct cognitive phenomena. Pennington (1997) identified at least three dimensions of executive functions with demonstrated validity in normal and clinical populations: verbal working memory, cognitive flexibility or set-shifting, and motor inhibition. Somewhat different components (i.e., fluid/speeded response, hypothesis testing/impulse control, and planning) have been reported in normal school-age children (Welsh et al., 1991). Moreover, Levin and associates (1991) found that three underlying factors best described executive task performance: semantic association/concept formation, freedom from perseveration, and planning strategy.

Executive function tasks, therefore, may not map onto component constructs in a one-to-one, linear manner. Executive functions, by the very nature of any definition, involve higher order, integrative control-type skills where the translation of the definition into measurement tools is somewhat more difficult than with a more discrete skill (e.g., language). These definitional issues render the study of individual differences in executive skill in children difficult. However, there are other measurement issues from the broader individual differences literature that also affect the study of such differences in executive functions in children.

WHAT ARE INDIVIDUAL DIFFERENCES? MEASUREMENT AND RELEVANCE

Differences among individual children have become increasingly important in neuropsychological research. Clinicians predict neuropsychological outcome, educational progress, and/or therapeutic needs of an individual, not of a diaphanous average of a group. Research studies focusing on the average of a group process provide a rich base and may illuminate fruitful subsequent directions for investigation. These relatively crude prognostications, however, may be of little comfort to parents who are seeking a better understanding of their child's problems and/or assistance in remediating these problems.

Individual differences traditionally have been conceptualized as factors that cause an individual to deviate from the "average" or mean group performance (Keppel, 1982). In randomized experimental designs, the degree to which an individual varies from the expected group mean is considered error variance. The goal in this type of investigation is to minimize error variance, that is, to reduce differences among individuals in order to maximize the hypothesized group effect. In practice, at least in quasi-experimental, clinical neuropsychological research, whether the hypothesized effect concerns a "group" or an "individual" is somewhat arbitrary. For example, the presence of a medical condition, such as traumatic brain injury, influences the manner by which an individual child deviates from expectations of normally developing peers. Children who have sustained traumatic brain injury also can be grouped according to injury severity in order to determine the risk for cognitive sequelae (Fletcher & Levin, 1988). Moreover, within severely brain injured children, those with pupillary abnormalities exhibit greater developmental differences in visuomotor skill relative to those without such eye findings (Francis, Fletcher, Steubing, Davidson, & Thompson, 1991). Which level or dimension represents the "individual difference": presence of brain injury, brain injury severity, or pupillary abnormality? This example illustrates that individual differences in almost any outcome can be demonstrated depending on the manner and/or level at which the independent variable is conceptualized.

The conceptualization of many neuropsychological phenomena has been driven by the reliance on medical, disease-based models of clinical phenomena in children. For example, dyslexia is the term often used in medical settings to describe children who are poor readers (Menkes, 1985). Dyslexia historically has been defined as "specific"—that is, as a discrete, biologically uniform category of children who presumably differ from children who read poorly for nonspecific, but "explainable" reasons, such as low intelligence (Rutter & Yule, 1975). This conceptualization is disease based, as it is thought to be present or absent in a manner such as infection (e.g., World Federation of Neurology definition; Critchley, 1970). More modern conceptualizations view poor readers as comprising the natural tail end of the normal distribution of reading skills (S. E. Shaywitz, Escobar, B. A. Shaywitz, Fletcher, & Makuch, 1992). In fact, other medical "disease" states also may represent a continuum of neuropathology and associated cognitive sequelae, for example, the degree of white matter damage is related linearly with cognitive outcome children with hydrocephalus (Fletcher et al., 1992).

Readily accessible, relatively simple, traditional statistics, such as *t* test and analysis of variance (ANOVA), also have promulgated discrete, group-based designs that focus on average performance differences between groups. The researcher may be compelled to form "artificial" groups in order to conduct these analyses. The problem is not in the statistics, in that the artificial grouping may not reflect the phenomena under study. In fact, many independent variables in neuropsychological research are continuously distributed and therefore are amenable to designs that relate individual differences in the independent variable to differences in outcome. Multiple regression is one such design that utilizes the inherent variability in both the independent and dependent measures. There are many naturally occurring grouping variables in quasi-experimental research, which when considered in more detail can be analyzed as a continuum.

When a child's neuropsychological development is considered in a longitudinal context, individual variability occurs at many levels. Individuals may differ in the age of onset of the emergence of skill development, the rate of development, the level of proficiency at any given age, and the shape of the trajectory of skill acquisition. When taken together, these individual differences yield various developmental patterns (Satz, Fletcher, Clark, & Morris, 1981). It is only recently with the advent of flexible and relatively accessible hierarchical or multilevel modeling techniques (Bryk & Raudenbush, 1992; Goldstein, 1995) that these individual differences in the patterns of skill development can be studied (e.g., Espy, Riese, & Francis, 1997; Francis, S. E. Shaywitz, Stuebing, B. A. Shaywitz, & Fletcher, 1996). Furthermore, these techniques can be used to investigate individual differences, which are nondevelopmental, but that also are nested at several levels (e.g., individual children in various classrooms within different schools).

Presumably, it is these individual differences in development that comprise important variability in outcome. Fletcher (1997) proposed that the fundamental structure–function relations and the mechanisms for individual variability differ. Individual variability, then, may result from phenomena not related to a given structure–function relation, but nevertheless are important in predicting outcome. For example, the relation of injury severity in traumatically brain injured children and outcome is well known

(Fletcher & Levin, 1988). The diffuse axonal injury due to shear strains and tearing of subcortical white matter tracts from impact (Strich, 1970) is associated with reduced information processing and impaired motor speed (Kaufmann, Fletcher, Levin, Miner, & Ewing-Cobbs, 1993; Levin et al., 1994; Yeates, Blumenstein, Patterson, & Delis, 1995). However, variability in outcome, such as school performance, is not a direct function of injury severity (Taylor & Schatschneider, 1992). Despite comparable injury severity, children with larger frontal lesions/contusions demonstrate greater problems on tasks involving judgment and planning (Levin et al., 1994). These differences in executive function performance may be important markers of poorer functional outcome at school and/or work in these children, but are not a direct consequence of the diffuse axonal injury to white matter.

Alternatively, there may be observed performance differences among individuals that actually do not result from differences in underlying psychological skill. For example, when performance variability on a given instrument changes with age, it may be inferred that as children mature, individual differences in performance become more prominent. Children may differ in the rate of skill development, which over time increases variability in the level of performance when measured at the chosen endpoint age. However, differential variability at different ages also may signify that the instrument does not adequately measure the underlying construct at all ages (Hertzog, 1985). Therefore, it is critical to thoroughly understand the underlying neuropsychological phenomena and the pertinent developmental manifestations prior to examining how and why individual children vary.

HOW MAY EXECUTIVE FUNCTIONS BE CHARACTERIZED IN INDIVIDUALS? DELAYED RESPONSE AND A-NOT-B TASKS

Given the unresolved issues of measurement and construct definition already discussed, one approach to disentangle some of the complexity in the study of executive functions in children is to trace the ontogeny "backward," that is, to return to the early emergence of these skills in infancy. At this point in development, executive skills presumably are less differentiated, less sophisticated, and more able to be mapped onto meaningful cognitive components. Once the origin of executive skills is better understood, the manner in which these executive functions subsequently differentiate in development can be investigated more fruitfully. It is our hope, then, that a review of studies of executive functions in infancy may shed light on the manifestation of the more complex executive skills later in

childhood. This review is limited to studies of individual differences on one particular executive function paradigm, the delayed response (DR) and the variant, A-not-B (AB) tasks. This paradigm was chosen because of its parallel roots in both the developmental neuroscience and cognitive literature bases. DR and AB have been used to investigate the relation between brain–behavior relations in animals (Goldman-Rakic, 1987) and, more recently, in infants and young children (Diamond, 1985; Espy, Kaufmann, & Glisky, 1999; Kaufmann, Leckman, & Ort, 1989; Wellman, Cross, & Bartsch, 1986). Table 5.1 contains a summary of the studies reviewed below.

In the classic DR task, a well is baited with a reward while the subject watches. A delay is imposed and then the subject searches for the reward. The side of hiding is switched randomly across trials. In order to maximize reward, the subject must remember where the reward was hidden on this trial and not search at the location that was rewarded on the previous trial. For AB, the infant observes a reward hidden at a location (A). The infant then retrieves the reward at location A for several trials. The reward is switched then to the alternative location (B). Between 8 and 12 months of age, the infant continues to search for the reward at location A, despite direct observation of the hiding of the reward at location B (the AB error). However, by 12 months of age, the infant searches at correct location B, regardless of where the reward was hidden on the previous trial (Piaget, 1954).

Diamond and Goldman-Rakic (1989) argued that AB and DR depend on "working memory" and on the inhibition of a prepotent response. Working memory has been defined as "the process by which symbolic representations are accessed and held on-line to guide a response" (Goldman-Rakic, 1987, p. 604). The AB error results when the location of the reward at the observed location B is not maintained across the temporal gap (Fuster, 1985). The imposition of a delay appears to be critical in order to activate working memory (Goldman-Rakic, 1987; Gratch, Appel, Evans, LeCompte, & Wright, 1974; Harris, 1973). If there is not a temporal interval between hiding and retrieval during which the representation must be held "online," neither infants nor monkeys with prefrontal lesions err (Diamond, 1985; Goldman & Rosvold, 1970). The infant, then, must rely on associative memory to find the reward, and therefore, searches at location A.

Differences in AB performance among individuals can be categorized in several ways. Because this chapter focuses on infants and children, one major source of individual differences in performance is that related to development, often operationalized as age effects. Howe (1994) proposed that individual differences could be construed also as those occurring between individuals (interindividual) and within individuals (intraindi-

TABLE 5.1
Studies Using AB or DR to Investigate Executive Functions in Infants

Study	Subjects	Design	Task	Delay	Results
Baillargeon & Graber (1988)	24 infants 7 & 8 months	Looking Time	Possible/ Impossible Paired 2 Location Discrimination	15 sec	8 months infants looked longer at impossible location 7 months infants looked at each location equally 8 months only looked at impossible location after hand appeared to retrieve object
Baillargeon, DeVos, & Graber (1989)	24 infants 7 & 8 months	Looking Time	Paired 2 Location Discrimination	30 sec 70 sec	Infants looked longer at impossible location Infants looked longer at first location
Baillargeon, Graber, DeVos, & Black (1990)	32 infants 5 months	Looking Time	Paired Means-End Discrimination (from vs. under vs. behind)	13 sec 17 sec	Infants looked longer at impossible location Infants looked less reliably at later conditions
Bell & Fox (1992)	13 infants (7–12 months) 36 infants 7, 8, 9, 10, 11, & 12 months	Longitudinal & Cross-sectional	AB Object Retrieval Response Inhibition Resting EEG	Incremental	AB delay increased with age Wide variability in delay—Long group $M = 13$ sec Short group $M = 3$ sec (at 12 months) Long group had decreased right frontal power at 7–8 months, increased left frontal coherence between 10 & 12 months Only short group showed decrease in right frontal power between 10 & 11 months Infants who passed AB early had greater power at 8 months at right frontal lead
Diamond (1985)	25 infants (approximately 6½–12 months)	Longitudinal	AB	Incremental	AB delay increased by 2 sec for each month of age Best performance on repeat following correct trials No differences on reversal following correct or reversal following error trials Girls outperformed boys in AB emergence 10-sec delay at 12 months; 2-sec delay at 7½ months No evidence of side preference
Diamond & Doar (1989)	12 infants (6–12 months) 36 infants 8, 10, & 12 months	Longitudinal & Cross-sectional	DR	Incremental	DR performance = AB (Diamond, 1985) Girls outperformed boys in DR emergence Best performance on repeat following correct trials No differences on reversal following error and reversal following correct trials Cross-sectional data pattern was similar, but wider individual variability (e.g., only 50% of 12 months passed 8-sec delay) No evidence of side preference
Espy, Kaufmann, & Glisky (1999)	17 cocaine-exposed 17 normal control toddlers (17–21 months)	Cross-sectional	AB Self-control	10 sec	Cocaine-exposed toddlers made more perseverative errors, perseverated on more trials, and achieved fewer sets than nonexposed toddlers Only set difference was related to cognitive skills
Espy, Kaufmann, McDiarmid, & Glisky (1999)	117 preschool children (23–66 months)	Cross-sectional	AB Self-control Delayed Alternation Spatial & Color Reversal	10 sec	AB performance improved with age Individual variability observed Older children had less performance variability

(Continued)

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TABLE 5.1
(Continued)

Study	Subjects	Design	Task	Delay	Results
Hostadter & Reznick (1996)	24 7 months 48 9 months 48 11 months 12 5 months	Cross-sectional Reach vs. Gaze	DR	3 sec	Gaze more likely to be correct than reach 7 months—significant percentage of AB errors Perseverative reach were more common than gaze Perseverations decreased with age Infants perseverated more following a correct rather than an incorrect response Perseverations were more likely on incorrect reach Reaching was more laterally perseverative to left 5 months—identified location with gaze Significant tendency to err on repeat correct trials
Matthews, Ellis, & Nelson (1996)	10 preterm 10 full term 28–60 weeks (corrected age)	Longitudinal Reach vs. Gaze	AB Object Retrieval Means–End	Incremental	Longer delays in reach for preterms No effect of term on gaze 2-sec difference between reach and gaze conditions OR performance improved with age, no term effect Low error rates on Means–End, no term effect
McEvoy, Rogers, & Pennington (1993)	17 autistic children 13 developmentally delayed children 16 normal control (10–80 months)	Matched Cross-sectional	AB DR	None 6 sec	No group differences on AB or DR Ceiling effects on AB
Ross, Tesman, Auld, & Nass (1992)	30 preterm infants with hemorrhage 30 preterm infants without hemorrhage 30 full-term infants (10 months)	Cross-sectional	AB	Incremental	AB errors differed by term birth status No differences among preterm infants 60% of premature infants were unable to find the reward on two out of three reversal trials; only 13% of full-term infants demonstrated this pattern

Note: Please see Wellman, Cross, and Bartsch (1986) for a complete listing of studies using the traditional Piagetian AB format (with few B trials).

vidual). It is this framework that will be used in order to review the pertinent findings regarding individual differences in AB performance.

Developmental Differences

Diamond (1985) found large individual differences in the delay at which AB error was demonstrated. Infants demonstrated the AB error at delays that increased by two additional seconds per month of age, on average. However, at 8 months of age, infants exhibited the AB error at delays ranging from 0 to 8 seconds, where at 12 months of age the range of delays were from 5 to 12 seconds. When this variability is expressed in terms of individual children, "Todd" was not able to perform the task until 8 months of age, and then only with no delay between hiding and retrieval. Until 10½ months, Todd demonstrated the AB error at a 5-second delay. At the last evaluation (11½), Todd demonstrated the AB error at a delay of 8 seconds. "Nina," on the other hand, was able to complete the task at 6½ months. At ages 8½ through 10½ months, she exhibited AB error at 10 seconds. By 11 months, Nina required 12 seconds of delay in order to demonstrate the AB error. The performance of these children illustrates the remarkable variability that is not captured by presentation of the group mean. A similar pattern of performance also has been observed on DR (Diamond & Doar, 1989).

Bell and Fox (1992) confirmed the marked individual variability in AB performance with a different analytic method. Bell and Fox utilized cluster analysis in order to group subjects according to their pattern of performance on AB across the testing period. Two groups emerged. The short delay infants tolerated a delay of almost 3 seconds at 12 months of age before making the AB error, and almost half of which were unable to perform the task at 7 months of age. In the long delay infant group, the delays tolerated prior to making the AB error were on the order of 13 seconds at 12 months of age, with the majority of the children able to complete the task and sustain a short delay at 7 months of age.

Findings from the studies by Diamond (1985; Diamond & Doar, 1989) and Bell and Fox (1992) indicate that AB skills emerge around 7 to 8 months in most infants, consistent with the original observation by Piaget (1954). However, Baillargeon and associates (Baillargeon, DeVos, & Graber, 1989; Baillargeon & Graber, 1988; Baillargeon, Graber, DeVos, & Black, 1990) demonstrated that young infants have the ability to "find" the location of an object if visual gaze, rather than manual reaching, is used as the dependent measure. In these studies, a preferential looking paradigm was used in order to evaluate whether infants identify the correct location of the reward. Younger (5½-month-old) and older (8-month-old) infants identified the location of the reward, that is, looked longer at location B at a comparatively long delay intervals (15 and 70 seconds) (Baillargeon et al., 1989; Baillargeon et al., 1990). Hofstadter and Reznick (1996) also found that in DR, 5-month-old infants identified reliably object location, if gaze direction is used as the dependent measure.

In terms of skill maturation, Piaget (1954) observed that infants, at about 12 months of age, no longer make the AB error. He proposed that at this age, infants are able to represent the object as independent of their own search strategy (i.e., object permanence), and therefore are able to find the reward at any given location. However, Diamond (1990a) proposed that the AB error could be demonstrated in older children, given a sufficiently long delay between hiding and retrieval. Espy, Kaufmann, McDiarmid, and Glisky (1999) found that 2- to 5-year-old children made the AB error with a 10-second delay. Out of 10 trials, the 2-year-old children made from 0 to 7 errors. The 5-year-old children, on the other hand, made 0 to 2 errors. There was some indication that performance was constrained at the older ages as a ceiling was reached, however, the age at which perfect performance was achieved varied markedly among preschool children. These findings lend support to Diamond's hypothesis.

Taken together, these studies suggest that individual variability in AB performance can be parsed to differences in skill onset, level of proficiency at the given age endpoint, rate of skill change, and shape of the developmental trajectory. Researchers, to this point at least, have not examined formally the rates and patterns of change in individual performance on AB. Given that the unit of measure is on a ratio scale (the number of trials, or seconds of delay), such data are well suited in recently developed techniques such as hierarchical modeling. These longitudinal modeling techniques allow the examination of developmental patterns of change and permit a more sensitive measure of individual differences, which may illuminate the underlying developmental process of executive function development in infants and young children.

Interindividual Differences

Individual differences occur as a result of phenomena other than those solely related to development. Sex differences are probably the most widely studied individual difference (Stumpf, 1995). AB performance has been demonstrated to differ in infants by sex. Girls outperformed boys in the age at which the AB error was demonstrated. Diamond (1985) found that 86% of the girls made the AB error at 7½ months, whereas 45% of the males could not search for the hidden reward. A longer delay was necessary in order to elicit the AB error in female infants, by an average margin of 2 seconds (Diamond, 1985). The same, sex-dependent pattern has been observed on DR (Diamond & Doar, 1989).

Other interindividual influences also affect AB performance. Matthews, Ellis, and Nelson (1996) found that healthy, low risk preterm infants tolerated longer delays before exhibiting the AB error than full-term infants. Matthews et al. concluded that better AB performance by preterm infants was related to the greater extra-utero experience (testing was conducted at the corrected age). Furthermore, Ross, Tesman, Auld, and Nass (1992) found that approximately two thirds of their sample of 10-month-old preterm infants with and without subependymal or intraventricular hemorrhages were unable to find the reward on two out of three reversal trials. Only 13% of full-term infants exhibited this response pattern. Of the children who succeeded on this task, however, there were no differences in the delays required to consistently exhibit the AB error.

Espy, Kaufmann, and Glisky (1999) examined AB performance in prenatally cocaine-exposed toddlers. Cocaine-exposed toddlers made more perseverative errors and erred perseveratively for more consecutive trials on AB relative to nonexposed controls. Toddlers who were exposed in utero to cocaine also obtained fewer correct sets, but this effect was nonsignificant when verbal intellectual abilities were controlled statistically. In a sample of infants with early and continuously treated phenylketonuria, mild hyperphenylalaniemia, siblings, and matched and general population controls, Diamond, Prevor, Callendar, and Druin (1997) found that infants with either phenylketonuria or mild hyperphenylalaniemia required longer delays to successfully retrieve the reward and performed more poorly compared to all control comparison groups. As toddlers, performance differences only were apparent in children with phenylketonuria with high phenylalanine levels after 21 months of age, compared to toddlers with lower phenylalanine levels and control groups. McEvoy, Rogers, and Pennington (1992), however, found no differences in DR or AB performance among autistic, chronologically age-matched developmentally delayed, and verbal ability-matched preschool control children. In this study, no delay was used between hiding and retrieval, which may have contributed to the null findings. To our knowledge, the impact of other individual difference variables, such as race or socioeconomic status, has not been examined, which is critical in order to understand the effects of the environment on AB and DR performance variability.

Intraindividual Differences

When individuals perform similarly on two tasks, the tasks often are inferred to be related, sharing some common measurement characteristic. Many studies have examined patterns of performance on AB and on pertinent comparison tasks in order to understand what cognitive ability underlies AB performance. For example, Diamond (1990b) compared performance on AB to that on the Object Retrieval (OR) task in order to assess the contribution of inhibition in AB performance. In this task, the infant retrieved an object from beneath a clear, plexiglass box with an opening on one lateral side. Similar to AB, a manual reaching response is required. However, performance on OR is not considered to depend on working memory processes because there is no delay and the object is in full view while the infant responds. The infant must inhibit the tendency to reach straight at the sight of the object (where there is a clear, but solid top), and reach obliquely through the side opening (out of direct sight of the object). Infants, age 6 to 12 months, showed the same pattern of improvement with age on AB and OR (Diamond, 1990b; Matthews et al., 1996). In addition, adult monkeys with lesions to the dorsolateral prefrontal cortex evidenced deficits on this task; they scratched repeatedly at the solid top and retrieved the object only when looking through the open side (Diamond, 1990b).

Although performance on two tasks may be related on average, not all individuals will exhibit the same performance. In this vein, although using a somewhat different procedure, Bell and Fox (1992) found no relation between the age at which maximal OR performance was achieved in the long and short delay groups, although the length of delay tolerated on AB was positively correlated with OR performance. Bell and Fox also examined performance on a Response Inhibition to Novelty task, where the infant had to inhibit reaching for a moving, novel toy. Infants differed on this task, however; the infants who performed well on this task and on AB were not the same infants. More studies should utilize this type of approach in order to study performance on other executive function tasks, particularly in clinical populations, where performance variability may be high.

Another important comparison within individuals is comparative task performance with differing dependent measures. For example, Hofstadter and Reznick (1996) utilized both gaze direction and reaching response as the dependent measures in DR. Perseverative errors were more common in the reach condition than in the gaze condition. Perseverative reaching responses also were significantly more likely on trials following incorrect responses, however, the number of perseverative gaze and reaching responses did not differ following correct responses. Hofstadter and Reznick concluded that reinforcement affected the likelihood of perseverative gaze and reach responses equally. However, the increase in perseverative manual responding was considered a priming effect, perhaps related to the proximity of the efferent connections from dorsolateral prefrontal cortex to the caudate nucleus. Hofstadter and Reznick did not report whether all individual infants manifested better performance in the gaze condition. It may be that those children who performed equivalently across conditions differed in important ways from those with discrepant performance.

Relation to Brain Structure and Function

Both AB and DR share a well-defined relation to dorsolateral prefrontal cortical function (Diamond & Goldman-Rakic, 1989; Goldman-Rakic, 1987). For example, perseverative searching behavior on AB and/or DR has been observed in frontally ablated adult monkeys (Diamond & Goldman-Rakic, 1989), intact and frontally ablated infant monkeys (Diamond & Goldman-Rakic, 1986), and intact human infants, from age 7½ to 12 months (Diamond, 1985; Diamond & Doar, 1989). On the basis of these findings, Diamond (1990a) concluded that AB and DR performances in 8- to 12-month-old infants are related to frontal lobe immaturity.

Individual differences in AB performance also have been related to variability in frontal lobe function, as measured by resting frontal EEG activity and increased anterior to posterior EEG coherence (Bell & Fox, 1992). Bell and Fox (1992) found that the infants who required the long delay in order to display the AB error evidenced: decreased right frontal power in the resting EEG signal between 7 and 8 months of age, greater increases in bilateral frontal EEG power each month between 9 and 10 months of age, and greater power in the EEG signal from the left occipital lead across the 6 months of the study, relative to the infants who displayed the AB error after a short delay. There were no differences in signal power from the parietal recording sites. When averaged across the frontal/parietal and frontal/occipital leads, signal coherence initially decreased between 8 and 9 months of age and then increased in the left hemisphere between 10 and 12 months of age. Coherence did not change between 9 and 10 months. The length of F3/P3 coherence was U-shaped in left hemisphere, whereas the length of the F3/O1 coherence was stable. In the right hemisphere, F4/02 sites were more coherent than F4/P4. The short-delay group, who tolerated, on average, a 3-second delay before exhibiting the AB error at 12 months of age, showed decreased power at the right frontal lead site only between 10 and 11 months of age. These findings suggest that the individual differences in executive behavior also are manifested in brain function, however, the ongoing relation between development of the prefrontal cortex and changes in AB or DR performance remains to be investigated.

There are many changes in the structure and function of the dorsolateral prefrontal cortex that occur during late infancy, concurrent with the emergence of AB performance. Maximal synaptic density is achieved (Huttenlocher & Dabholkar, 1997), glucose metabolism is increased (Chugani & Phelps, 1990), and myelination of the prefrontal, subcortical brain regions is completed, at least at the level visualized by magnetic resonance imaging (Barkovich, 1995). Goldman-Rakic (1987; Diamond & Goldman-Rakic, 1989) suggested that it is the emergence of function in the prefrontal cortex that drives the emergence of AB and DR performance in young infants. Bell and Fox (1992) found infants who solved the AB problem without a delay before 8 months of age, differed in the amount of signal power at the right frontal lead at 8 months of age from those infants who solved the AB problem at older ages. However, Bell and Fox did not find that EEG power or coherence differed between the last age at which AB was unable to be solved and the age at which AB was solved initially on any lead site.

Bell and Fox (1992) found no relation between the age at which maximal OR performance was achieved and the delay tolerated on AB. Furthermore, frontal EEG power and coherence among frontal and other electrode sites were unrelated to performance on OR and response inhibition to novelty tasks. Bell and Fox concluded that the dorsolateral prefrontal cortex was unrelated to performance on OR. In light of Fletcher's (1997) formulation of individual differences, it may be that differences in OR performance may, in fact, be related to the inhibition component of AB and DR performance. Inhibition, however, may not be subserved by the dorsolateral prefrontal cortex, but may remain an important contributor to executive function performance differences among individual children.

The well-developed relation of AB/DR and the dorsolateral prefrontal cortex is unusual in most neuropsychological work. The application of such neuroscience paradigms offers a rich methodology by which to study executive function development in individual children (Kaufmann et al., 1989). However, tasks must be developmentally sensitive, in a like manner as AB and DR. For example, Espy, Kaufmann, McDiarmid, and Glisky (1999) found that performance on a Delayed Alternation task was sensitive to development in preschool children and was not related to verbal intellectual skill. Performance on this task, however, was not successful in discriminating among school-age traumatically brain-injured children with frontal lobe lesions (Levin et al., 1994). In that study, Levin cautioned that the task may not have been valid in this age range, as children tried to "out think" the simple alternation problem. The demand characteristics of any given task may influence heavily the sensitivity to individual performance differences.

HOW DO AB/DR INVESTIGATIONS INFORM THE STUDY OF INDIVIDUAL DIFFERENCES IN PERFORMANCE ON EXECUTIVE FUNCTION TASKS? FUTURE DIRECTIONS

The investigations reviewed suggest several directions of inquiry that should be pursued in order to better understand the nature of individual differences in executive function in children. First, the findings from AB and DR indicate that individual differences are manifest at several levels.

Individuals may differ in the age of skill acquisition, the level of proficiency at a given age, the rate of development, or more complex developmental parameters. The differences were apparent on AB/DR because behavior was examined longitudinally (Bell & Fox, 1992; Diamond, 1985; Hofstadter & Reznik, 1996; Matthews et al., 1996). The next step is to examine how other components of executive function, measured by other tasks, may change with development. In order to accomplish this goal, multiple tasks must be administered at each age and sophisticated analytic techniques, such as structural equation or multilevel modeling, should be used (Goldstein, 1995; McArdle, 1996).

There are, however, inherent difficulties in using other executive function measures in longitudinal studies. For example, one hallmark of several of the executive function definitions is the synthesis of novel information. The repeated administration of any executive function instrument may render the task less novel, especially in older children. After the task has become familiar, the task may no longer measure executive skills. Perhaps a mixed cross-sectional, longitudinal design would be more useful in disentangling the developmental and practice effects. Alternatively, the delayed response paradigm may be suited uniquely for longitudinal use. In the latter case, the delay between hiding and retrieval may be adjusted incrementally in order to maintain sensitivity across a wide age range, presumably without grossly distorting the measurement characteristics (Diamond, 1990a; Espy, Kaufmann, McDiarmid, & Glisky, 1999). In addition, the complexity of the retrieval principle also may be increased with age (Kaufmann et al., 1989). For example, in AB/DR, the infant simply retrieves the reward at the observed location across trials. In the more complex variant, Delayed Matching to Sample, familiar and novel are placed on top of the well covers as cues to signal reward location. Invariably, the increased task complexity will produce different patterns of developmental proficiencies (Janowsky, 1993), which may be related somewhat differently to brain function than the more simple tasks. However, this paradigm is a powerful tool by which to investigate executive skill development across age.

Second, given the diverse definitions of executive function (Lyon & Krasnegor, 1996), one way to better understand how individual children differ in executive functions is to trace skill development back to that which is observable early in development. Investigations of performance on AB/DR represent such efforts. Unlike some of the other executive function tasks, AB/DR has not been used extensively to document interindividual differences in performance, perhaps related to its history in the developmental and neuroscientific literatures. Other more complex tasks, such as TOH (Simon, 1975) and WCST (Heaton, 1981), have been used routinely in studies of interindividual differences, particularly in various clinical populations (Pennington, 1997). Similar developmental task analyses are being employed with these tasks in order to elucidate the nature of individual performance differences (Welsh et al., 1991; Zelazo, Reznick, & Pinion, 1995). Other interindividual differences in executive function remain to be investigated on all tasks, such as the impact of environmental risk (e.g., socioeconomic status or parenting effects). Such interindividual differences in executive skill would be particularly relevant to the clinician when trying to distinguish one child from another, particularly for the purposes of diagnosis or prognosis.

Individual differences within the individual—the intraindividual—generally have not been investigated. Bell and Fox (1992) used cluster analysis in order to group infants according to AB performance and then examined differences in performance on comparison tasks and in resting brain electrophysiology. Cluster analysis is the method of choice by which to quantify and group how individuals differ across tasks (Aldenderfer & Blashfield, 1984). Such methods have been used successfully in the learning disabled population, where problematic definitional issues have clouded the identification of particular children (Morris, Blashfield, & Satz, 1986). The study of executive functions in older children also could benefit from utilization of cluster analytic approaches. Discriminating among individuals may be important, particularly for intervention research. It is likely that the pattern of skill discrepancies among various components of executive function may limit or enhance intervention efficacy in both normal and clinically identified children.

Finally, individual differences are apparent at all levels of analysis. The brain also undergoes remarkable development, concurrent with behavioral maturation. Thatcher (1997) characterized three major growth cycles in brain electrical activity across childhood. Individual differences in brain electricity were related to AB/DR performance differences (Bell & Fox, 1992). However, Goldman (1974) observed that the expression of behavioral deficits after early lesions to the prefrontal cortex varies with time since injury. The manner by which changes in the brain dynamically underlie behavioral changes in discrete groups of children is just beginning to be known. Unfortunately, the present knowledge of how these brain–behavior relations vary among individual children is primitive at best. Individual differences in performance may be subserved by brain structures other than those related to the prominent deficit of the group (Fletcher, 1997). In fact, the dissociation of the structure–function relations of individual differences from that of the group process may be more common for higher order skills that integrate diverse information, such as executive functions. It is this level of analysis that will ultimately inform the clinician who faces the anxious parent of a brain injured child.

Ultimately, individual variability in childhood executive functions may be a consequence of the cumulative effects of both the particular genetic predispositions of the infant interacting with the unique environmental condition. This interaction predates birth and continues through senescence. Consequently, Pennington's (1997) observation of increasing interest in the "frontal metaphor" for understanding normal development, developmental disabilities, behavioral disturbance following acquired lesions of the central nervous system, although overapplied, may be of heuristic value. If neuropsychology is to meet the challenge of

> determining whether or not organic factors were playing a role in an older person's behavioral difficulties; the need to devise ways to help a patient who had sustained a stroke to recovery his/her lost functions; the need to fathom why a school child of adequate general intelligence was failing academically or engaging in self-defeating behavior; the need to understand seemingly inexplicable disturbances in mood in persons of all ages (Benton, 1987, p. 7).

then the case for investing resources in studying the early emergence of executive functions cannot be overstated.

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REFERENCES

Aldenderfer, M. S., & Blashfield, R. K. (1984). *Cluster analysis* (Vol. 44). Newbury Park, CA: Sage.

Baillargeon, R., DeVos, J., & Graber, M. (1989). Location memory in 8-month-old infants in a nonsearch AB task: Further evidence. *Cognitive Development, 4*, 345–367.

Baillargeon, R., & Graber, M. (1988). Evidence of location memory in 8-month-old infants in a nonsearch AB task. *Developmental Psychology, 24*(4), 502–511.

Baillargeon, R., Graber, M., DeVos, J., & Black, J. (1990). Why do young infants fail to search for hidden objects? *Cognition, 36*, 255–284.

Barkley, R. A. (1996). Linkages between attention and executive functions. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 307–326). Baltimore: Paul H. Brookes.

Barkovich, A. J. (1995). *Pediatric neuroimaging* (2nd ed.). New York: Raven.

Bell, M. A., & Fox, N. A. (1992). The relations between frontal brain electrical activity and cognitive development during infancy. *Child Development, 63*, 1142–1163.

Benton, A. (1987). Evolution of a clinical specialty. *Clinical Neuropsychologist, 1*, 5–8.

Borkowski, J. G., & Burke, J. E. (1996). Theories, models, and measurements of executive functioning: An information processing perspective. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 235–262). Baltimore: Paul H. Brookes.

Bryk, A. S., & Raudenbush, S. W. (1992). *Hierarchical linear models*. Newbury Park, CA: Sage.

Chelune, G. J., & Baer, R. A. (1986). Developmental norms for the Wisconsin Card Sorting Test. *Journal of Clinical and Experimental Neuropsychology, 8*, 219–228.

Chugani, H. T., & Phelps, M. E. (1990). Imaging human brain development with positron emission tomography. *Journal of Nuclear Medicine, 32*, 23–25.

Critchley, M. (1970). *The dyslexic child*. Springfield, IL: Thomas.

Damasio, A. R., Tranel, D., & Damasio, H. (1990). Individuals with sociopathic behavior caused by frontal damage fail to respond autonomically to social stimuli. *Behaviour Brain Research, 41*(2), 81–94.

Diamond, A. (1985). Development of the ability to use recall to guide action, as indicated by infants' performance on AB. *Child Development, 56*, 868–883.

Diamond, A. (1990a). The development and neural bases of memory functions as indexed by AB and delayed response tasks in human infants and infant monkeys. *Annals of the New York Academy of Sciences, 608*, 267–317.

Diamond, A. (1990b). Developmental time course in human infants and infant monkeys, and the neural bases of inhibitory control in reaching. *Annals of the New York Academy of Sciences, 608*, 637–676.

Diamond, A., & Doar, B. (1989). The performance of human infants on a measure of frontal cortex function, the delayed response task. *Developmental Psychobiology, 22*, 271–294.

Diamond, A., & Goldman-Rakic, P. S. (1986). Comparative development of human infants and infant rhesus monkeys of cognitive functions that depend on the prefrontal cortex. *Neuropsychological Abstracts, 12*, 274.

Diamond, A., & Goldman-Rakic, P. S. (1989). Comparison of human infants and rhesus monkeys on Piaget's AB task: Evidence for dependence on dorsolateral prefrontal cortex. *Experimental Brain Research, 74*, 24–40.

Diamond, A., Prevor, M. B., Callendar, G., & Druin, D. P. (1997). Prefrontal cortex cognitive deficits in children treated early and continuously for PKU. *Monographs for the Society for Research in Child Development, 62*(Serial 252).

Embretson, S. (1983). Construct validity: Construct representation versus nomothetic span. *Psychological Bulletin, 93*, 179–197.

Eslinger, P. J. (1996). Conceptualizing, describing, and measuring components of executive function: A summary. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 367–396). Baltimore: Paul H. Brookes.

Eslinger, P. J., Biddle, K. R., & Grattan, L. M. (1997). Cognitive and social development in children with prefrontal cortex lesions. In N. A. Krasnegor, G. R. Lyon, & P. S. Goldman-Rakic (Eds.), *Development of the prefrontal cortex: Evolution, neurobiology, and behavior* (pp. 295–336). Baltimore: Paul H. Brookes.

Eslinger, P. J., & Damasio, A. R. (1985). Severe disturbance of higher cognition after bilateral frontal lobe ablation: Patient EVR. *Neurology, 35*, 1731–1741.

Espy, K. A., Kaufmann, P. M., & Glisky, M. L. (1999). Neuropsychological function in toddlers exposed to cocaine in utero: A preliminary study. *Developmental Neuropsychology, 15*, 447–460.

Espy, K. A., Kaufmann, P. M., McDiarmid, M. D., & Glisky, M. L. (1999). Executive functioning in preschool children: A-not-B and other delayed response format task performance. *Brain and Cognition, 41*, 178–199.

Espy, K. A., Riese, M. L., & Francis, D. J. (1997). Neuropsychological development in preterm neonates prenatally exposed to cocaine. *Infant Behavior and Development, 20*, 297–309.

Fletcher, J. M. (1997, August). *Brain–behavior relationships in children with developmental disabilities: concepts and methods*. Paper presented at the American Psychological Association, Chicago, IL.

Fletcher, J. M., Bohan, T. P., Brandt, M. E., Brookshire, B. L., Beaver, S. R., Francis, D. J., Davidson, K. C., Thompson, N. M., & Miner, M. E. (1992). Cerebral white matter and cognition in hydrocephalic children. *Archives of Neurology, 49*, 818–834.

Fletcher, J. M., & Levin, H. S. (1988). Neurobehavioral effects of brain injury in children. In D. K. Routh (Ed.), *Handbook of pediatric psychology* (pp. 258–298). New York: Guilford.

Fletcher, J. M., & Taylor, H. G. (1984). Neuropsychological approaches to children: Towards a developmental neuropsychology. *Journal of Clinical Neuropsychology, 6*, 39–56.

Francis, D. J., Fletcher, J. M., Steubing, K. K., Davidson, K. C., & Thompson, N. M. (1991). Analysis of change: Modeling individual growth. *Journal of Consulting and Clinical Psychology, 59*, 27–37.

Francis, D. J., Shaywitz, S. E., Stuebing, K. K., Shaywitz, B. A., & Fletcher, J. M. (1996). Developmental lag vs. deficit models of reading disabilities: A longitudinal, individual, and growth curves analysis. *Journal of Educational Psychology, 88*, 3–17.

Fuster, J. M. (1985). The prefrontal cortex and temporal integration. In A. Jones (Ed.), *Cerebral cortex* (Vol. 4, pp. 151–177). New York: Plenum.

Golden, C. J. (1981). The Luria–Nebraska Children's Battery; theory and formulation. In G. W. Hynd & J. E. Obrzut (Eds.), *Neuropsychological assessment and the school-age child* (pp. 277–302). New York: Grune & Stratton.

Goldman, P. S. (1974). An alternative to developmental plasticity: Heterology of CNS structures in infants and adults. In D. Stein, J. Rosen, & N. Butters (Eds.), *Plasticity and recovery of function in the central nervous system* (pp. 149–174). New York: Academic Press.

Goldman, P. S., & Rosvold, H. E. (1970). Localization of function within the dorsolateral prefrontal cortex of the rhesus monkey. *Experimental Neurology, 27*, 291–304.

Goldman-Rakic, P. S. (1987). Development of cortical circuitry and cognitive function. *Child Development, 58*, 601–622.

Goldstein, H. (1995). *Multilevel statistical models* (2nd ed.). New York: Wiley.

Graham, S., & Harris, K. R. (1996). Addressing problems in attention, memory, and executive functioning: An example from self-regulated strategy development. In G. R. Lyons & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 349–366). Baltimore: Paul H. Brookes.

Gratch, G., Appel, K. J., Evans, W. F., LeCompte, G. K., & Wright, N. A. (1974). Piaget's stage IV object concept error: Evidence of forgetting or object conception. *Child Development, 45*, 71–77.

Harlow, J. M. (1848). Passage of an iron bar through the head. *Boston Medical and Surgical Journal, 39*, 389–393.

Harlow, J. M. (1868). Recovery from the passage of an iron bar through the head. *Publication of the Massachusetts Medical Society, 2*, 327–347.

Harris, P. L. (1973). Perseverative errors in search by young infants. *Child Development, 44*, 28–33.

Hayes, S. C., Gifford, E. V., & Ruckstuhl, L. E. (1996). Relational frame theory and executive function: A behavioral approach. In G. R. Lyons & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 279–306). Baltimore: Paul H. Brookes.

Heaton, R. K. (1981). *Wisconsin Card Sorting Test manual*. Odessa, FL: Psychological Assessment Resources.

Hertzog, C. (1985). An individual difference perspective: Implications for cognitive research in gerontology. *Research on Aging, 7*, 7–45.

Hofstadter, M., & Reznick, J. S. (1996). Response modality affects human infant delayed-response performance. *Child Development, 67*, 646–658.

Howe, M. L. (1994). Dynamics of cognitive development: A unifying approach to universal trends and individual differences. Special Issue: Developmental perspectives on individual differences in learning and memory. *Learning and Individual Differences, 6*(3), 365–367.

Huttenlocher, P. R., & Dabholkar, A. S. (1997). Developmental anatomy of prefrontal cortex. In N. A. Krasnegor, G. R. Lyon, & P. S. Goldman-Rakic (Eds.), *Development of the prefrontal cortex: Evolution, neurobiology, and behavior* (pp. 69–83). Baltimore: Paul H. Brookes.

Janowsky, J. S. (1993). The development of neural basis of memory systems. In M. H. Johnson (Ed.), *Brain development and cognition* (pp. 665–678). Cambridge, England: Basil Blackwell.

Kaufmann, P., Leckman, J. M., & Ort, S. I. (1989). Delayed response performance in males with Fragile-X. *Journal of Clinical and Experimental Neuropsychology, 12*, 69.

Kaufmann, P. M., Fletcher, J. M., Levin, H. S., Miner, M. E., & Ewing-Cobbs, L. (1993). Attentional disturbance following pediatric closed head injury. *Journal of Child Neurology, 8*, 348–353.

Keppel, G. (1982). *Design & analysis: Researcher's handbook* (2nd ed.). Englewood Cliffs, NJ: Prentice-Hall.

Levin, H. S., Culhane, K. A., Fletcher, J. M., Mendelsohn, D. B., Lilly, M. A., Harward, H., Chapman, S. B., Bruce, D. A., Bertolino-Kusnerik, L., & Eisenberg, H. M. (1994). Dissociation between delayed alternation and memory after pediatric head injury: Relationship to MRI findings. *Journal of Child Neurology, 9*, 81–89.

Levin, H. S., Culhane, K. A., Hartmann, J., Evankovich, K., Mattson, A. J., Harward, H., Ringholtz, G., Ewing-Cobbs, L., & Fletcher, J. M. (1991). Developmental changes in performance on tests of purported frontal lobe functioning. *Developmental Neuropsychology, 7*, 377–395.

Luria, A. R. (1973). *The working brain*. New York: Basic Books.

Lyon, G. R., & Krasnegor, N. A. (Eds.). (1996). *Attention, memory, and executive function*. Baltimore: Paul H. Brookes.

Matthews, A., Ellis, A. E., & Nelson, C. A. (1996). Development of preterm and full-term infant ability on AB, recall memory, transparent barrier detour, and means-end tasks. *Child Development, 67*, 2658–2676.

McArdle, J. J. (1996). Current directions in structural factor analysis. *Current Directions in Psychological Science, 5*(1), 11–18.

McEvoy, R. E., Rogers, S. J., & Pennington, B. F. (1993). Executive function and social communication deficits in young autistic children. *Journal of Child Psychology and Psychiatry, 34*(4), 563–578.

Menkes, J. H. (1985). *Textbook of child neurology* (3rd ed.). Philadelphia: Lea & Febiger.

Morris, R., Blashfield, R., & Satz, P. (1986). Developmental classification of reading-disabled children. *Journal of Clinical and Experimental Neuropsychology, 8*(4), 371–392.

Pennington, B. F. (1997). Dimensions of executive functions in normal and abnormal development. In N. A. Krasnegor, G. R. Lyon, & P. S. Goldman-Rakic (Eds.), *Development of the prefrontal cortex: Evolution, neurobiology, and behavior* (pp. 265–282). Baltimore: Paul H. Brookes.

Pennington, B. F., Bennetto, L., McAleer, O., & Roberts, R. J. (1996). Executive functions and working memory: Theoretical and measurement issues. In G. R. Lyons & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 327–348). Baltimore: Paul H. Brookes.

Piaget, J. (1954). *The construction of reality in the child*. New York: Basic Books.

Ross, G., Tesman, J., Auld, P., & Nass, R. (1992). Effects of subependymal and mild intraventricular lesions on visual attention and memory in premature infants. *Developmental Psychology, 28*, 1067–1074.

Rutter, M., & Yule, W. (1975). The concept of specific reading retardation. *Journal of Child Psychology and Psychiatry, 16*, 181–197.

Satz, P., Fletcher, J. M., Clark, W., & Morris, R. (1981). Lag, deficit, rate and delay constructs in specific learning disabilities: A re-examination. In A. Ansara (Ed.), *Sex differences in dyslexia* (pp. 129–150). New York: Orton Dyslexia Society.

Shaywitz, S. E., Escobar, M. D., Shaywitz, B. A., Fletcher, J. M., & Makuch, R. (1992). Evidence that dyslexia may represent the lower tail of a normal distribution of reading ability. *New England Journal of Medicine, 326*(3), 145–150.

Simon, H. A. (1975). The functional equivalence of problem solving skills. *Cognitive Psychology, 7*, 268–288.

Strich, S. J. (1970). Lesions in the cerebral hemisphere after blunt head injury. In S. Sevitt & H. B. Stoner (Eds.), *The pathology of trauma* (pp. 166–171). London: BMA House.

Stumpf, H. (1995). Gender differences in performance on tests of cognitive abilities: Experimental design issues and empirical results. Special issue: Psychological and psychobiological perspectives on sex differences in cognition: I. Theory and research. *Learning and Individual Differences, 7*(4), 275–287.

Taylor, H. G. (1996). Critical issues and future directions in the development of theories, models, and measurements of attention, memory, and executive function. In G. R. Lyons & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 399–412). Baltimore: Paul H. Brookes.

Taylor, H. G., & Schatschneider, C. (1992). Clinical neuropsychological assessment: A test of basic assumptions. *The Clinical Neuropsychologist, 6*, 259–275.

Thatcher, R. W. (1997). Human frontal lobe development: A theory of cyclical cortical reorganization. In N. A. Krasnegor, G. R. Lyon, & P. S. Goldman-Rakic (Eds.), *Development of the prefrontal cortex: Evolution, neurobiology, and behavior* (pp. 85–113). Baltimore: Paul H. Brookes.

Wellman, H. M., Cross, D., & Bartsch, K. (1986). Infant search and object permanence: A meta-analysis of the A-not-B error. *Monographs of the Society for Research in Child Development, 51*(Serial No. 214).

Welsh, M. C., Pennington, B. F., & Groisser, D. B. (1991). A normative-developmental study of executive function: A window on prefrontal function in children. *Developmental Neuropsychology, 7*(2), 131–149.

Yeates, K. O., Blumenstein, E., Patterson, C. M., & Delis, D. C. (1995). Verbal learning and memory following pediatric closed-head injury. *Journal of the International Neuropsychological Society, 1*, 78–87.

Zelazo, P. D., Reznick, J. S., & Pinion, D. E. (1995). Response control and the execution of verbal roles. *Developmental Psychology, 31*, 508–517.