Behavioral Inhibition, Sustained Attention, and Executive Functions: Constructing a Unifying Theory of ADHD

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Attention deficit hyperactivity disorder (ADHD) comprises a deficit in behavioral inhibition. A theoretical model is constructed that links inhibition to 4 executive neuropsychological functions that appear to depend on it for their effective execution: (a) working memory, (b) self-regulation of affect–motivation–arousal, (c) internalization of speech, and (d) reconstitution (behavioral analysis and synthesis). Extended to ADHD, the model predicts that ADHD should be associated with secondary impairments in these 4 executive abilities and the motor control they afford. The author reviews evidence for each of these domains of functioning and finds it to be strongest for deficits in behavioral inhibition, working memory, regulation of motivation, and motor control in those with ADHD. Although the model is promising as a potential theory of self-control and ADHD, far more research is required to evaluate its merits and the many predictions it makes about ADHD.

For over 20 years, attention deficit hyperactivity disorder (ADHD) has been viewed as comprising three primary symptoms, these being poor sustained attention, impulsiveness, and hyperactivity (American Psychiatric Association [APA], 1980, 1987; Barkley, 1981; Douglas, 1972, 1983). These behavioral deficits arise relatively early in childhood, typically before the age of 7, and are fairly persistent over development (Barkley, 1990; Hinshaw, 1994; Weiss & Hechtman, 1993). The three major impairments now have been reduced to two, with hyperactivity and impulsivity constituting a single impairment. As a result, three subtypes of the disorder have been proposed in the current clinical view of ADHD offered in the fourth edition of the *Diagnostic and Statistical Manual of Mental Disorders* (*DSM–IV;* APA, 1994): predominantly inattentive, predominantly hyperactive–impulsive, and combined types.

ADHD occurs in approximately 3–7% of the childhood population (Barkley, 1990; Szatmari, 1992), with boys being overrepresented, on average, approximately 3:1. The disorder persists into adolescence in 50–80% of cases clinically diagnosed in childhood and into adulthood in 30–50% or more of these same cases (Barkley, Fischer, Edelbrock, & Smallish, 1990; Klein & Mannuzza, 1991; Weiss & Hechtman, 1993). Over development, ADHD is associated with greater risks for low academic achievement, poor school performance, retention in grade, school suspensions and expulsions, poor peer and family relations, anxiety and depression, aggression, conduct problems and delinquency, early substance experimentation and abuse, driving accidents and speeding violations, as well as difficulties in adult social relationships, marriage, and employment (Barkley, 1990; Barkley, Fischer, et al., 1990; Barkley, Guevremont, Anastopoulos, DuPaul, & Shelton, 1993; Barkley, Murphy, & Kwasnik, 1996, in press; Biederman, Faraone, & Lapey, 1992; Hinshaw, 1994; Murphy & Barkley, in press; Nadeau, 1995; Weiss & Hechtman, 1993). Most of these developmental risks may be exacerbated by the presence of comorbid aggression–conduct problems (Barkley, Fischer, et al., 1990; Barkley et al., 1993; Hinshaw, 1987, 1992, 1994). Treatments for ADHD often include parent, family, and teacher counseling about the disorder; parent and teacher training in behavior management techniques; special education resources; and psychoactive medications (Barkley, 1990).

The history of ADHD has been reviewed elsewhere (Barkley, 1990; Schachar, 1986; Werry, 1992), so I only briefly consider it here. Initially, the symptoms were thought to arise out of poor volitional inhibition and defective moral regulation of behavior (Still, 1902). Later, problems with hyperactivity were thought to be the major feature of the disorder (Chess, 1960; Laufer & Denhoff, 1957). Eventually, Douglas (1972; Douglas & Peters, 1979) stressed an equal if not greater role for poor sustained attention and impulse control in the disorder. She subsequently amended her view to include four major deficits: (a) poor investment and maintenance of effort, (b) deficient modulation of arousal to meet situational demands, (c) a strong inclination to seek immediate reinforcement, along with (d) the originally proposed difficulties with impulse control (Douglas, 1980, 1983). Douglas (1988) later concluded that these four deficiencies arise from a more central impairment in self-regulation in ADHD.

Others have argued that the cognitive deficits in ADHD may best be understood as a motivational deficit (Glow & Glow, 1979) or as arising from poor stimulus control, a diminished sensitivity to reinforcement, or deficient rule-governed behavior (Barkley, 1981, 1989; Haenlein & Caul, 1987). Such views, however, were not widely adopted, nor did they serve as an impetus to much new research. Zentall (1985) set forth an optimal stimulation theory of ADHD, arguing that the hyperactivity arises from low levels of arousal and serves to maintain an optimal arousal level; the hyperactivity, in a sense, is a form of self-stimulation. More recently, researchers theorizing on ADHD have emphasized poor behavioral inhibition as the central impairment of the disorder (Barkley, 1990, 1994; Quay, 1988a; Schachar, Tannock, & Logan, 1993; Schachar, Tannock, Marriott, & Logan, 1995).

In keeping with this trend, in this article I attempt to provide a unifying model of ADHD that is founded on prior theories of the neuropsychological functions of the brain's prefrontal lobes. Poor behavioral inhibition is specified as the central deficiency in ADHD. The model then sets forth a linkage between response inhibition and four executive functions that depend on such inhibition for their own effective performance. These four functions serve to bring behavior under the control of internally represented information and self-directed actions. By doing so, the four functions permit greater goal-directed action and task persistence. The model provides a more comprehensive account of research findings on the cognitive deficits associated with ADHD than does the current clinical view, which sees ADHD as primarily an attention deficit. The model also predicts many additional deficits likely to be associated with ADHD that have received little or no testing in research. Such predictions provide avenues for attempts at falsification of the model and point to new areas for scientific investigation.

The goal here is admittedly ambitious, perhaps overly so, because the model I propose may be potentially misconstrued as a "theory of everything." Yet its boundaries are generally circumscribed to the domain of self-regulation in developmental psychology or executive functions in neuropsychology. Albeit a broad domain, it is not unlimited. It can be readily distinguished from other major domains of neuropsychological functioning such as sensation and perception, memory, language, and the spatial, sequential, emotional, and motivational domains, among others. The model may overlap with these other domains, however, to the extent that self-regulation may affect them. Before I proceed to discuss the origins of the model, its components, and its extension to ADHD, the ambitiousness of this undertaking demands a justification for why a new model of ADHD is even necessary at this time.

The Need for a New Model of ADHD

A new theory of ADHD is needed for a number of reasons. First, current research on ADHD is nearly atheoretical, at least in regards to its basic nature. That research is mainly exploratory and descriptive, with two exceptions. One is Quay's (1988a, 1988b, 1996) use of Gray's (1982) neuropsychological model of anxiety to explain the origin of the poor inhibition seen in ADHD. This Quay–Gray model states that the impulsiveness arises from an underfunctioning of the brain's behavioral inhibition system. That system is said to be sensitive to signals of conditioned punishment, and the model predicts that those with ADHD should prove less sensitive to such signals, particularly in passive avoidance paradigms (Milich, Hartung, Martin, & Haigler, 1994; Quay, 1988b). The second exception is the work of Sergeant and van der Meere (1988; Sergeant, 1995a, 1995b, 1996; van der Meere, in press; van der Meere, van Baal, & Sergeant, 1989), who successfully used information-processing theory and its associated energetic model (arousal, activation, and effort) for isolating the central deficit(s) in ADHD within that paradigm (Sergeant, 1995b). However, this approach does not set forth a theory of ADHD; like the Quay–Gray theory, it makes no effort at large-scale theory construction so as to provide a unifying account of the various cognitive deficits associated with ADHD. Apart from these exceptions, the current clinical view of ADHD (i.e., that of the *DSM–IV*) and the vast majority of current research being conducted on its nature are not theory driven (Taylor, 1996). One sign of advancement in a scientific field is that its research becomes so driven. This synthesis is an attempt to move research on ADHD further along in that direction.

Douglas's (1980) earlier model of ADHD is not actually a theory; it is mainly descriptive and was arrived at inductively from a review of the extant research findings on ADHD in which Douglas (1980, 1983; Douglas & Peters, 1979) discerned a pattern among the findings consistently noted in this field. That pattern comprised the four deficiencies noted earlier. Although it was tremendously helpful at the time, such pattern discernment remains at a descriptive level, albeit one more synthetic than prior efforts at conceptualizing ADHD. But it is neither explanatory nor, more important, predictive of new hypotheses that are testable. It still begs the question of just how the pattern itself is to be explained. Appealing to the construct of self-regulation (Douglas, 1988) is a step in the right direction but is of only modest help unless self-regulation itself is defined and the manner in which it leads to the four impairments is explained. Both the pattern and the later use of self-regulation as an explanatory construct by Douglas fit well within the model developed below. This theory, however, goes much further by providing the needed definition of self-regulation, articulating the cognitive components that contribute to it, specifying the primacy of behavioral inhibition within the theory, and setting forth a motor control component to ADHD. Most important, the model reveals a diversity of new, untested, yet testable predictions about cognitive and behavioral deficits deserving of study.

A second reason why a theory of ADHD is sorely needed is that the current clinical view of ADHD (i.e., that of the *DSM–IV*), being purely descriptive of two behavioral deficits (inattention and hyperactivity–impulsivity), also cannot readily account for the many cognitive and behavioral deficits associated with ADHD that are reviewed later in this article. To account for such findings, any model must fulfill at least five key requirements: (a) It must explain why an actual deficit in attention in children with ADHD has not been found (Schachar et al., 1993, 1995; Sergeant, 1995a, 1995b; van der Meere, in press; van der Meere & Sergeant, 1988a, 1988b, 1988c), even though research on parent and teacher ratings of ADHD repeatedly identifies a

factor of "inattention"; (b) it must explain the link between poor behavioral inhibition (hyperactivity–impulsivity) and this sister impairment of inattention, or whatever this symptom turns out to be; (c) it also must link these two constructs with executive or metacognitive functions because most, if not all, of the cognitive deficits associated with ADHD seem to fall within the realm of self-regulation or executive functions (Barkley, 1995; Denckla, 1994, 1995; Douglas, 1988; Grodzinsky & Diamond, 1992; Pennington & Ozonoff, 1996; Pennington, Grossier, & Welsh, 1993; Seidman et al., 1995; Torgesen, 1994; Welsh, Pennington, & Grossier, 1991; Weyandt & Willis, 1994); (d) it must ultimately connect the literature on ADHD with the larger literatures of developmental psychology and developmental neuropsychology as they pertain to self-regulation and executive functions if it is to argue that ADHD arises from a disruption in developmental processes; and (e) it must be useful as a scientific tool and must make explicit predictions about new phenomena that will both drive research initiatives and provide a means of falsifying the theory.

A third reason for a new model of ADHD is that the current view treats the subtypes of ADHD as sharing qualitatively identical deficits in attention while differing only in the presence of hyperactive–impulsive symptoms. As noted above, it is doubtful that the problems with inattention associated with hyperactive–impulsive behavior lie in the realm of attention, whereas those seen in the predominantly inattentive type of ADHD appear to do so. A digression is necessary here. The predominantly hyperactive–impulsive type actually seems to be a developmental precursor to the combined type. In the field trial for ADHD in the *DSM–IV,* this hyperactive–impulsive type was chiefly found among preschool children (Applegate et al., 1995). In contrast, the combined type was far more represented in school-aged children, as was nearly the entire sample of the inattentive type. This relationship of ADHD type to the ages associated with it likely arises from a simple observation made in prior studies. The hyperactive–impulsive behavior pattern seems to emerge first in development, during the preschool years, whereas the symptoms of inattention associated with it appear to have their onset several years later, at least according to parental reports (Hart, Lahey, Loeber, Applegate, & Frick, 1995; Loeber, Green, Lahey, Christ, & Frick, 1992). Moreover, the types of problems with inattention seen in the predominantly inattentive type appear to have their onset even later than those that would eventually be associated with hyperactive–impulsive behavior (Applegate et al., 1995).

Returning, then, to the start of this digression, it appears that the predominantly inattentive type may not, in fact, have its impairment in the same form of attention as that found in the other two types (see Barkley, 1990; Barkley, Grodzinsky, & DuPaul, 1992; Goodyear & Hynd, 1992; Hinshaw, 1994; and Lahey & Carlson, 1992, for reviews). Research on the inattentive subtype suggests that symptoms of daydreaming, "spacing out," being "in a fog," being easily confused, staring frequently, and being lethargic, hypoactive, and passive are more common (Barkley, DuPaul, & McMurray, 1990; Lahey & Carlson, 1992). This type of ADHD has a deficit in speed of information processing, generally, and in focused or selective attention, specifically (Goodyear & Hynd, 1992; Lahey & Carlson, 1992).

The deficit in the combined type of ADHD has been characterized as being in the realm of sustained attention (persistence) and distractibility. If this distinction is valid, the present clinical view of ADHD may be clustering into a single set of disorders what are, in reality, two qualitatively different disorders. Such a distinction would also argue that children with ADHD combined type who may develop the inattentive type as they get older (because of reductions in hyperactive behavior) are not actually changing types of ADHD at all. The type of inattention that they continue to manifest (lack of persistence and distractibility) is still qualitatively different from the inattention manifested by children classified as the inattentive type. Any new theory of ADHD needs to address this emerging distinction. The model presented here provides a means of testing this dissociation between types of inattention by using functional neuroimaging methods along with measures of the executive functions whose deficiencies are linked in this model to the hyperactive–impulsive types of ADHD.

Clarification of Terms and Assumptions

The term *ADHD* is used here to refer only to that subgroup of this population previously identified as hyperactive (Chess, 1960), hyperkinetic (APA, 1968), attention deficit disorder with hyperactivity (APA, 1980), ADHD (APA, 1987), or, more recently, ADHD–combined type and hyperactive–impulsive type (APA, 1994). In this article, ADHD and the model of it developed here do not refer to that subgroup whose chief problem is inattention alone (predominantly inattentive type).

The model set forth below presumes that the essential impairment in ADHD is a deficit involving response inhibition. This deficit leads to secondary impairments in the four neuropsychological abilities that are partially dependent on inhibition for their effective execution. These secondary impairments then lead to decreased control of motor behavior by internally represented information and self-directed action. One consequence of this hierarchical relationship is that improvement or amelioration of the inhibitory deficit should result in improvement or normalization in the four executive functions that depend on it and also in improved motor control. Another consequence is that this successive chain of impairments creates the appearance of poor sustained attention in those with ADHD. However, this inattention actually represents a reduction in the control of behavior by the internally represented information contributed by these four executive functions. That information permits the tracking of the adherence of behavior to it (i.e., rules, plans, intentions, goals, time, etc.), thus creating goal-directed persistence.

Behavioral inhibition refers to three interrelated processes: (a) inhibition of the initial prepotent response to an event; (b) stopping of an ongoing response, which thereby permits a delay in the decision to respond; and (c) the protection of this period of delay and the self-directed responses that occur within it from disruption by competing events and responses (interference control). It is not just the delay and the self-directed actions within it that are protected but also the eventual execution of the goal-directed responses generated from those self-directed actions (Bronowski, 1977; Fuster, 1989). The *prepotent response* is defined as that response for which immediate rein-

forcement (positive or negative) is available or has been previously associated with that response. The inhibitory process involved in interference control may be separable from that involved in the delay or cessation of a response. Nevertheless, the previous neuropsychological models on which the present one is based clustered these processes together. That fact, along with research reviewed below which suggests that all three inhibitory activities are impaired in ADHD, has led to their treatment here as a single construct.

This definition of inhibition is not exactly the same as that used by Kagan, Reznick, and Snidman (1988) to study shy (inhibited) and sociable (uninhibited) children. In Kagan et al.'s research, uninhibited behavior is defined by reactions to social settings involving unfamiliar people in which children are consistently sociable, talkative, and affectively spontaneous. It is the polar opposite of shyness (clinging, quiet, timid, and withdrawn behavior). In contrast, inhibition is assessed by performance on cognitive and behavioral tasks that require withholding of responding, delayed responding, cessation of ongoing responses, and resisting distraction or disruption by competing events. The social characteristics of children with low social inhibition in Kagan et al.'s research may be similar to some of the behavioral effects in the model developed here. The two concepts and their correlates, however, do not appear to map precisely onto each other, nor do they seem to predict the same outcomes.

For instance, Caspi and Silva (1995) found that separate dimensions of temperament for undercontrolled behavior (impulsive, emotionally reactive, easily frustrated, and overactive) and for socially confident behavior (sociable, talkative, and eager to explore unfamiliar contexts) could be extracted from ratings of 3-year-olds. These two dimensions predicted very different personality characteristics in adulthood, with the former associated with more maladaptive behavior than the latter. The undercontrolled behavior pattern seems more closely related to the poor inhibition in the present model than is the socially confident pattern, which resembles Kagan et al.'s (1988) sociable (uninhibited) children.

This is hardly the first article to argue that behavioral inhibition is a central impairment in ADHD. Distinctive of the model to be offered here, however, is its linkage of this deficiency in inhibition to the disruption of five other neuropsychological abilities that depend on inhibition for their efficient execution. Four of these abilities are critical for self-regulation and goal-directed persistence, so they are called *executive* functions here. ADHD is believed to disrupt these executive functions because the first executive, self-regulatory act must be inhibition of responding. Such inhibition permits a delay in the decision to respond that is used for further self-directed, executive actions. Those actions affect the decision to respond and control the eventual responses these executive functions generate.

This is not to say that behavioral inhibition directly causes these executive or self-directed actions to occur. However, it does set the occasion for their performance by providing the delay necessary for them to occur. These four executive functions, therefore, should be viewed as neuropsychological systems separate from the behavioral inhibition system yet hierar-

chically (or pyramidally) perched on it to assist in self-regulation.

Self-regulation is any response, or chain of responses, by the individual that serves to alter the probability of the individual's subsequent response to an event and, in so doing, functions to alter the probability of a later consequence related to that event (Kanfer & Karoly, 1972; Skinner, 1953). These self-directed behaviors need not be publicly observable, although it is likely that in early development many of them are. Over development, they may become progressively more private, or internal–cognitive, in form. The development of internalized, self-directed speech, to be discussed later, may serve to exemplify this process. Although eventually private, these actions remain essentially self-directed forms of behavior. The term *executive function* refers to these mainly private (cognitive) self-directed actions that contribute to self-regulation. So defined, the term incorporates most of the attributes often ascribed to it by others (Denckla, 1994; Stuss & Benson, 1986; Torgesen, 1994; Welsh & Pennington, 1988), including (a) self-directed actions; (b) the organization of behavioral contingencies across time; (c) the use of self-directed speech, rules, or plans; (d) deferred gratification; and (e) goal-directed, future-oriented, purposive, or intentional actions.

A conflict between the immediate and distal consequences of an act may be critical for identifying those circumstances that serve to initiate inhibition and self-regulation (Kanfer & Karoly, 1972). Inhibition and its related executive functions may be most obvious (and most needed) when a delay of a consequence is imposed in a task, when a conflict is confronted between the immediate and delayed consequences of a response, or when a problem arises that requires generating a novel response to resolve it. Time, conflicts in temporally related outcomes, or novelty of a response, therefore, may serve as initiating events for these executive functions. The future consequence is not actively influencing this process because it has not yet occurred. Instead, conditioned signals of punishment from experiences and prior socialization may be the determinants of when inhibition and self-regulation are engaged (Quay, 1988a). When such initiating events arise, self-regulation can result in a reduction in immediately available rewards (self-imposed deprivation) or an increase in the aversive consequences in the immediate context (self-imposed pain or hardship). Yet these self-directed acts may result in later, considerably larger, rewards or the avoidance of later, and greater, aversive consequences. The net gain of considering both the immediate and delayed consequences would be greater than that achieved by consideration of the immediate consequences alone (Kanfer & Karoly, 1972; Thoresen & Mahoney, 1974).

Circumstances or tasks that involve temporal delays, conflicts in temporally related consequences, or the generation of novel responses most heavily tax the type of behavioral inhibition and self-regulation described here. Tasks requiring resistance to temptation or deferred gratification are of this sort. Among the several dimensions of impulsivity discovered in past research (behavioral and cognitive–motor, typically; Milich & Kramer, 1985; Olson, 1989), it is that dimension reflected in deferred gratification and resistance to temptation, or what others have also called "behavioral inhibition" (White et al., 1994), that

is associated with the inhibitory processes described here. Problem-solving tasks are also likely to tax behavioral inhibition and its related executive functions. By definition, *problems* are situations for which the individual has no readily available response and that require the generation of a novel response to resolve. And so problem-solving tasks, tasks involving temporal delays, and tasks involving temporal conflicts in outcomes would all prove useful in research studying not only the linkages between behavioral inhibition and the four executive functions in development but their impairment in ADHD as well.

It is the behavioral dimension of impulse control, rather than the cognitive dimension of impulsiveness (as measured by the Matching Familiar Figures Test and the Draw-A-Line Slowly Test), that seems to be most stable over development, to correspond most closely to parent or teacher ratings of hyperactive–impulsive behavior, and to correlate most highly with later cognitive and social competence (Mischel, Shoda, & Peake, 1988; Olson, 1989; Silverman & Ragusa, 1992). This may explain why methods of assessing the behavioral type of inhibition (parent–teacher ratings, delayed reward tasks, and reinforcer conflict tasks) have been more useful than those assessing cognitive impulse control in distinguishing those with ADHD from those without it, in predicting which infants and preschool children are at risk for ultimately developing ADHD, and in predicting the extent of later cognitive and social problems associated with ADHD, as shown below.

The immediate purpose of the four executive functions described below seems to be the achievement of greater prediction and control over the individual's own behavior and environment, but their ultimate purpose seems to be an alteration in the future consequences a response is likely to produce (Bronowski, 1977; Fuster, 1989; Skinner, 1953). Such executive functions likely arise from (a) the development of neural networks within the prefrontal lobes, which underly these neuropsychological abilities and permit the acquisition of more specific skills used for self-control (Bronowski, 1977; Fuster, 1989); (b) the success these actions have had in the past for maximizing the net consequences of behavior, both immediate and delayed, when considered across long time periods (Kanfer & Karoly, 1972); (c) the socialization of the child; and (d) the ongoing reinforcement of the individual for using self-regulatory actions (Hayes, 1989; Kopp, 1982; Skinner, 1953). The teleological trap set here by the use of terms that connote future, purpose, or intent can be dealt with by recognizing that such apparently future-directed behaviors are actually determined by experience and by ongoing self-directed actions such as self-directed speech and self-directed imaging (Fuster, 1989).

Origins of the Model

Much of the present model linking inhibition to four executive functions was set forth by Bronowski (1967) 30 years ago. Bronowski's theory has been discussed in more detail elsewhere as it pertains to ADHD (Barkley, 1994). The present explication differs substantially from the initial application of Bronowski's ideas to ADHD (Barkley, 1994, 1995) in the following respects:

(a) the incorporation of portions of Fuster's (1989, 1995) theory and the views of others (Knights, Grabowecky, & Scabini, 1995; Milner, 1995) on the neuropsychological functions subserved by the prefrontal cortex into a new hybrid model; (b) the inclusion of more precise definitions of behavioral inhibition and self-regulation; (c) the addition of a motor control–fluency–syntax component to the model; (d) the inclusion of the self-regulation of drive and motivation as well as that of emotion in the model; (e) the reconfiguration of the model components more logically than before (Barkley, 1994); (f) the addition of numerous recent findings bearing on the linkages among these components and their applicability to ADHD; and (g) additional predictions about ADHD.

In some sense, the evidence reviewed in this article in support of the hypothesized link between inhibition and executive functions, and even the extension of Bronowski's (1967, 1977) theory to ADHD, would have been anticipated by his theory and could be viewed as subsequent validation of it. The model developed here also includes the later theory of Fuster (1989, 1995) on the neuropsychological functions of the prefrontal cortex, which was drawn from his extensive review of the animal and human neuropsychological literatures pertaining to these functions. Though developed independently, and for somewhat different purposes, Bronowski's and Fuster's models have a substantial number of similarities, so their combination into a hybrid model of behavioral inhibition and executive functions makes sense. Space permits only a brief summary of these two earlier theories to illustrate their many points of overlap.

Bronowski's Theory on the Uniqueness of Human Language

Bronowski (1977) identified four unique properties of human language that distinguish it from the languages of animals. He argued that human language is distinctive because it is not simply a means of communication but of reflection, during which plans of action are proposed, played out, and tested. Reflection can only happen if there is a delay between the arrival of a stimulus or event and the response to that event. Bronowski treated this capacity to inhibit and delay responses as the central and formative feature in the evolution of the unique features of human language. It is not just the response that is being delayed but the decision to respond (Bronowski, 1976). Four consequences flow from the evolution of this ability to inhibit and delay responses: prolongation, separation of affect, internalization, and reconstitution. The capacity to delay responses as well as the four consequent mental functions flowing from it are attributed to the brain's prefrontal cortex.

Prolongation is the ability to refer backward and forward in time and to exchange messages with others that propose action in the future. This prolongation of reference, or the relation of past events to future actions, requires a special form of memory. During the delay in responding, the features of the signal, situation, or event must be briefly prolonged, fixed, and held in some symbolic form, so they can be retained for later recall when they will serve to revive the responses associated with them in the future. The recall of the past and the manipulation of the imagery of recall permit the construction of hypothetical situa-

tions and their associated consequences. From such conjecturing, plans can be formulated and anticipatory behaviors initiated. This form of memory is, in a sense, remembering so as to do. It is similar to the contemporary concept of working memory in neuropsychology (for reviews, see Becker, 1994). For instance, Goldman-Rakic (1995) defined working memory as "the ability to keep an item of information in mind in the absence of an external cue and utilize that information to direct an impending response" (p. 57). This form of memory and the prolongation of reference it affords are said to permit both imagination and the concept of time. The recall of the past surely is of the self-past, and the holding in mind of present events is the self-present, both of which should contribute to self-awareness. Thus are the functions of working memory, hindsight, forethought, anticipatory set, sense of time, and self-awareness dependent on inhibition.

A second, subsidiary consequence of inhibition and response delay is the *separation of affect*. This refers to the separation of the emotional charge from the content of a message or event and, as a result, the separation of the emotional valence from the content of the response to the event. This involves the self-regulation of emotion apart from motor behavior, and it affords the generation of neutral responses despite emotionally provocative events that may elicit highly charged feelings within the individual. Examples include remaining silent or speaking calmly when angered.

The delay between event and response also permits time for the event to be referred to more than one center in the brain and gives rise to an inner discussion of alternatives before a response is formed. This *internalization of language* gives a unique form to human thought and speech. During the delay in responding, language comes to be turned on the self. It thereby moves from being primarily a means for communication with others to one of communication with the self, a means of reflection and exploration that permits the construction of hypothetical messages or responses before one is chosen to utter or perform. It also permits the creation of self-directed instructions and thereby becomes a fundamental tool for self-control. In supporting his assertions, Bronowski (1967, 1977) referenced the views of Vygotsky (1978, 1987), so they are briefly discussed here.

Vygotsky's (1978, 1987) theory on the development of private speech remains the most accepted view on the topic at this time (Berk, 1994). Such speech starts out as "speech uttered aloud by children that is addressed either to the self or to no one in particular" (Berk & Potts, 1991, p. 358). In its earliest stages, it is thought spoken out loud that accompanies ongoing action. As it matures, it functions as a form of self-guidance and direction by assisting with the formulation of a plan that will eventually assist the child in controlling his or her own actions (Berk & Potts, 1991). Gradually, speech becomes progressively more private or internalized, and behavior comes increasingly under its control; private speech thus becomes internal verbal thought that can exert a substantial controlling influence over behavior. This internalization of speech proceeds in an orderly fashion. It seems to evolve from more conversational, task-irrelevant, and possibly self-stimulating forms of speech to more descriptive, task-relevant forms and then on to more prescriptive and self-guiding speech. It then progresses to more

private, inaudible speech and finally to fully private, subvocal speech (Berk, 1986, 1994; Berk & Garvin, 1984; Berk & Potts, 1991; Bivens & Berk, 1990; Frauenglas & Diaz, 1985; Kohlberg, Yaeger, & Hjertholm, 1968).

The internalization of language brings with it the fourth consequence of inhibition, which Bronowski (1977) called *reconstitution*. It comprises two processes. The first is *analysis*, which is the decomposition of sequences of events or messages into their parts. This allows the progressive redistribution of the event or message to other parallel information-processing systems within the brain

> so that its cognitive content becomes more particularized, and its hortative content more generalized . . .. The physical world is pictured as made up of units that can be matched in language, and human language itself thereby shifts its vocabulary from command to description or predication. (Bronowski, 1977, p. 121)

The second process is *synthesis*, wherein these parts can be manipulated and used to construct or reconstitute entirely new messages or responses to others. In addition, because the units in such messages can represent and initiate units of behavior, those behavioral units also can be reconstituted into entirely novel behavioral structures. This gives a synthetic and increasingly hierarchical structure to both human language and behavior. Increasingly complex, novel units come to be formed out of more elemental ones, and thus a layered structure to behavior is created. Reconstitution, it is argued, creates the potential for original productivity in human language and hence in the human actions controlled by that language (Bronowski, 1977). The rules or syntax for the sequencing of these verbal and behavioral productions are an inherent part of the process of reconstitution.

Reconstitution is quite evident in verbal fluency and discourse because they represent the capacity to rapidly access and reconstitute parts of speech into complete messages for others. The speed, accuracy, fluency, syntax, and general efficiency with which cognitive content is translated into units of speech and then into whole messages to others reflect the synthetic function of reconstitution. Verbal reconstitution should be most evident in confrontational language tasks or in goal-directed speech or writing, where ideas must be rapidly conveyed to achieve the goal of the task. However, it should also be evident in goal-directed behavioral creativity in general because this reflects the capacity to generate a variety of novel, complex sequences of behavior directed toward goals. Various hypothetical futures and the potential responses to them can now be internally simulated and tested before one is executed.

Bronowski (1977) attributed these four executive functions to the prefrontal lobes. Consequently, theories of and research findings on the functions subserved by this cortex may have some bearing on the many questions left open by Bronowski's theorizing. They may also have something to say about ADHD, given that the origin of ADHD has been repeatedly ascribed to this same brain region (Benton, 1991; Heilman, Voeller, & Nadeau, 1991; Mattes, 1980). Several neuroimaging studies also support this view (Castellanos et al., 1994; Lou, Henriksen, & Bruhn, 1984; Lou, Henriksen, Bruhn, Borner, & Nielsen, 1989; Rapoport, 1996; Sieg, Gaffney, Preston, & Hellings, 1995).

Fuster's Theory of Prefrontal Functions

Fuster's (1989, 1995) theory of prefrontal functions was proposed apparently independently of Bronowski's (1977) model, yet the two have much in common. Fuster concluded that the overarching function of the prefrontal cortex is the formation of cross-temporal structures of behavior that have a unifying purpose or goal. It is the novelty of these behavioral structures, and especially the temporal discontiguities among their elements, that makes the prefrontal cortex essential in their formation. To a lesser extent, their complexity may additionally necessitate the involvement of the prefrontal cortex. However, complexity alone is not sufficient to place such acts within the purview of the prefrontal cortex. On the other hand, time being inserted between the elements of the contingency (i.e., event, responses, and consequences) would be sufficient to do so. Similarly, novelty of the response would also lead to involvement of the prefrontal lobes.

It is this synthesis of novel, cross-temporal behavioral structures mediating cross-temporal contingencies that requires the involvement of prefrontal functions. It is also the goal they subserve that defines these behaviors and gives them cohesion and direction. Smaller sequences of behavior linked over shorter time periods can be used to create longer, more complex units of behavior with increasing durations and complexities and longer term objectives. This pyramiding of simpler units of behavior into more complex ones produces a hierarchical structure to goal-directed behavior and bridges the temporal delays. This function is quite similar to Bronowski's (1977) concept of reconstitution.

Several functions must occur for behavioral structures to be linked across time. Two of these are temporally symmetrical and are called retrospective and prospective functions. The *retrospective function* entails the retention of information about past events that are held in their temporal sequence as they pertain to a goal. Such memory is provisional, having timeliness and term, and permits the referring of current events to previous events in a sequence as well as the retention of action-related information derived from that analysis. The retrospective function gives rise to formulation and retention of a goal-directed behavioral structure. This forms the *prospective function,* and it leads to a preparation to act in anticipation of events or an *anticipatory set.* The behavioral scheme and its relevant events are temporarily represented, deployed in the preparation to act and the execution of those actions, and retained until the goal has been accomplished. These functions are identical to Bronowski's (1977) concepts of prolongation, hindsight, and forethought, as well as to the neuropsychological concept of working memory (Fuster, 1989, 1995).

Fuster (1989, 1995) argued that the proficiency of working memory is dependent on response inhibition and interference control, just as Bronowski (1977) had done. It is in working memory that goals and intentions to act are retained and that action plans are formulated and used to guide the performance of the goal-directed responses. The delay in responding, during which the cross-temporal behavioral structures are being formed and retained, is a critical time that requires protection from a variety of sources of interference that can pervert, distort, or completely disrupt the planning taking place. Internal sources may also interfere, such as traces of information still held in working memory from the formation of immediately previous behavioral structures. This retention of previous motor plans past their timeliness and term can lead to perseveration of responding. Old habits more familiar to the individual or having similarity to ongoing behavior may likewise disrupt this synthetic, goal-directed function, as might impulses to immediate gratification.

The dissociation of an inhibitory function from a working memory function is not only conceptual but neuroanatomical as well. The inhibitory functions are ascribed to the orbital–frontal regions of the prefrontal cortex and its reciprocal interconnections with the ventromedial region of the striatum (Iverson & Dunnett, 1990). The functions of working memory are subserved by the dorsolateral region of the prefrontal cortex and its reciprocal connections to the more central region of the striatum (Iversen & Dunnett, 1990). Substantial evidence from neuropsychological and neuroimaging studies supports this dissociation (D'Esposito et al., 1995; Fuster, 1989, 1995; Goldman-Rakic, 1995; Iversen & Dunnett, 1990; Knights et al., 1995; Milner, 1995; Vendrell et al., 1995; Williams & Goldman-Rakic, 1995). Even within working memory, the retrospective (sensory) and prospective (motor setting) elements are likewise dissociable though interactive functions (Fuster, 1995; Goldman-Rakic, 1995). Each may be subserved by separate, neighboring, and interacting cortical regions in the dorsolateral prefrontal lobes.

This capacity for holding events in mind in a correct temporal sequence may give rise to the psychological sense of time (Michon, 1985). If so, time perception would be directly dependent on the integrity of working memory, as Bronowski (1977) claimed. A subjective sense of time would seem to be critical in Fuster's (1989, 1995) model as well, given his emphasis on the cross-temporal organization of behavior as being the major function of the prefrontal cortex. A capacity for marking time and sensing its passage would be essential to anticipatory setting of motor responses in preparation for the arrival of impending events. That sense would also be necessary for programming the syntax or temporal structure of the complex behavioral chains generated in the service of goal attainment.

The initiation and maintenance of cross-temporal, goal-directed actions require that the prefrontal cortex assist in regulating basic drive or motivational states in the service of such goal-directed acts. Otherwise, new behaviors would rarely be initiated or sustained on the way to their intended goal. Hence the self-regulation of drive and motivational states in the service of goal-directed actions appears to be another function of the prefrontal cortex. Fuster (1989, 1995) also recognized that disorders of the prefrontal cortex often give rise to disturbances in the regulation of affective and emotional states. Yet he found these difficult to interpret within his model. Bronowski (1977), in contrast, made the separation and self-regulation of affect one of the major consequences of delayed responding in his model. As discussed later, drive and motivation appear to be part of the same functional brain system that governs emotion (Lang, 1995), so the capacity to self-regulate affect may also entail the capacity to self-regulate motivation.

These functions of the prefrontal cortex clearly influence motor control. The prefrontal cortex is unnecessary for the performance of any motor act or even complex, overlearned responses. It is essential for the orderly execution of novel, complex behaviors having a cross-temporal structure. Thus, working memory, hindsight, forethought, sense of time, anticipatory set, and the goal-directed behavioral structures they create influence motor control, fluency, flexibility, syntax, and persistence as they pertain to goal-directed actions. This influence of executive functions over motor control could be seen in three ways, Fuster (1989) concluded (a) in the retention of information about past events and acts already executed that then feeds forward to influence subsequent responding (i.e., a sensitivity to errors), (b) in the anticipatory setting of the premotor and motor functions (i.e., a preparation to act), and (c) in the inhibition of motor impulses inappropriate to the goal or task. A lack of the inhibitory control that provides for the delay of responses and protection of the delay from interference would have many manifestations, Fuster reasoned, including distractibility, hyperreactivity, and impulsivity—the very symptoms attributed to ADHD.

A Hybrid Neuropsychological Model of Executive (Self-Regulatory) Functions

To combine the constructs identified in each of these highly overlapping theories into a single model appears to create a more thorough accounting of self-control through these executive functions than does either theory alone. For instance, Bronowski's (1977) theory places great emphasis on the internalization of speech, not only for the control over behavior it provides but also for its value in the creation of novel, complex goal-directed behaviors (reconstitution). Fuster (1989) initially overlooked this important realm of human self-regulation, perhaps because he was attempting to integrate the human and primate literatures to deduce the similarities in the functions of the prefrontal cortex. However, he included verbal behavior within the purview of his model of prefrontal functions (Fuster, 1995), though its role in self-control still seems undervalued. Fuster made explicit mention of the role of the prefrontal cortex in the creation of drive or motivational states that facilitate goal-directed behavior. Bronowski did not concern himself with this function, most likely because his brief essay was intended to focus primarily on the uniqueness of human language. Both noted the critical nature of a special kind of memory (working memory) that gives rise to hindsight, forethought, anticipatory behavior, and goal-directed or purposive action (see also Baddeley & Hitch, 1994). Bronowski additionally linked this special form of memory to the development of the subjective sense of time and the future.

Both theorists also noted the unique capacity of humans to create extraordinarily complex and novel behavioral structures in the service of attaining future goals, and both assigned this analytic–synthetic ability (reconstitution) to the prefrontal cortex. It is this function in combination with that of working memory that gives rise to the capacity for the internal simulation of potential behaviors or, as Bronowski (1977) noted, the conjecturing of hypothetical futures. Both theorists also observed that the syntax (organizational rules) of behavior generally, like

that of speech production specifically, appears to arise out of this special function of the prefrontal cortex, as others also noted (Knights et al., 1995). Thus, the combination of these theories into a hybrid model of executive prefrontal functions deals with the apparent gaps in each.

The hybrid model developed below specifies that behavioral inhibition permits the proficient performance of four executive abilities: working memory, internalization of speech, self-regulation of affect–motivation–arousal, and reconstitution. The four executive functions influence the motor system in the service of goal-directed behavior, labeled *motor control–fluency–syntax* in the model. The motor control–fluency–syntax component emphasizes not only the features of control or management of the motor system which these executive functions afford but also the synthetic capacity for generating a diversity of novel, complex responses and their sequences in a goal-directed manner. Such complex behavior requires a syntax that is placed for now within the reconstitution component of the model that must be translated into actual motor responding. So the generation of behavioral syntax is placed under the reconstitution component, whereas its translation into the actual execution of motor syntax is placed within the motor control component.

These functions originate within the brain's motor system, broadly construed (prefrontal and frontal cortex). However, they may also produce effects beyond the motor system, such as on the sensory–perceptual, linguistic, memory, emotional, and other brain systems in an executive, managerial manner to the extent that the regulation of those other brain systems is necessary for the execution of goal-directed behavior. Thus, although the memory, linguistic, spatial, emotional, or even perceptual systems are viewed as brain systems relatively independent of the prefrontal cortex, these nonexecutive systems may be influenced by the executive system as needed in the service of goal-directed behavior.

The model is shown in Figure 1, along with the subfunctions believed to take place within each component. I have already described most of these subfunctions, but a few have been added or modified slightly, particularly in the domains of the self-regulation of affect and in the internalization of speech, and so require brief clarification here.

Behavioral Inhibition

As previously defined, behavioral inhibition in Figure 1 refers to three inhibitory functions. These exert a direct controlling influence over the motor system, hence the direct downward arrow in Figure 1 between behavioral inhibition and motor control–fluency–syntax. Behavioral inhibition, however, does not directly cause the four intermediate executive functions to occur but merely sets the occasion for their performance. Visibly representing this crucial point, the lines connecting inhibition to those four executive functions are blunted. But because those executive functions produce direct and causal effects on motor control, arrows connect each executive function with motor control.

Self-Regulation of Affect–Motivation–Arousal

This component includes Bronowski's (1977) concept of the separation and self-regulation of affect. Unlike Bronowski, how-

Behavioral inhibition

Inhibit prepotent response
Stop an ongoing response
Interference control

Working memory

Holding events in mind
Manipulating or acting on the events
Imitation of complex behavior sequences
Retrospective function (hindsight)
Prospective function (forethought)
Anticipatory set
Sense of time
Cross-temporal organization of behavior

Self-regulation of affect/ motivation/arousal

Emotional self-control
Objectivity/social perspective taking
Self-regulation of drive and motivation
Regulation of arousal in the service of goal-directed action

Internalization of speech

Description and reflection
Rule-governed behavior (instruction)
Problem solving/self-questioning
Generation of rules and meta-rules
Moral reasoning

Reconstitution

Analysis and synthesis of behavior
Verbal fluency/behavioral fluency
Goal-directed behavioral creativity
Behavioral simulations
Syntax of behavior

Motor control/fluency/syntax

Inhibiting task-irrelevant responses
Executing goal-directed responses
Execution of novel/complex motor sequences
Goal-directed persistence
Sensitivity to response feedback
Task re-engagement following disruption
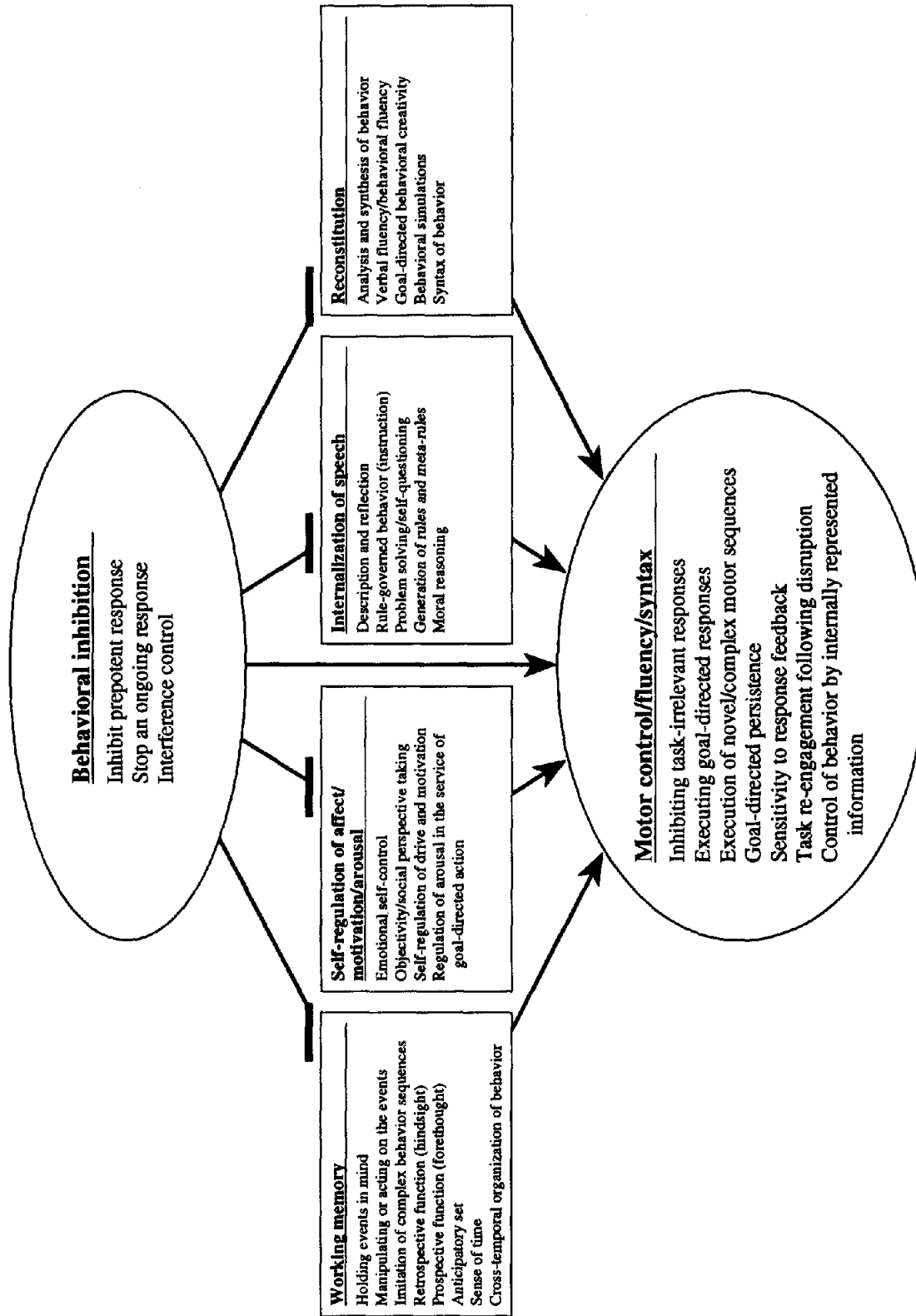Control of behavior by internally represented information

Figure 1. A schematic configuration of a conceptual model that links behavioral inhibition with the performance of the four executive functions that bring motor control, fluency, and syntax under the control of internally represented information.

ever, I believe that affect may not be completely separable from the decision to respond or even from the response itself (see Dimasio, 1994). Instead, a more self-regulatory role of the executive system is stressed here in that emotions, once elicited, come to be moderated or regulated by self-directed, executive actions. Included in this component is also the self-generation of drive or motivational and arousal states that support the execution of goal-directed actions and persistence toward the goal. This combination into a single component makes some sense. Lang (1995) cogently argued that the array of human emotions can be reduced to a two-dimensional model, of which one dimension is motivation (reinforcement and punishment) and the other, level of arousal. So the ability to self-regulate and even induce emotional states as needed in the service of goal-directed behavior also may involve the ability to regulate and induce motivation, drive, and arousal states in support of such behavior. Thus, children may learn to create more positive emotional and motivational states in themselves when angered, frustrated, disappointed, saddened, anxious, or bored by learning to manipulate the variables of which such negative states and their positive alternatives are a function (Cole, Zahn-Waxler, & Smith, 1994; Eisenberg et al., 1993; Kopp, 1989). Such self-directed actions may involve efforts at self-comforting, self-directed speech, visual imagery, and self-reinforcement, among other means (Kopp, 1989). This process of self-regulating affect may begin as early as 5–10 months of age (Stifter & Braungart, 1995). It is also conceivable that children may learn to self-regulate arousal levels for the purposes of goal accomplishment. This component of the model, therefore, includes the following subfunctions, all of which are performed in the service of goal-directed actions: (a) the self-regulation of emotion, (b) a capacity for objectivity and social perspective, (c) the self-regulation of drive and motivational states, and (d) the self-regulation of arousal.

Among the variety of human emotions, it may be the negative ones that are most in need of such self-control (Kopp, 1989). This is because negative affect may prove more socially unacceptable and thereby produce more salient, long-term negative social consequences for the individual relative to the positive emotions, such as laughter or affection. In the immediate context, such negative displays may achieve positive reinforcement or, more likely, escape from or avoidance of aversive events (Patterson, 1982, 1986).

Internalization of Speech

Fuster's (1989) model had little to say about the internalization of speech as a function of the prefrontal cortex. Bronowski (1977), however, stressed the uniqueness and importance of the self-direction and internalization of speech and the profound control it may exert on the individual's behavior. Developmental psychologists (Berk & Potts, 1991; Kopp, 1982) and developmental neuropsychologists (Vygotsky, 1978, 1987) have likewise emphasized the importance of this process for the development of self-control. So I have included it here. Berk and Potts argued that the influence of private speech on self-control certainly may be reciprocal—inhibitory control contributes to the internalization of speech, which contributes to even greater self-restraint and self-guidance. Despite this reciprocity, initial pri-

macy within this bidirectional process is given here to behavioral (motor) inhibition. Self-directed speech also is believed to provide a means for reflection, description, and self-questioning through language, creating an important source of problem-solving ability as well as a means of formulating rules and plans. Eventually, rules about rules (metarules) can be generated into a hierarchically arranged system that resembles the concept of metacognition in developmental psychology (Flavell, Miller, & Miller, 1993). The combination of internal speech with the prospective function of working memory (forethought) may well contribute to moral reasoning (the internalization of community norms, mores, or morals). And so I have listed these various functions related to internal speech under this component of Figure 1.

Although the progressive shift from public to private speech is fascinating in its own right, a more important aspect of this privatization may be the increasing control language comes to have over motor behavior with development (Berk & Potts, 1991; Vygotsky, 1978). This control has been referred to within behavioral analysis as rule-governed behavior (Cerutti, 1989; Hayes, 1989; Skinner, 1953). Rules are defined as behavior-specifying stimuli. Language constitutes a large class of such stimuli. Skinner hypothesized that this influence of language over behavior occurs in three stages: (a) the control of behavior by the language of others; (b) the progressive control of behavior by self-directed and eventually private speech, as discussed above; and (c) the creation of new rules by the individual, which came about through the use of self-directed questions (second order rules). Both Bronowski (1977) and Skinner stressed two important aspects of internalized speech. One was informational—the power of self-directed speech for description, reflection, and the creation of new rules by which to guide behavior (problem solving). The other was instructive—the power of these messages to actually control motor responses. Rule-governed behavior appears to provide a means of sustaining behavior across large gaps in time among the units of a behavioral contingency (event–response–consequence). By formulating rules, the individual can construct novel, complex (hierarchically organized), and prolonged behavioral chains. These rules can then provide the template for reading off the appropriate sequences of behavioral chains and can guide behavior toward the attainment of a future goal (Cerutti, 1989). By this process, the individual's behavior is no longer under the total control of the immediate surrounding context. Control of behavior is now shifted to internally represented information (rules). The control of behavior by the sense of past and future, as well as by the more general rules or metarules formulated from them or acquired through socialization, most likely makes some contribution to the development of conscience and moral reasoning (Hoffman, 1970; Kochanska, DeVet, Goldman, Murray, & Putnam, 1994).

Hayes (1989) and Cerutti (1989) stipulated a number of specific effects on behavior that rule governance produces. These become important later as predictions from the model about ADHD: (a) The variability of responses to a task is much less when rule-governed behavior is in effect than when behavior is contingency shaped (developed and maintained by the environmental contingencies alone); (b) behavior that is rule

governed may be less affected or entirely unaffected by the immediate contingencies operating in a situation or by momentary and potentially spurious changes in those contingencies; (c) when rules and immediate contingencies compete in a given situation, the rule is more likely to gain control over the individual's behavior, and this will be progressively more the case as the individual matures; (d) rule-governed responding under some conditions may be rigid or inflexible, even if the rule being followed is incorrect; and (e) self-directed rules permit individuals to persist in responding under conditions of very low levels of immediate reinforcement, or even in the absence of reward, as well as during extreme delays in the consequences for responding.

In short, self-directed rules assist with bridging temporal gaps in behavioral contingencies and thus contribute to the cross-temporal organization of behavior. The motor execution of such verbal rules appears to be partially dependent on the capacity to retain them in working memory and to inhibit prepotent or irrelevant responses that compete with the rule (Zelazo, Reznick, & Pinon, 1995).

Motor Control—Fluency—Syntax

The self-directed and frequently private actions constituting these four executive components serve to create a shift in the control of behavior, from control exclusively by the external environment to control by internally represented information (Fuster, 1989, 1995; Godbout & Doyon, 1995; Goldberg & Podell, 1995; Goldman-Rakic, 1995). Both sensory input as well as motor behavior that is unrelated to the goal and its internally represented behavioral structures become minimized or even suppressed. This occurs not only during the performance of these four executive functions but also during the execution of the complex, goal-directed motor responses they generate. Throughout the execution of goal-directed behaviors, working memory permits the feedback from the last response(s) to be held in mind (retrospective function) and fed forward (prospective function) to modify subsequent responding; thus a sensitivity to errors is created. Just as important, when interruptions in this chain of goal-directed behaviors occur, the individual is able to disengage, respond to the interruption, and then re-engage the original goal-directed sequence because that plan has been held in mind despite the interruption. Thus, inhibition sets the occasion for the engagement of the four executive functions, which then provide considerably greater control of behavior by the internally represented information they generate.

Extension of the Model to ADHD

Tremendous progress has been made in the last 2 decades in understanding the neuropsychological functions subserved by the prefrontal cortex. This progress has led to the development of theories for organizing and explaining these functions (Fuster, 1989, 1995). Increasing evidence suggests that ADHD appears to arise from abnormalities in the structure and function of the prefrontal cortex and its networks with other brain regions, especially the striatum (Castellanos et al., 1994; Heilman et al., 1991; Lou et al., 1984, 1989; Rapoport, 1996; Seig et al., 1995;

Zametkin et al., 1990). A model of prefrontal executive functions, therefore, should offer some promise as a model for understanding ADHD as well.

The hybrid model developed in Figure 1 predicts that the deficiency in behavioral inhibition that characterizes ADHD diminishes the effective deployment of the four executive abilities that subserve self-control and goal-directed behavior. This inhibitory deficit thereby indirectly disrupts the control of goal-directed motor behavior by its influence on these executive functions. As a consequence, the behavior of those with ADHD is controlled more by the immediate context and its consequences than is the behavior of others. The behavior of others, in contrast, is more controlled by internally represented information, such as hindsight, forethought, time, plans, rules, and self-motivating stimuli that ultimately provide for the maximization of future net outcomes.

What follows is a brief review of the evidence that supports the view of ADHD as a deficit in behavioral inhibition. This is followed by a selective review of evidence linking behavioral inhibition to each of the components of the present model. Fuster (1989, 1995) and others (Goldberg & Podell, 1995; Goldman-Rakic, 1995; Knights et al., 1995; Milner, 1995; Stuss & Benson, 1986) have reviewed a far more extensive body of evidence from both animal and human neuropsychological research that also supports the existence of these prefrontal functions and their link to inhibitory processes. More important to the purpose here, findings are reviewed that implicate the impairment of these functions among those with ADHD.

ADHD and Deficient Inhibition

The evidence supporting a deficiency in behavioral inhibition in ADHD comes from a number of sources. Many studies using parent and teacher ratings of hyperactive and impulsive behaviors in children find these behaviors to cluster into a single dimension, often called impulsive–hyperactive or undercontrolled behavior (Achenbach & Edelbrock, 1983, 1985; Goyette, Conners, & Ulrich, 1978; Hinshaw, 1987; Lahey et al., 1988, 1994). It is this dimension of behavior that, virtually by definition, distinguishes those with ADHD from others without it (Hinshaw, 1987, 1994). This argument, however, is circular; ratings of hyperactive–impulsive behavior are used to create a diagnostic category of ADHD, and then those with ADHD are found to differ on such ratings. The circularity is dealt with by evidence of external validation from sources other than parent–teacher ratings. Many studies that have used objective measures have shown that children rated as being more hyperactive–impulsive or who were clinically diagnosed as ADHD, in fact, displayed a higher activity level than other children not so rated or diagnosed (Gomez & Sanson, 1994; Porrino et al., 1983; see Luk, 1985, for a review). ADHD children also talk more than other children, whether to others (Barkley, Cunningham, & Karlsson, 1983; Cunningham & Siegel, 1987) or out loud to themselves (Berk & Potts, 1991; Copeland, 1979), and make more vocal noises than do other children (Copeland & Weissbrod, 1978). All of this may be taken as evidence of poor behavioral inhibition.

Children with ADHD, compared with controls, also have

more difficulties restricting their behavior in conformance with instructions to do so (Barkley & Ullman, 1975; Milich, Landau, Kilby, & Whitten, 1982; Routh & Schroeder, 1976; Ullman, Barkley, & Brown, 1978), deferring gratification (Campbell, Pierce, March, Ewing, & Szumowski, 1994; Rapport, Tucker, DuPaul, Merlo, & Stoner, 1986), and resisting temptation (Campbell et al., 1994; Campbell, Szumowski, Ewing, Gluck, & Breaux, 1982; Hinshaw, Heller, & McHale, 1992; Hinshaw, Simmel, & Heller, 1995). Again, a significant deficit in inhibition, especially in situations where rewards are immediately available for emitting impulsive responses, might be inferred from these results.

Further evidence of poor inhibition in ADHD comes from studies that used motor inhibition tasks, such as go–no-go paradigms (Iaboni, Douglas, & Baker, 1995; Milich et al., 1994; Shue & Douglas, 1989; Trommer, Hoeppner, Lorber, & Armstrong, 1988; Voeller & Heilman, 1988), the stop-signal task (Oosterlaan & Sergeant, 1995; Schachar & Logan, 1990; Schachar et al., 1993), the change paradigm (related to the stop-signal paradigm; Schachar et al., 1995), and delayed response tasks (Gordon, 1979; Schweitzer & Sulzer-Azaroff, 1995; Sonuga-Barke, Taylor, & Hepinstall, 1992; Sonuga-Barke, Taylor, Sembi, & Smith, 1992). Blurting out incorrect verbal responses and disrupting the conversations of others with such intrusive responses are considered primary symptoms of impulsiveness in those with ADHD (APA, 1994) and have been objectively documented (Malone & Swanson, 1993).

Numerous studies also demonstrate that children with hyperactivity or ADHD produce greater errors of commission on continuous performance tasks, whether computerized (Barkley, 1991; Barkley, DuPaul, et al., 1990; Barkley et al., 1992; Grodzinsky & Diamond, 1992; Robins, 1992; see Corkum & Siegel, 1993, for a review) or given by paper and pencil such as letter cancellation tasks (Aman & Turbott, 1986; Brown & Wynne, 1982; Carte, Nigg, & Hinshaw, in press; Keogh & Margolis, 1976). However, results for the latter tasks, particularly when self-paced, have proven contradictory (Gomez & Sanson, 1994; van der Meere, Wekking, & Sergeant, 1991). Problems with response inhibition in children with ADHD have even been noted on tasks that assess more molecular motor movements, such as occular gaze shifts on delayed response tasks (Ross, Hommer, Breiger, Varley, & Radant, 1994).

Poor behavioral inhibition likewise should be evident in deficient performances in learning under passive versus active avoidance paradigms. Here passivity or the inhibiting of a response is required to terminate, escape, or avoid punishment. In such tasks, those with ADHD have been found to show more such punished trials than is normal (Freeman & Kinsbourne, 1990; Milich et al., 1994). Poor behavioral inhibition also should be evident when a task requires stopping an ongoing response when signalled to do so or when feedback suggests that the response is ineffective or maladaptive. Many studies of those with ADHD have noted them to have such difficulties (Oosterlaan & Sergeant, 1995; Schachar & Logan, 1990; Schachar et al., 1993, 1995).

The stopping of an ongoing response pattern is required in the performance of the Wisconsin Card Sorting Test (WCST). Patients with frontal lobe damage often have difficulties on this test, and its performance has been associated with activation of the dorsolateral prefrontal cortex (Berman et al., 1995). Children with ADHD seem to have difficulties performing the WCST as well. Barkley et al. (1992) reviewed 13 studies that used the WCST, 8 of which found significant differences between ADHD and control participants. Methodological problems, such as low statistical power due to small samples and diverse age groups, may well have limited some of the studies that yielded nonsignificant findings. Performance on this test has been shown to improve with age in both children with ADHD and controls (Seidman et al., 1996). Family history of ADHD may also determine the severity of results (Seidman et al., 1996). Even so, of 6 additional studies of ADHD that used the WCST, 4 (Krener, Carter, Chaderjian, Wolfe, & Northcutt, 1993; McBurnett et al., 1993; Seidman et al., 1995, 1996) also found differences between ADHD and control groups on this test; the remaining 2 did not (Narhi & Ahonen, 1995; Pennington et al., 1993). Although the evidence is not entirely consistent, the weight of the evidence shows those with ADHD to have a problem with response perseveration, despite feedback about errors.

In keeping with this interpretation, Sergeant and van der Meere (1988) found that children with ADHD performing an information-processing task were less likely to alter their subsequent responding when they made an error than were children in the control group. Response perseveration in those with ADHD also has been demonstrated in research with the card-playing task (Milich et al., 1994). Similarly, patients with prefrontal lobe injuries have been noted to show persistence in a previously reinforced response pattern, even though the contingencies changed and they could verbally report that such changes occurred (Dimasio, 1994; Rolls, Hornak, Wade, & McGrath, 1994).

According to Fuster (1989), the failure to adjust motor performance given feedback concerning its ineffectiveness may actually reflect an interaction between behavioral inhibition and the retrospective–prospective functions of working memory. The individual fails to hold in mind information on the success of his or her responding on the immediately preceding trials (retrospection), which then feeds forward to influence or even stop immediately future responses (prospection leading to inhibition). If correct, this suggests that the cessation, shifting, and re-engagement of ongoing responses according to task feedback belongs under the motor control component of the model as an effect of working memory on this component. Regardless, this separation of motor shifting and re-engagement from behavioral inhibition has recently been demonstrated in children with ADHD, who were inferior to controls in both processes (Schachar et al., 1995). A distinction between the two processes also suggests that the perseverative responding seen on the WCST by those with ADHD may be less reflective of poor inhibition and more reflective of deficient working memory—an interpretation more consistent with neuroimaging research involving this test (Berman et al., 1995).

Evidence of Poor Interference Control

Evidence for poor interference control in those with ADHD comes from several sources. Studies that used the Stroop Color–

Word Interference Test with children having ADHD nearly always found them to perform poorly on this test. In a previous review (Barkley et al., 1992), six such studies were located, five of which found children with ADHD to take more time and make more errors than control children during the interference portion of the task. Four more studies produced similar results (Krener et al., 1993; Leung & Connolly, 1996; Pennington et al., 1993; Seidman et al., 1996). The consistency of such findings across studies is striking despite differences in cultures, group selection procedures, and sample sizes. It suggests that a deficiency in the control of interference from prepotent responses is reliably associated with ADHD. Group differences could not be attributed to comorbid learning or conduct disorders (Leung & Connolly, 1996; Pennington et al., 1993; Seidman et al., 1996), which argues for the specificity of these differences to ADHD. Neuroimaging research with this task has identified the orbital–prefrontal regions, particularly the right prefrontal region, as being involved in its performance (Bench et al., 1993; Vendrell et al., 1995). Other neuroimaging studies have found these regions to be significantly smaller than normal in children with ADHD (Castellanos et al., 1994; Rapoport, 1996).

The capacity to maintain performance toward a task despite distraction might also serve as an indicator of poor interference control. Whether or not distractors disrupted task performance, however, would depend on the prepotency of the response likely to be elicited by the distracting event as well as the extent to which any executive functions taking place during the task performance required protection from such interference. Those task-related factors calling for such executive control might be temporal delays, temporally related conflicts in consequences, and problem-solving tasks requiring the formulation of novel, complex responses. Research on ADHD suggests that distractions outside of the immediate task materials are unlikely to differentially affect the performances of children with and without ADHD; distractions embedded within the task seem more likely to do so (Leung & Connolly, 1996). The more salient the type of distraction, the more it occurs within the task; or the more that time and delays occur within the task parameters, the greater the likelihood that distractors will interfere with the task performance by ADHD children (Barkley, Koplowicz, & Anderson, 1996; Bremer & Stern, 1976; Cohen, Weiss, & Minde, 1972; Landau, Lorch, & Milich, 1992; Rosenthal & Allen, 1980; Steinkamp, 1980). Other evidence of poor interference control in ADHD might have been found in a study of college students with ADHD who had more task-irrelevant thoughts during performance of a continuous performance test than did the control group (Shaw & Giambra, 1993). Although this might imply poor interference control over internal sources of distraction, other interpretations could account for these findings.

The studies reviewed above indicate that children with ADHD have difficulties with behavioral inhibition on various tasks (see also Pennington & Ozonoff, 1996). Is there evidence for the inverse relationship as well? That is, do young children with poor behavioral inhibition have a higher likelihood of having symptoms of ADHD? Some studies suggest that this may be the case. Young children identified as more impulsive and less

able to delay responses, particularly in resistance-to-temptation tasks, have been rated by others as displaying higher levels of ADHD symptoms both concurrently and later in development (Campbell & Ewing, 1990; Mischel, Shoda, & Peake, 1988; Mischel, Shoda, & Rodriguez, 1989; Shoda, Mischel, & Peake, 1990; Silverman & Ragusa, 1991). Likewise, children with higher levels of activity at Age 2 displayed less self-control at Age 7 (Halverson & Waldrop, 1976).

To summarize, the evidence that ADHD involves impaired behavioral inhibition seems compelling, arising as it does from multiple studies, methods, and sources. Suggestive evidence from developmental psychology also points to the inverse relationship as well, that early deficits in behavioral inhibition may be predictive of risks for later ADHD symptoms.

Working Memory

The hybrid model in Figure 1 predicts that poor behavioral inhibition, as in ADHD, should lead to secondary deficiencies in working memory and its subfunctions. (a) Children with ADHD should be more influenced by context and less controlled by internally represented information than same-age peers without ADHD. (b) Children with ADHD should be more influenced by immediate events and their consequences than by those more distant in time. (c) Those with ADHD should be less likely to recall and hold in mind information about the past (hindsight) for the formulation of a plan in the future (forethought and planning). (d) Anticipatory or preparatory behaviors founded on such planning should be less evident in those with ADHD, so motor presetting in anticipation of the arrival of future events should likewise be less proficient. (e) A form of temporal myopia should exist in children with ADHD, in that behavior is more controlled by the temporal "now" than by internally represented information pertaining to the past, the future, and the sense of time. (f) Children with ADHD should exhibit less control of behavior by time and more deficient organization of behavior relative to time. (g) Performance under cross-temporal (if–then) contingencies should be less effective in those with ADHD because they cannot bridge the delays in the contingencies, using internally represented information. And (h) the larger the delays in time that separate the components of a behavioral contingency (events, responses, and their consequences), the less successful those with ADHD should be in effectively managing those tasks. There should also be less ability to successfully persist in goal-directed behavior in those with ADHD. And even when those with ADHD undertake goal-directed behavior, it should be subject to greater interference by sources of disruption in both the external and internal environments and result in less success at goal attainment.

The model in Figure 1 predicts six additional deficits in association with ADHD: (a) There should be an inability to imitate lengthy sequences of goal-directed behavior demonstrated by others, given that such sequences cannot be held in mind as well for the orchestration of their execution. (b) The sense of time should be impaired. (c) Information recalled from memory (retrospective function) should be temporally disorganized—that is, the very syntax of recall should be deficient. (d) Consequently, the syntax of motor planning and execution should like-

wise be disorganized. (e) Discourse with others should reflect fewer references to time, the past, and especially the future. And (f) significant deficiencies should exist in the performance of those social skills (i.e., sharing, cooperation, etc.) as well as other adaptive behaviors (i.e., concern for safety, health consciousness, etc.) that are predicated on the valuation of future personal and social consequences over immediate ones. The knowledge of those social and adaptive skills or behaviors is not at issue here; that knowledge should not be deficient in those with ADHD. It is the application of that knowledge in day-to-day functioning that should be impaired. The problem, then, for those with ADHD is not one of knowing what to do but one of doing what you know when it would be most adaptive to do so. This same problem is typical of patients with injuries to the prefrontal cortex (Delis, Squire, Bihrle, & Massman, 1992; Stuss & Benson, 1986).

Is there evidence for these predicted deficiencies in impulsive individuals or in those with ADHD? There is limited evidence, mainly because little research has specifically set out to test these predictions. Research on young children suggests that measures of response inhibition (resistance to temptation) appear to be significantly and positively associated with measures of memory for spatial location or working memory (Lee, Vaughan, & Kopp, 1983). The performance of delayed response tasks also requires waiting for a reward while keeping in mind its hidden location. Children as young as 18–30 months of age demonstrate both the presence of such working memory and its apparent dependence on response inhibition (Diamond, Cruttenden, & Neiderman, 1994).

Working memory has often been assessed in neuropsychological research with the following tasks: retention and oral repetition of digit spans (especially in reverse order); mental arithmetic, such as serial addition; locating stimuli within spatial arrays of information that must be held in memory; and holding sequences of information in memory to properly execute a task, as in self-ordered pointing tasks (see Becker, 1994; and Milner, 1995). Consistent with the model, children with ADHD appear to be less proficient in mental arithmetic (Ackerman, Anhalt, & Dykman, 1986; Barkley, DuPaul, et al., 1990; Mariani & Barkley, in press; Zentall & Smith, 1993). Both children and adults with ADHD have also shown more difficulties with repetition of digit spans (particularly backwards; Barkley, Murphy, & Kwasnik, 1996; Mariani & Barkley, in press; Milich & Loney, 1979), memory for spatial location (Mariani & Barkley, in press), and memory for finger-pointing or hand-movement sequences than have control group participants (Barkley, Murphy, & Kwasnik, 1996; Breen, 1989; Grodzinsky & Diamond, 1992; Mariani & Barkley, in press).

The Freedom From Distractibility factor of the Wechsler Intelligence Scale for Children–Revised comprises tests of digit span, mental arithmetic, and coding. These tests entail the use of working memory, among other mental functions. Children with ADHD score more poorly on this factor than do those without ADHD (Anastopoulos, Spisto, & Maher, 1994; Lufi, Cohen, & Parish-Plass, 1990; Milich & Loney, 1979). By themselves, such findings might suggest a variety of problems besides working memory (i.e., deficient arithmetic knowledge, slow motor speed, etc.). However, Zentall and Smith (1993) were able

to rule out these potential confounding factors in their study of mental computation in children with ADHD, thus giving greater weight to deficient working memory in ADHD.

The Tower of Hanoi and Tower of London tasks require that individuals be able to mentally represent and test out various ways of removing and replacing disks on a set of pegs or spindles before undertaking the actual motor execution of the rearrangement. Patients with injuries to the prefrontal cortex often have difficulty performing these tests (Goel & Grafman, 1995; Levin et al., 1994), and neuroimaging research has found activation of the prefrontal cortex to be involved in their performance (Morris, Ahmed, Syed, & Toone, 1993). Studies of ADHD that used these tasks found children with ADHD to perform both tasks more poorly than children without ADHD (Brady & Denckla, 1994; Pennington et al., 1993; Weyandt & Willis, 1994). The tasks have been interpreted (Pennington et al., 1993) as taxing three of the processes represented in the model: working memory, problem solving, and planning. Others, however, believe the Tower of London task at least reflects difficulties in inhibiting prepotent responses (Goel & Grafman, 1995).

The storage and recall of simple information in memory tests has not been found to be impaired in those with ADHD (Barkley, DuPaul, et al., 1990; Cahn & Marcotte, 1995; Douglas, 1983, 1988). Instead, it seems that when more, and more complex, information must be held in mind, especially over a lengthy delay period, deficits become evident (Douglas, 1983, 1988; Seidman et al., 1995, 1996). Also, when strategies are required for organizing material so as to remember it more effectively, those with ADHD perform less well than controls (August, 1987; Benezra & Douglas, 1988; Borcherding et al., 1988; Douglas, 1983; Douglas & Benezra, 1990; Felton, Wood, Brown, Campbell, & Harter, 1987; Frost, Moffitt, & McGee, 1989; Shapiro, Hughes, August, & Bloomquist, 1993).

The use of strategies by children with ADHD to organize complex material has primarily been studied with verbal information. Some studies, however, have used the Rey–Osterrieth Complex Figure Drawing Test. A number of studies of ADHD have identified organizational deficits (Douglas & Benezra, 1990; Grodzinsky & Diamond, 1992; Seidman et al., 1996), but a few others have not (Moffitt & Silva, 1988) or have found deficits only in children with ADHD and reading disorders (McGee, Williams, Moffitt, & Anderson, 1989). The two studies that found nonsignificant results used samples drawn from community screenings of children, whereas those studies that found differences used clinic-referred samples, which perhaps may explain these discrepant results.

As noted earlier, the incapacity to hold information in mind in those with ADHD creates a disability in imitating complex and lengthy behavioral sequences performed by others that may be novel to the individual. I found no studies of ADHD that expressly tested this prediction. However, several studies have found that children with ADHD are less proficient at imitating increasingly lengthy and novel sequences of simple motor gestures than are children without ADHD (Breen, 1989; Grodzinsky & Diamond, 1992; Mariani & Barkley, in press). Adults with ADHD have also been shown to be less able to replicate increasingly longer sequences involving pointing to locations than are adults without ADHD (Barkley et al., in press). Though

hardly definitive, such findings suggest that this prediction is worth testing in future studies of ADHD.

Figure 1 also links poor inhibition with an impaired sense of time (working memory). Gerbing, Ahadi, and Patton (1987) also argued that the performance of time estimation–production tasks may be related to impulsiveness, and White et al. (1994) found some evidence supporting that argument. But more direct evidence for an impairment in the sense of time in children with ADHD has been found in two separate studies by Cappella, Gentile, and Juliano (1977) and in three studies of mine, in which both rating scales assessing the sense of time and its regulation of child behavior and a time reproduction task similar to that used by Zakay (1992) were used (Barkley, Koplowicz, et al., 1996; Koplowicz & Barkley, 1995). In a fourth study, a trend ($p < .07$) was found toward less accurate time estimations by young adults with ADHD despite the limited statistical power of that study. All of these studies had a number of significant methodological flaws, which makes attempts at replication imperative, but their general consistency supports the hypothesis about an impaired sense of time in ADHD.

The model in Figure 1 also predicts that temporal delays should more adversely affect the performance of those with ADHD than that of controls. Numerous studies of ADHD have found that both delays interposed in tasks and temporal uncertainties produce poorer performances (Chee, Logan, Schachar, Lindsay, & Wachsmuth, 1989; Gordon, 1979; Sonuga-Barke, Taylor, & Hepinstall, 1992; Sonuga-Barke, Taylor, Sembi, & Smith, 1992; van der Meere, Shalev, Borger, & Gross-Tsur, 1995; van der Meere, Vreeling, & Sergeant, 1992; Zahn, Krusei, & Rapoport, 1991). Although supportive of a deficit in time, timing, and the cross-temporal organization of behavior in those with ADHD, such delays may simply create boredom and may increase off-task behavior in children with ADHD that proves detrimental to their performance, as suggested in Zentall's (1985) optimal stimulation theory.

Hindsight and forethought have not been well studied in those with ADHD. But if in its most elementary form hindsight can be taken to mean the ability to alter subsequent responses on the basis of immediately past mistakes, then the research findings imply a deficit in hindsight in those with ADHD. Children with ADHD, like adults with prefrontal lobe injuries (Milner, 1995), are less likely to adjust their subsequent responses on the basis of an immediately past incorrect response in an information-processing task (Sergeant & van der Meere, 1988). The findings of perseveration on the WCST, as noted earlier, also suggest such a problem.

Research that used complex reaction time tasks with warning stimuli and preparation intervals may be relevant to the construct of forethought. In such research, children with ADHD often failed to use the warning stimulus to prepare for the upcoming response trial (Douglas, 1983), and longer preparatory intervals were associated with poorer performance in children with ADHD than in control children (Chee et al., 1989; van der Meere et al., 1992; Zahn et al., 1991). The capacity to create and maintain anticipatory set for an impending event also has been shown to be impaired by ADHD (van der Meere et al., 1992).

Maze performance may reflect planning ability or fore-

thought. Some studies have found children with ADHD to perform poorly on maze tasks; others, however, have not (Barkley et al., 1992; Grodzinsky & Diamond, 1992; Mariani & Barkley, in press; McGee et al., 1989; Milich & Kramer, 1985; Moffit & Silva, 1988). The young age of the participants may be a factor in some of the negative findings (Mariani & Barkley, in press), as may be the low power associated with the use of small samples ($n < 20$ per group; Barkley et al., 1992; McGee et al., 1989; Moffit & Silva, 1988). As noted earlier, the Tower of Hanoi and Tower of London tasks may reflect the capacity to plan or "look ahead" (Pennington et al., 1993), and children with ADHD performed poorly on these tasks. Although they are hardly definitive, the findings reviewed here are at least suggestive of deficiencies in hindsight, forethought, and planning ability.

No researchers of ADHD have examined verbal references to time, plans for the future, the future more generally, and other aspects of hindsight and forethought in discourse with others. Also, just how well those with ADHD are able to temporally tag or organize their recall and internal representation of sequential events has not been studied. Such deficits are common in patients with prefrontal lobe injuries (Gershberg & Shimamura, 1995; Godbout & Doyon, 1995), however, which argues for their likely impairment in those with ADHD as well. Recent research on the verbal discourse of children with ADHD (Tannock, 1996) found deficits in the children's organization of sequential material in the retelling of stories, which might imply such a difficulty. Prior studies of narrative ability (Tannock, Purvis, & Schachar, 1992) and elicited language (Zentall, 1988) have also noted organizational deficits in children with ADHD. Although organizational deficits in discourse are suggested by these results, they may also reflect the presence of comorbid language problems known to exist in a substantial minority of children with ADHD (Cantwell, & Baker, 1992). Possibly ruling against such an interpretation is that Tannock (1996) used a control group of children with reading disorders who were known to have language problems, and she still found greater organizational deficits in the ADHD group.

The present model suggests that those with ADHD are less well controlled by internally represented information than are others. Like patients with prefrontal lobe injuries (Stuss & Benson, 1986), those with ADHD may be more controlled by external stimuli. For instance, patients with prefrontal injuries are more likely than nonpatients to have objects in the surrounding context elicit responses that may be appropriate as far as the objects' use is concerned but that are not appropriate in that particular context (e.g., opening an umbrella found inside an examination room; Goldberg & Podell, 1995); such phenomena are referred to as "utilization behavior." The model predicts that utilization behavior should be more evident in children with ADHD, yet no research has been conducted on the issue. Such research might profit from borrowing the methodologies used to study this issue in patients with brain injury (see Goldberg & Podell, 1995).

As noted earlier, those with ADHD have more trouble doing what they know than knowing what to do. Suggestive of this are past studies that have found hyperactive–impulsive children to be more prone to accidents than children who are not so

diagnosed (Bijur, Golding, Haslum, & Kurzon, 1988; Gayton, Bailey, Wagner, & Hardesty, 1986; Methany & Fisher, 1984; Taylor, Sandberg, Thorley, & Giles, 1991), yet hyperactive–impulsive children are not deficient in their knowledge of safety or accident prevention (Mori & Peterson, 1995). Barkley et al. (in press) also found that teens and young adults with ADHD have significantly more motor vehicle accidents and exhibit other driving risks (speeding) but demonstrate no deficiencies in their knowledge of driving, safety, and accident prevention.

Self-Regulation of Affect–Motivation–Arousal

Inhibition is important in the development of emotional self-regulation (Kopp, 1989). Figure 1 makes the following predictions about those who have deficiencices in inhibition, as in ADHD. They should show (a) greater emotional reactivity to emotionally charged immediate events; (b) fewer anticipatory emotional reactions to future emotionally charged events (in view of the decreased capacity for forethought); (c) decreased ability to act with the impact of their emotions on others in mind; (d) less capacity to induce and regulate emotional, drive or motivational, and arousal states in the service of goal-directed behavior (the further away in time the goal, the greater the incapacity to sustain the arousal and drive toward the goal); and, the corollary of d, (e) a greater dependence on external sources affecting drive, motivation, and arousal that are within the immediate context in determining the degree of persistence of effort in goal-directed actions.

Only a few of these predictions have been examined in research. The development of inhibition has been shown to be important for developing self-regulation of emotion and motivation (see Garber & Dodge, 1991; Kopp, 1989; and Mischel et al., 1989, for reviews). Preschool children's emotional responses to disappointment also have been shown to be related to self-regulation and disruptive behavior patterns (Cole et al., 1994). Similarly, children's emotional intensity and negative emotion have also been related to teacher ratings of interference control (Eisenberg et al., 1993). And Shoda et al. (1990) also found significant associations between inhibition in a resistance-to-temptation task in children's preschool years and parent ratings of the same children's emotional control and frustration tolerance at adolescence.

More evidence of a link between inhibition and emotional self-regulation comes from research on neurologically injured patients. Disorders of emotion are common in individuals with injury sustained to the prefrontal cortex, which suggests that this region is critical not only for inhibition but for the self-control of emotion (Fuster, 1989; Rolls et al., 1994; Stuss & Benson, 1986). The emotional changes secondary to frontal lobe injury can be grouped into three types of disturbance: (a) disorders of drive or motivation, (b) subjective emotional experience (mood), and (c) emotional expression (affect; Stuss, Gow, & Hetherington, 1992). Emotional hyperreactivity, irritability, low frustration tolerance, loss of emotional self-control, and lack of concern for others (Rolls et al., 1994) are commonly noted in such patients. Although these findings are suggestive of a link between behavioral inhibition and emotional self-regulation, they do not confirm it.

Irritability, hostility, excitability, and a general emotional hyperresponsiveness toward others have been frequently described in the clinical literature on ADHD (see Barkley, 1990; Still, 1902). Douglas (1983, 1988) anecdotally observed and later objectively documented the tendency of children with ADHD to become overaroused and excitable in response to rewards and to be more visibly frustrated when past rates of reinforcement declined (Douglas & Parry, 1994; Wigal et al., 1993, cited in Douglas & Parry, 1994). Rosenbaum and Baker (1984) also reported finding greater negative affect expressed by children with ADHD during a concept learning task involving noncontingent negative feedback. And Cole et al. (1994) found that levels of negative affect were significantly and positively correlated with symptoms of and risk for ADHD but only in boys. The opposite proved true for girls.

The foregoing studies intimate that emotional self-control may be problematic for children with ADHD. However, children with ADHD may experience a greater number of failures on such tasks because of their other cognitive deficits (working memory) or comorbid learning disabilities that could lead to greater frustration and other negative emotional reactions. Future researchers must therefore take care to equate the levels of success between children with and without ADHD before concluding that children with ADHD are more emotional during their performance on learning tasks.

Greater emotional reactivity has been reported as well in the social interactions of children with ADHD. E. J. Mash (personal communication, February 1993) found that children with ADHD displayed greater emotional intonation in their verbal interactions with their mothers than children without ADHD. Studies of peer interactions have also found children with ADHD, compared with those without ADHD, to be more negative and emotional in their social communications with peers (Pelham & Bender, 1982). The commonly noted association of ADHD with defiant and hostile behavior (for reviews, see Barkley, 1990; and Hinshaw, 1987) may, at least in part, stem from a deficiency in emotional self-regulation in those with ADHD. Again, however, these findings are merely suggestive rather than confirmatory of such a link.

The model also predicts that the perception of others' emotions will not be affected by ADHD because such perception is nonexecutive in nature. The only study of this issue of which I am aware supports this view (Shapiro et al., 1993), but caution must be exercised, given the many possible explanations for a failure to reject the null hypothesis.

As for ADHD being associated with less drive, motivation, or effort in the performance of goal-directed behaviors, researchers have frequently commented on the appearance of such difficulties when those with ADHD perform repetitive tasks that involve little or no reinforcement (Barber, Milich, & Welsh, 1996; Barkley, 1990; Douglas, 1972, 1983, 1988). Written productivity in arithmetic tasks, in particular, may be taken as a measure of persistence; those with ADHD are often found to be less productive on such tasks than control children (Barkley, DuPaul, et al., 1990). Multiple studies also have documented an impairment in persistence of effort in laboratory tasks with children with ADHD (August, 1987; Barber et al., 1996; Borcherding et al., 1988; Douglas & Benezra, 1990; Milich, in press; van der

Meere, Hughes, et al., 1995; Wilkison, Kircher, McMahon, & Sloane, 1995). Thus, the evidence for difficulties in the self-regulation of motivation (effort) in those with ADHD is fairly impressive.

It is possible that this component of the model (self-regulation of motivation) provides an explanation for the apparent insensitivity to reinforcement reported in some studies of children with ADHD (see Barkley, 1989; Douglas, 1988; Haenlein & Caul, 1987; and Sagvolden, Wultz, Moser, Moser, & Morkrid, 1989, for reviews). Studies that used varying schedules of reinforcement typically found that children with and without ADHD did not differ in their task performances under immediate and continuous reward (Barber et al., 1996; Cunningham & Knights, 1978; Douglas & Parry, 1983, 1994; Parry & Douglas, 1983). In contrast, in some studies when partial reinforcement was introduced, the performance of children with ADHD declined relative to that of children without ADHD (Parry & Douglas, 1983; Freibergs & Douglas, 1969). Just as many studies, however, did not find this decline (Barber et al., 1996; Pelham, Milich, & Walker, 1986) or found that the difficulty of the task moderated the effect (Barber & Milich, 1989). In a similar vein, the performance of children with ADHD during relatively tedious tasks involving little or no reward was often enhanced by the addition of reinforcement, yet so was the performance of children without ADHD (Carlson & Alexander, 1993; Iaboni et al., 1995; Kupietz, Camp, & Weissman, 1976; Pelham et al., 1986; Solanto, 1990; van der Meere, Hughes, Borger, & Sallee, 1995). These findings have been interpreted as suggesting that children with ADHD have a reduced sensitivity to reinforcement (Haenlein & Caul, 1987) or are dominated by immediate reinforcement (Douglas, 1983; Sagvolden et al., 1989). But the similar enhancement of the performance of children without ADHD by reward in some studies has challenged this interpretation (Pelham et al., 1986; Solanto, 1990). Douglas (Iaboni et al., 1995) also did not find the predicted reward dominance effect in those with ADHD.

The model in Figure 1 suggests a more plausible explanation for these results. It focuses on the observations that the performance of children without ADHD is superior to that of those with ADHD under conditions of little or no reward and may be less affected by reductions in schedules of reinforcement depending on the task duration and its difficulty level. This may result from children without ADHD developing the capacity to bridge temporal delays between the elements of behavioral contingencies through the executive functions in the model. Combined with working memory as well as self-directed speech and the rule-governed behavior it permits, the self-regulation of motivation may allow children without ADHD not only to retain the goal of their performance in mind and subvocally encourage themselves in their persistence but also to create the drive necessary for such persistence. This line of reasoning suggests that, across development, the behavior of those with ADHD remains more contingency shaped, or more under the control of the immediate and external sources of reward, than does the behavior of children without ADHD. Children without ADHD are becoming increasingly rule governed and internally controlled. Therefore, it is not that children with ADHD are less sensitive to reinforcement or are dominated by a tendency to seek immediate

rewards. Rather, they have a diminished capacity for self-regulation of motivation (effort) as well as poorer working memory and internalized self-speech, all of which assist with bridging delays in reinforcement and permit the persistence of goal-directed acts despite a dearth of immediate reinforcement for doing so.

Concerning the self-regulation of arousal, some evidence does exist for possible problems in those with ADHD in the regulation of central and autonomic nervous system arousal for meeting task demands. Multiple reviews of the psychophysiological (Brand & van der Vlugt, 1989; Hastings & Barkley, 1978; Klorman et al., 1988; Rosenthal & Allen, 1978; Rothenberger, 1995) and cognitive (Douglas, 1983, 1988) literatures have concluded that children with ADHD show greater variability in central and autonomic arousal patterns and seem underreactive to stimulation in evoked response paradigms, particularly in the later P300 features of the evoked response. These P300 characteristics have been shown to be associated with frontal lobe activation (Klorman, 1992; Klorman et al., 1988; Knights et al., 1995). Children with ADHD, relative to control groups, have also been shown to display less anticipatory activation on electroencephalograms in response to impending events within tasks, known as the contingent negative variation (CNV) or "expectancy" wave (Hastings & Barkley, 1978), and to have less recruiting of psychophysiological activity over the frontal regions when necessary for appropriate task performance (Brand & van der Vlugt, 1989; Rothenberger, 1995). Studies that used positron emission tomography (PET) to measure brain activity also found diminished brain activation in adults as well as in adolescent girls with ADHD (Ernst et al., 1994; Zametkin et al., 1990). Results obtained with adolescent boys were more equivocal (Zametkin et al., 1993). Similarly, studies that used cerebral blood flow to measure brain activity found decreased perfusion of the frontal regions and striatum in those with ADHD (Lou et al., 1984, 1989; Seig et al., 1995). The evidence available to date is certainly suggestive of problems in the regulation of arousal or activation in those with ADHD, with much of this evidence implicating frontal lobe underactivity.

Internalization of Speech

The association of uninhibited behavior with less mature self-directed speech, rule governance of behavior, and moral reasoning, as stipulated in Figure 1, has been suggested in studies of school children (Kochanska et al., 1994; Weithorn & Kagen, 1984; Zelazo et al., 1995). The few studies dealing with these issues in hyperactivity or ADHD have also found such an immaturity (Berk & Potts, 1991; Copeland, 1979; Gordon, 1979; Rosenbaum & Baker, 1984). Furthermore, children with ADHD are less compliant with directions and commands given by their mothers than are those without ADHD (see Danforth, Barkley, & Stokes, 1991, for a review). Children with ADHD are also less able to restrict their behavior in accordance with experimenter instructions to do so during lab playroom observations when rewarding activities are available for not doing so (see Luk, 1985, for a review). And in studies noted earlier, children with ADHD were found to be much less able to resist forbidden temptations than were same-age peers without ADHD. Such

rule following seems to be particularly difficult for children with ADHD when the rules compete with rewards available for rule violation (Hinshaw et al., 1992, 1995). These results might indicate problems with the manner in which rules and instructions control behavior in children with ADHD.

Further evidence consistent with delayed rule-governed behavior comes from studies showing that children with ADHD are less adequate at problem solving (Douglas, 1983; Hamlett, Pellegrini, & Conners, 1987; Tant & Douglas, 1982) and are also less likely to use organizational rules and strategies in their performance of memory tasks (August, 1987; Douglas & Benezra, 1990; Voelker, Carter, Sprague, Godowski, & Lachar, 1989), particularly where effort must be applied in doing so (Butterbaugh et al., 1989). Problem solving and the discovery of such strategies may be a direct function of rule-governed behavior (Cerutti, 1989). Similar deficits have also been noted in patients with prefrontal injuries (Delis et al., 1992; Verin et al., 1993).

Consistent with the predictions of Hayes (1989) noted earlier concerning the specific effects of rule governance on behavior, children with ADHD seem to (a) demonstrate significantly greater variability in patterns of responding to laboratory tasks, such as those involving reaction time or continuous performance tests (see Corkum & Siegel, 1993; Douglas, 1983; and Douglas & Peters, 1979, for reviews; van der Meere & Sergeant, 1988b, 1988c; Zahn et al., 1991); (b) perform better under conditions of immediate versus delayed rewards; (c) have significantly greater problems with task performance when delays are imposed within the task and as these delays increase in duration; (d) display a greater and more rapid decline in task performance as contingencies of reinforcement move from being continuous to intermittent; and (e) show a greater disruption in task performance when noncontingent consequences occur during the task (see Barkley, 1989; Douglas, 1983; Haenlein & Caul, 1987; and Sagvolden et al., 1989, for reviews; see also Douglas & Parry, 1994; Freibergs & Douglas, 1969; Parry & Douglas, 1983; Schweitzer & Sulzer-Azaroff, 1995; Sonuga-Barke, Taylor, & Hepinstall, 1992; Sonuga-Barke, Taylor, Sembi, & Smith, 1992; Zahn et al., 1991). The difficulties that children with ADHD have working for delayed rewards in delay-of-gratification tasks have also been previously noted (Rapport et al., 1986).

However, as discussed earlier, others have not found evidence for d above—that partial reinforcement schedules are necessarily detrimental to the task performances of children with ADHD relative to their performance under continuous reinforcement (Barber et al., 1996; Cunningham & Knights, 1978; Douglas & Parry, 1983; Pelham et al., 1986). Instead, the schedule of reinforcement appears to interact with task difficulty in determining the effect of reinforcement on performance by children with ADHD (Barber & Milich, 1989). It is also possible, as suggested earlier, that differences in the delay periods between reinforcement contribute to these inconsistent findings; if delay intervals are sufficiently brief, no differences between children with ADHD and without ADHD under partial reinforcement should be noted. So studies of reinforcement schedules and children with ADHD cannot be interpreted in any straightforward fashion as supportive of the view that poor rule-governed

behavior underlies any problem children with ADHD may have with partial reinforcement schedules. As noted above, Barber et al. (1996) suggested that an inability to sustain effort over time may better explain these findings. And so these results seem more suggestive of poor self-regulation of motivation.

Children with ADHD have been shown to have more difficulty spontaneously developing a strategy to organize material to be memorized (August, 1987). Even after being given an organizational rule to follow and initially benefiting from its usage in the task, children with ADHD eventually decline in their adherence to the strategy in later trials (August, 1987). Similarly, Conte and Regehr (1991) found that hyperactive children had more difficulties with transfering initially learned rules to new learning tasks and required more hints to aid in the transfer. Both studies imply a problem with the manner in which rules are extracted and deployed by children with ADHD in governing their own behavior. Comparable difficulties have also been noted in patients with prefrontal lobe injuries (Gershberg & Shimamura, 1995; Kesner, Hopkins, & Fineman, 1994).

Figure 1 indicates that internalized speech contributes to moral reasoning, probably in concert with the retrospective and prospective functions of working memory. Consistent with this model, delays in moral development, especially if characterized by hedonistic moral reasoning, have been found to be significantly predictive of disruptive and aggressive classroom behavior, diminished social competencies, and, consequently, diminished social status (Bear & Rys, 1994). Moral reasoning also has been shown to be less well developed in hyperactive–impulsive children or those with ADHD (Hinshaw, Herbsman, Melnick, Nigg, & Simmel, 1993; Nucci & Herman, 1982). That this is due to deficient internalization of speech is less certain.

Reconstitution

Within the domain of verbal behavior, tests of verbal fluency, confrontational story narratives or writing, joint peer communication tasks, or other situations and tasks that demand the accurate and efficient communication of information should reflect the process of reconstitution. This process should also be evident in nonverbal behavior and in problem-solving tasks requiring complex and novel motor sequences or goal-directed behavioral creativity. This facility for the creation of multiple novel, complex alternative response sequences, whether in language or motor behavior, is often impaired in patients with damage to the prefrontal lobes (Fuster, 1989, 1995; Milner, 1995; Stuss & Benson, 1986).

The model in Figure 1 predicts that those with ADHD also should manifest greater difficulties with tasks, settings, and interpersonal interactions in which reconstitution is essential. There is evidence suggestive of just such deficiencies within the domain of verbal behavior and discourse in those with ADHD. Children with ADHD have been noted to perform more poorly on tests of simple verbal fluency (Carte et al., in press; Grodzinsky & Diamond, 1992), although others have not documented such differences (Fischer, Barkley, Edelbrock, & Smallish, 1990; Loge, Staton, & Beatty, 1990; McGee et al., 1989; Weyandt & Willis, 1994). The discrepancy in findings may pertain, in part, to the type of fluency test used. Tests in which partici-

pants generate words within semantic categories (Weyandt & Willis, 1994), such as names for animals or fruits, are easier and so are not as likely to discriminate between children with ADHD and controls as are those that use more subtle organizing cues, such as letters (Grodzinsky & Diamond, 1992). Age may also be a factor given that older children with ADHD may have far fewer difficulties on such simple fluency tests than younger children with ADHD (Grodzinsky & Diamond, 1992; Fischer et al., 1990). Low statistical power and the use of nonclinical samples (Loge et al., 1990; McGee et al., 1989) could also have contributed to the inconsistencies in results across studies. So it is not clear as yet that simple word fluency is impaired in children with ADHD.

Studies of more complex language fluency and discourse organization, however, have been more likely to reveal problems in children with ADHD. Children with ADHD, compared with those without ADHD, appear to produce less speech in response to confrontational questioning (Tannock, 1996; Ludlow, Rapoport, Bassich, & Mikkelson, 1980), are less competent in verbal problem-solving tasks (Douglas, 1983; Hamlett et al., 1987), and are less capable of communicating task-essential information to peers in cooperative tasks (Whalen, Henker, Collins, McAuliffe, & Vaux, 1979). They also produce less information and less organized information in their story narratives (Tannock, 1996; Tannock et al., 1992; Zentall, 1988) and in describing their own strategies used during task performance (Hamlett et al., 1987). When no goal or task is specified, the verbal discourse of children with ADHD does not appear to differ from that of children without ADHD (Barkley et al., 1983; Zentall, 1988). I could find no studies of nonverbal motor or gestural fluency and behavioral simulation in children with ADHD, however, so the predictions of the model for this domain of reconstitution remain untested.

The evidence for a deficit in behavioral or verbal creativity, as opposed to fluency, is considerably weaker, primarily because so few researchers have examined the issue as well as because of problems in the very definition of creativity itself (Brown, 1989). Creativity during free play (Alessandri, 1992) and performance of nonverbal, figural creativity tasks (Funk, Chessare, Weaver, & Exley, 1993) have been noted to be significantly below normal levels in children with ADHD. However, Shaw and Brown (1990) did not find a deficit in creativity in a small sample of high-IQ children with ADHD. They did find that those with ADHD gathered and used more diverse, nonverbal, and poorly focused information and displayed higher figural creativity. The use of so small a sample and of only bright children with ADHD, however, hardly makes for a reasonable test of this prediction. More research on creativity in ADHD is clearly needed.

Motor Control—Fluency—Syntax

Inhibition and the executive functions described in Figure 1 contribute greater control, timing, persistence, flexibility, novelty, complexity, and syntax to motor actions that are goal directed (Fuster, 1989, 1995). These effects may assist with the development of ever finer, more varied and complex, and more hierarchically organized patterns of motor responses directed

toward goals. Some evidence exists for a linkage of behavioral inhibition with this type of motor control. In the research literature on ADHD, motor problems also have been noted (Barkley, DuPaul, et al., 1990; Hartsough & Lambert, 1985; Stewart, Pitts, Craig, & Dieruf, 1966; Szatmari, Offord, & Boyle, 1989), but they have rarely been discussed for their theoretical implications except, perhaps, by Denckla (1985). Neurological examinations for "soft" signs related to motor coordination and motor overflow movements find children with ADHD to demonstrate more such signs and movements than control children, including those with purely learning disabilities (Carte et al., in press; Denckla & Rudel, 1978; Denckla, Rudel, Chapman, & Krieger, 1985; McMahon & Greenberg, 1977; Shaywitz & Shaywitz, 1984; Werry et al., 1972). These overflow movements have been interpreted as indicators of delayed development of motor inhibition (Denckla et al., 1985).

Studies that used tests of fine motor coordination, such as balance, fine motor gestures, electronic or paper-and-pencil mazes, and pursuit tracking, often found children with ADHD to be less coordinated in these actions than controls (Hoy, Weiss, Minde, & Cohen, 1978; Mariani & Barkley, in press; McMahon & Greenberg, 1977; Moffitt, 1990; Shaywitz & Shaywitz, 1984; Ullman et al., 1978). Simple motor speed, as measured by finger-tapping rate or grooved pegboard tests, does not seem to be as affected in children with ADHD as is the execution of complex, coordinated sequences of motor movements (Barkley et al., in press; Breen, 1989; Grodzinsky & Diamond, 1992; Mariani & Barkley, in press; Seidman et al., 1995, 1996). The bulk of the available evidence, therefore, supports motor control deficits in ADHD.

But the most rigorous and compelling body of evidence for a motor control deficit in ADHD comes from the substantial programmatic research of Sergeant, van der Meere, and their colleagues in Holland (Sergeant, 1995a). Using an information-processing paradigm, these researchers have isolated the cognitive deficit in those with ADHD to the motor control stage rather than to an attentional or information-processing stage. More specifically, their research suggests that the deficit is not at the response choice stage but at the motor presetting stage involved in motor preparedness to act (Oosterlaan & Sergeant, 1995). Fuster (1989) identified this type of motor preparedness, or anticipatory set, as one of the major effects that the executive functions would have on motor control. But he also identified a sensitivity to errors or response feedback as being a second influence the executive functions would have over the motor control system. Deficits in behavioral inhibition should lead to an insensitivity to errors and to a loss of behavioral flexibility as a consequence (Fuster, 1995; Knights et al., 1995; Milner, 1995). As noted earlier, research has also identified such an insensitivity in children with ADHD (Oosterlaan & Sergeant, 1995; Sergeant & van der Meere, 1988).

Complex motor sequencing and the generating of complex, novel motor responses as well as their syntax have not received much attention in research on ADHD. Handwriting, however, is just such a complex sequencing of simpler motor movements built into complex, novel patterns of new arrangements of letters, words, and sentences that requires great flexibility and fluency of fine motor movement. Handwriting has often been

noted in the clinical literature (Sleator & Pelham, 1986) to be less mature in those with ADHD. Difficulties with drawing have likewise been found in children with ADHD (Hoy et al., 1978; McGee, Williams, & Feehan, 1992). And those with ADHD have been found to be more likely to have speech problems relative to controls (Barkley, DuPaul, et al., 1990; Hartsough & Lambert, 1985; Munir, Biederman, & Knee, 1987; Szatmari et al., 1989; Taylor et al., 1991). All of these findings might imply problems with the programming and rapid execution of complex, fine motor sequences in those with ADHD.

One test that seems to capture a simpler form of motor sequencing is the Hand Movements Test from the Kaufman Assessment Battery for Children (Kaufman & Kaufman, 1983). Patients with frontal lobe injuries have difficulties with such tasks (Kesner et al., 1994). Three studies have used this task in the study of ADHD, and all found the ADHD group to be significantly less proficient than the non-ADHD group (Breen, 1989; Grodzinsky & Diamond, 1992; Mariani & Barkley, in press), which suggests a problem with temporal ordering of motor sequences in those with ADHD (Kesner et al., 1994). The developers of the test battery also commented that hyperactive children performed poorly on this task during the clinical validation trials of the battery (Kaufman & Kaufman, 1983). This could reflect the children's simply having a problem with the working memory demands of this task. However, other research discussed above that involved motor tasks with few or no working memory demands still found motor control deficits in ADHD.

The Place of Inattention in the Model

The executive function deficits discussed in the previous sections can account for the appearance of inattention seen in ADHD despite the fact that research has not identified a deficit in attention in these children. The model also explains the rather dramatic fluctuation in symptoms across settings and tasks. The poor sustained attention that apparently characterizes those with ADHD probably represents an impairment in goal- or task-directed persistence arising from poor inhibition and the toll it takes on self-regulation. And the distractibility ascribed to those with ADHD most likely arises from poor interference control that allows other external and internal events to disrupt the executive functions that provide for self-control and task persistence. The net effect is an individual who cannot persist in effort toward tasks that provide little immediate reward and who flits from one uncompleted activity to another as disrupting events occur. The inattention in ADHD can now be seen as not so much a primary symptom as a secondary one; it is a consequence of the impairment that poor behavioral inhibition and interference control create in the self-regulation or executive control of behavior.

This line of reasoning suggests a critical distinction between two forms of sustained attention (persistence); that distinction is between persistence that is contingency-shaped and that which is self-regulated and goal directed. The former is largely a function of immediate contextual factors, such as the schedule of reinforcement associated with the task, the novelty of the task, and the close temporal contiguity of the elements of the contingency. The second type of sustained attention arises as an emer-

gent property out of the interactions of the executive functions discussed above that permit self-regulation and control over the motor system. This form of persistence is controlled by internally represented information that permits much longer, more complex, and novel chains of responses to be created and executed in the achievement of later goals. These behavioral structures do not require immediate reward for execution because the motivation driving them is self-created. And it is this self-regulatory type of sustained attention that is probably developmentally delayed in children with ADHD, not the type that is contingency shaped. So long as immediate and frequent reinforcement is available in the context for persisting in performing responses, those with ADHD should be less or even not distinguishable from those without ADHD. But those with ADHD should become increasingly distinct from those without ADHD when tasks and settings demand that longer chains of behaviors be strung together to achieve more temporally distant consequences in the absence of immediate consequences for doing so. This explanation clarifies why the "inattentive" symptoms are found to form a separate but only semi-independent dimension from hyperactive–impulsive behavior in parent–teacher ratings. The inattention (impersistence) is at least one step (or more) removed from the problems with behavioral inhibition through the intermediary constructs of working memory and the other executive functions. It is also this self-regulated form of attention that should prove to be qualitatively distinct from the type of inattention seen in children with the predominantly inattentive type of ADHD. The latter children, as discussed earlier, likely have a deficiency in focused or selective attention that is not related to problems with behavioral inhibition and self-regulation.

Some evidence already exists to support a distinction between goal-directed persistence (internal or self-dependent) and contingency-shaped (context-dependent) sustained attention as well as the association of the former with poor inhibitory control. Shoda et al. (1990) found that preschool children's ability to inhibit responding in a resistance-to-temptation task significantly predicted parent ratings of those same children's later concentration, sustained attention, and distractibility at adolescence. Measures of working memory, such as delayed spatial memory, mental arithmetic, digit span, and reproduction of hand movement sequences, have been found to correlate with tests and behavioral observations frequently interpreted as measuring sustained attention and behavioral persistence in preschool children with ADHD (Mariani & Barkley, in press). Levy and Hobbes (1989), likewise, found that a measure of vigilance (a card-playing task) loaded on the same factor as a measure of working memory (related to spelling ability) and that this factor significantly distinguished their ADHD and control groups. These studies suggest links between inhibition, working memory, and persistence or sustained attention.

Developmental Considerations

Research on the components of this theory should find that response inhibition and the neuropsychological processes dependent on it are deficient in their development in those with ADHD. Each executive function most likely represents a semi-

independent neuropsychological system that falls along a continuum of normal functioning and interacts with the other executive functions in producing self-regulation. The degree of delay in these functions would vary in severity partly as a function of the degree of ADHD (disinhibition). And each executive function probably emerges at separate times in development rather than all executive functions emerging simultaneously (Bronowski, 1977). Illustrating this differential timing for the development of these executive functions is the work of Levin et al. (1991), who found significant increases in sensitivity to feedback, problem solving, concept formation, and impulse control between groups of children without ADHD 7–8 years old and 9–12 years old. Further significant developmental advances were noted in memory strategies, memory efficiency, planning time, problem solving, and hypothesis seeking between similar groups of children 9–12 years old and 13–15 years old. Similarly, Welsh et al. (1991) and Passler, Isaac, and Hynd (1985) found that, whereas organized strategic and planful behavior was detected as early as Age 6, more complex search behavior and hypothesis testing matured by Age 10, and verbal fluency, motor sequencing, and complex planning abilities had not reached adult-level performances by Age 12. It would not be difficult to reinterpret these findings in terms of the executive functions in Figure 1. Kopp (1989) has set forth an explanation of the development of emotional self-regulation that is also quite consistent with the present model.

Were test batteries of the executive functions given to children with ADHD, the theory presented here would predict that, at each age level studied, children with ADHD would perform like younger children without ADHD. They would show a pattern of development otherwise similar to that of children without ADHD in shape and trajectory. This already seems evident in the findings of studies of different ages of those with ADHD and those without ADHD on tests of executive functions (Barkley et al., 1992; Grodzinsky & Diamond, 1992; Pennington & Ozonoff, 1996). These studies were cross-sectional, however, which limits the degree to which inferences about true developmental processes can be made.

Unresolved Issues

An important issue deserving of research and critical to the model is the extent to which the deficits in inhibition and its associated executive functions are specific to ADHD or result from disorders often coexisting with it, such as aggression (oppositional defiant disorder) and conduct disorder or, less often, learning disabilities. Few of the studies on ADHD cited here attempted to disentangle these effects. Some of the more recent studies did so, however, and their findings suggest that these cognitive disturbances are more closely associated with ADHD than with these other disorders (Pennington & Ozonoff, 1996).

Research suggests that impairment in behavioral inhibition is more characteristic of children with ADHD than of those with academic underachievement, emotional disturbance, conduct disorder, or autism (Milich et al., 1994; Pennington & Ozonoff, 1996; Schachar & Logan, 1990; Werry, Elkind, & Reeves, 1987). Likewise, the disturbance in the motor inhibition, presetting, effort, and control stages of information-processing par-

adigms are specific to children with ADHD and are not seen in those without ADHD but with anxiety or pure aggression (Oosterlaan & Sergeant, 1995). Direct observations of playroom behavior have also shown that problems with impulsive, undercontrolled behavior and adherence to rules to restrict behavior are more characteristic of children with ADHD than of aggressive children (Milich et al., 1982). These and other studies (Werry et al., 1987) also seem to show that children with mixed ADHD and conduct problems are likely to have as many or more cognitive impairments than those with ADHD alone. And the difficulties with motor control, response perseveration, rule following, and verbal fluency have likewise been shown to be associated more with ADHD than with purely aggressive behavior (Carte et al., in press; McBurnett et al., 1993; Seidman et al., 1995, 1996; Werry et al., 1987). As other reviews have concluded (Hinshaw, 1987; Pennington & Ozonoff, 1996; Taylor et al., 1991; Werry, 1988), ADHD is most closely associated with cognitive impairments, whereas conduct disorder is more aligned with adverse child-rearing variables and social disadvantage. Similarly, studies that used control groups of children with reading disabilities or more generally learning disabilities did not find such children to demonstrate the inhibitory or executive function deficits characteristics of those with ADHD (Barkley, DuPaul, et al., 1990; Dykman & Ackerman, 1992; Epstein, Shaywitz, Shaywitz, & Woolston, 1992; Pennington & Ozonoff, 1996). Thus, although it is hardly definitive, what research does exist places the inhibitory, neuropsychological, and motor deficits described here in the domain of ADHD rather than in the domain of aggression–conduct problems or learning disabilities. Still unresolved, however, is whether the group with mixed ADHD and conduct problems has a qualitatively different disorder, as some have suggested (Biederman et al., 1992; Schachar & Logan, 1990), or just a more severe form of the same disorder as those with ADHD alone.

There are numerous other unresolved issues related to this hybrid model of executive functions and ADHD that speak to its present limitations and the need for future research. These issues include determining (a) the precise strength of the relationship between behavioral inhibition and each of the executive functions; (b) the precise degree to which each executive function contributes to the motor control module in the model; (c) the extent to which the subfunctions placed within each component of the model are best placed where they are now; (d) whether there is some hierarchical organization to these four executive functions; (e) whether the number of components of the model can be further reduced (i.e., Is self-directed speech the source of verbal working memory, as current research implies?; Becker, 1994); (f) whether all four executive functions represent a larger process of the internalization and self-direction of all human behavior generally rather than just that of speech (i.e., self-directed seeing, hearing, manipulation, etc.); (g) the developmental and sequential staging of these executive functions; (h) the degree to which each executive function and its subfunctions are impaired by the behavioral inhibition deficit in ADHD; (i) the degree to which stimulant medications differentially affect each of these domains of executive functions and motor control in ADHD; (j) whether the predominantly inattentive type of ADHD can be dissociated from the remaining

hyperactive–impulsive types on measures of these executive functions; (k) the manner in which socialization influences the development and organization of these executive functions; and (1) the potential gender and cultural differences that may exist in the development of these executive functions and in their deficiencies in those with ADHD.

Conclusion

The present theory holds that the satisfactory development of inhibition is essential for the normal performance of five other neuropsychological abilities: working memory, internalization of speech, self-regulation of affect–motivation–arousal, reconstitution, and motor control–fluency–syntax. The first four of these are considered executive in nature because they permit self-regulation, the control of behavior by internally represented information, and the cross-temporal organization of behavior. Such self-regulation gives rise to the direction and persistence of behavior toward future goals and the ability to re-engage that behavior if disrupted. This intentional, purposive form of goal-directed behavior apparently functions to maximize future consequences over immediate ones for the individual. So behavioral inhibition is linked to working memory and sense of time, internalization, self-motivation, behavioral creativity, and self-control more generally. Besides its immediate application here to the understanding of ADHD, the hybrid model shown in Figure 1 would seem to have significant explanatory power within both neuropsychology and developmental psychology, perhaps helping to bridge these literatures with respect to the concepts of executive functions and self-regulation.

Substantial evidence points to an impairment in three processes involving behavioral inhibition in ADHD: inhibition of prepotent responses, stopping of ongoing responses given feedback on errors, and interference control. When the hybrid model of executive functions discussed above is extended to ADHD, impairments are predicted in the four executive functions in those having this disorder. These executive deficits then create deficiencies in motor control–fluency–syntax or the control of motor behavior by internally represented information. Research findings on ADHD, to varying degrees, seem to be consistent with deficits in the components of the model. The most consistent evidence to date appears to support the components of behavioral inhibition, working memory, poor self-regulation of motivation, and motor control and sequencing. It is not so much that the remaining components (internalized speech and reconstitution) have gone unsupported but that they have been less studied in ADHD. The few researchers who have ventured to examine them have produced suggestive evidence that these components may also be impaired in ADHD.

Much of the literature that does exist on the cognitive or neuropsychological deficits in ADHD suffers from numerous methodological problems. Most significant among these would have to be (a) the use of such small sample sizes that there is inadequate statistical power for detecting the small to moderate effect sizes that are probably associated with deficits in these executive functions; (b) the use of inconsistent selection criteria across studies in defining ADHD; (c) the failure to control for potentially confounding comorbid disorders; (d) the lack of

attention to maturational and gender effects; and (e) the lack of regard for the effects of family history of ADHD on the deficits associated with ADHD in children. Such procedural compromises make much of the extant research inadequate for testing and potentially falsifying the predictions of the present model. Better designed research should help to resolve these inconsistencies and will undoubtedly lead to modifications of the model presented here.

The hybrid model of executive functions developed here and the impairments it predicts in those with ADHD point to a large number of additional avenues for future investigation. These may yield new and important information on both the nature of executive functions and self-regulation as well as on the nature of ADHD itself. Such theory-driven research is to be welcomed into the science of ADHD and should offer much promise for improving the understanding and treatment of those with the disorder.

References

Achenbach, T. M., & Edelbrock, C. S. (1983). *Manual for the Child Behavior Profile and Child Behavior Checklist*. Burlington, VT: Author.

Achenbach, T. M., & Edelbrock, C. S. (1985). *Manual for the Teacher's Report Form and Teacher Version of the Child Behavior Profile*. Burlington, VT: Author.

Ackerman, P. T., Anhalt, J. M., & Dykman, R. A. (1986). Arithmetic automatization failure in children with attention and reading disorders: Associations and sequela. *Journal of Learning Disabilities, 19*, 222–232.

Alessandri, S. M. (1992). Attention, play, and social behavior in ADHD preschoolers. *Journal of Abnormal Child Psychology, 20*, 289–302.

Aman, M. G., & Turbott, S. H. (1986). Incidental learning, distraction, and sustained attention in hyperactive and control subjects. *Journal of Abnormal Child Psychology, 14*, 441–455.

American Psychiatric Association. (1968). *Diagnostic and statistical manual of mental disorders* (2nd ed.). Washington, DC: Author.

American Psychiatric Association. (1980). *Diagnostic and statistical manual of mental disorders* (3rd ed.). Washington, DC: Author.

American Psychiatric Association. (1987). *Diagnostic and statistical manual of mental disorders* (3rd ed., rev). Washington, DC: Author.

American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders* (4th ed.). Washington, DC: Author.

Anastopoulos, A. D., Spisto, M. A., Maher, M. C. (1994). The WISC–III Freedom from Distractibility factor: Its utility in identifying children with attention deficit hyperactivity disorder. *Psychological Assessment, 6*, 368–371.

Applegate, B., Lahey, B. B., Hart, E. L., Waldman, I., Biederman, J., Hynd, G. W., Barkley, R. A., Ollendick, T., Frick, P. J., Greenhill, L., McBurnett, K., Newcom, J., Kerdyk, L., Garfinkel, B., & Shaffer, D. (1995). The age of onset for DSM–IV *attention-deficit hyperactivity disorder: A report of the DSM–IV field trials.* Manuscript submitted for publication.

August, G. J. (1987). Production deficiencies in free recall: A comparison of hyperactive, learning-disabled, and normal children. *Journal of Abnormal Child Psychology, 15*, 429–440.

Baddeley, A. D., & Hitch, G. J. (1994). Developments in the concept of working memory. *Neuropsychology, 8*, 485–493.

Barber, M. A., & Milich, R. (1989, February). *The effects of reinforcement schedule and task characteristics on the behavior of attention-deficit hyperactivity disordered boys.* Paper presented at the annual

meeting of the Society for Research in Child and Adolescent Psychopathology, Miami, FL.

Barber, M. A., Milich, R., & Welsh, R. (1996). Effects of reinforcement schedule and task difficulty on the performance of attention deficit hyperactivity disordered and control boys. *Journal of Clinical Child Psychology, 25,* 66–76.

Barkley, R. A. (1981). *Hyperactive children: A handbook for diagnosis and treatment.* New York: Guilford.

Barkley, R. A. (1989). The problem of stimulus control and rule-governed behavior in children with attention deficit disorder with hyperactivity. In J. Swanson & L. Bloomingdale (Eds.), *Attention deficit disorders.* New York: Pergamon.

Barkley, R. A. (1990). *Attention deficit hyperactivity disorder: A handbook for diagnosis and treatment.* New York: Guilford Press.

Barkley, R. A. (1991). The ecological validity of laboratory and analogue assessments of ADHD symptoms. *Journal of Abnormal Child Psychology, 19,* 149–178.

Barkley, R. A. (1994). Impaired delayed responding: A unified theory of attention deficit hyperactivity disorder. In D. K. Routh (Ed.), *Disruptive behavior disorders: Essays in honor of Herbert Quay* (pp. 11–57). New York: Plenum.

Barkley, R. A. (1995). 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.

Barkley, R., Cunningham, C., & Karlsson, J. (1983). The speech of hyperactive children and their mothers: Comparisons with normal children and stimulant drug effects. *Journal of Learning Disabilities, 16,* 105–110.

Barkley, R. A., DuPaul, G. J., & McMurray, M. B. (1990). A comprehensive evaluation of attention deficit disorder with and without hyperactivity. *Journal of Consulting and Clinical Psychology, 58,* 775–789.

Barkley, R. A., Fischer, M., Edelbrock, C. S., & Smallish, L. (1990). The adolescent outcome of hyperactive children diagnosed by research criteria. I: An 8-year prospective follow-up study. *Journal of the American Academy of Child and Adolescent Psychiatry, 29,* 546–557.

Barkley, R. A., Grodzinsky, G., & DuPaul, G. (1992). Frontal lobe functions in attention deficit disorder with and without hyperactivity: A review and research report. *Journal of Abnormal Child Psychology, 20,* 163–188.

Barkley, R. A., Guevremont, D. C., Anastopoulos, A. D., DuPaul, G. J., & Shelton, T. L. (1993). Driving-related risks and outcomes of attention deficit hyperactivity disorder in adolescents and young adults: A 3–5 year follow-up survey. *Pediatrics, 92,* 212–218.

Barkley, R. A., Koplowicz, S., & Anderson, T. (1996). Sense of time in children with ADHD. II: Effects of duration, distraction, and medication. Manuscript submitted for publication, University of Massachusetts Medical Center, Worcester, MA.

Barkley, R. A., Murphy, K. R., & Kwasnik, D. (1996). Psychological adjustment and adaptive impairments in young adults with ADHD. *Journal of Attention Disorders, 1,* 41–54.

Barkley, R. A., Murphy, K. R., & Kwasnik, D. (in press). Motor vehicle driving competencies and risks in teens and young adults with ADHD. *Pediatrics.*

Barkley, R. A., & Ullman, D. G. (1975). A comparison of objective measures of activity level and distractibility in hyperactive and non-hyperactive children. *Journal of Abnormal Child Psychology, 3,* 213–244.

Bear, G. G., & Rys, G. S. (1994). Moral reasoning, classroom behavior, and sociometric status among elementary school children. *Developmental Psychology, 30,* 633–638.

Becker, J. T. (1994). (Ed.). Working memory [Special section]. *Neuropsychology, 8,* 483–562.

Bench, C. J., Frith, C. D., Grasby, P. M., Friston, K. J., Paulesu, E., Frackowiak, R. S. J., & Donal, R. J. (1993). Investigations of the functional anatomy of attention using the Stroop test. *Neuropsychologia, 31,* 907–922.

Benezra, E., & Douglas, V. I. (1988). Short-term serial recall in ADDH, normal, and reading-disabled boys. *Journal of Abnormal Child Psychology, 16,* 511–525.

Benton, A. (1991). Prefrontal injury and behavior in children. *Developmental Neuropsychology, 7,* 275–282.

Berk, L. E. (1986). Relationship of elementary school children's private speech to behavioral accompaniment to task, attention, and task performance. *Developmental Psychology, 22,* 671–680.

Berk, L. E. (1994, November). Why children talk to themselves. *Scientific American, 271,* 78–83.

Berk, L. E., & Garvin, R. A. (1984). Development of private speech among low-income Appalachian children. *Developmental Psychology, 20,* 271–286.

Berk, L. E., & Potts, M. K. (1991). Development and functional significance of private speech among attention-deficit hyperactivity disorder and normal boys. *Journal of Abnormal Child Psychology, 19,* 357–377.

Berman, K. F., Ostrem, J. L., Randolph, C., Gold, J., Goldberg, T. E., Coppola, R., Carson, R. E., Herscovitch, P., & Weinberger, D. R. (1995). Physiological activation of a cortical network during performance of the Wisconsin Card Sorting Test: A positron emission tomography study. *Neuropsychologia, 33,* 1027–1046.

Biederman, J., Faraone, S. V., & Lapey, K. (1992). Comorbidity of diagnosis in attention-deficit hyperactivity disorder. In G. Weiss (Ed.), *Child and adolescent psychiatry clinics of North America: Attention deficit disorder* (pp. 335–360). Philadelphia: W. B. Saunders.

Bijur, P., Golding, J., Haslum, M., & Kurzon, M. (1988). Behavioral predictors of injury in school-age children. *American Journal of Diseases of Children, 142,* 1307–1312.

Bivens, J. A., & Berk, L. E. (1990). A longitudinal study of the development of elementary school children's private speech. *Merrill Palmer Quarterly, 36,* 443–463.

Borcherding, B., Thompson, K., Krusei, M., Bartko, J., Rapoport, J. L., & Weingartner, H. (1988). Automatic and effortful processing in attention deficit/hyperactivity disorder. *Journal of Abnormal Child Psychology, 16,* 333–345.

Brady, K. D., & Denckla, M. B. (1994). *Performance of children with attention deficit hyperactivity disorder on the Tower of Hanoi task.* Unpublished manuscript, Johns Hopkins University, School of Medicine, Baltimore, MD.

Brand, E., & van der Vlugt, H. (1989). Activation: Base-level and responsivity—A search for subtypes of ADDH children by means of electrocardiac, dermal, and respiratory measures. In T. Sagvolden & T. Archer (Eds.), *Attention deficit disorder: Clinical and basic research* (pp. 137–150). Hillsdale, NJ: Erlbaum.

Breen, M. J. (1989). ADHD girls and boys: An analysis of attentional, emotional, cognitive, and family variables. *Journal of Child Psychology and Psychiatry, 30,* 711–716.

Bremer, D. A., & Stern, J. A. (1976). Attention and distractibility during reading in hyperactive boys. *Journal of Abnormal Child Psychology, 4,* 381–387.

Bronowski, J. (1967). Human and animal languages. In *To honor Roman Jakobson* (Vol. 1). The Hague, Netherlands: Mouton.

Bronowski, J. (1976). *The ascent of man.* Cambridge, MA: MIT Press.

Bronowski, J. (1977). Human and animal languages. In J. Bronowski (Ed.), *A sense of the future* (pp. 104–131). Cambridge, MA: MIT Press.

Brown, R. T. (1989). Creativity: What are we to measure? In J. A.

Glover, R. R. Ronning, & C. R. Reynolds (Eds.), *Handbook of creativity* (pp. 3–32). New York: Plenum.

Brown, R. T., & Wynne, M. E. (1982). Correlates of teacher ratings, sustained attention, and impulsivity in hyperactive and normal boys. *Journal of Clinical Child Psychology, 11*, 262–267.

Butterbaugh, G., Giordani, B., Dillon, J., Alessi, N., Breen, M., & Berent, S. (1989, October). *Effortful learning in children with hyperactivity and/or depressive disorders.* Paper presented at the meeting of the American Academy of Child and Adolescent Psychiatry, New York, NY.

Cahn, D. A., & Marcotte, A. C. (1995). Rates of forgetting in attention deficit hyperactivity disorder. *Child Neuropsychology, 1*, 158–163.

Campbell, S. B., & Ewing, L. J. (1990). Follow-up of hard-to-manage preschoolers: Adjustment at age nine years and predictors of continuing symptoms. *Journal of Child Psychology and Psychiatry, 31*, 891–910.

Campbell, S. B., Pierce, E. W., March, C. L., Ewing, L. J., & Szumowski, E. K. (1994). Hard-to-manage preschoolers: Symptomatic behavior across contexts and time. *Child Development, 65*, 836–851.

Campbell, S. B., Szumowski, E. K., Ewing, L. J., Gluck, D. S., & Breaux, A. M. (1982). A multidimensional assessment of parent-identified behavior problem toddlers. *Journal of Abnormal Child Psychology, 10*, 569–592.

Cantwell, D. P., & Baker, L. (1992). Association between attention deficit-hyperactivity disorder and learning disorders. In S. E. Shaywitz & B. A. Shaywitz (Eds.), *Attention deficit disorder comes of age: Toward the twenty-first century* (pp. 145–164). Austin, TX: Pro-Ed.

Cappella, B., Gentile, J. R., & Juliano, D. B. (1977). Time estimation by hyperactive and normal children. *Perceptual and Motor Skills, 44*, 787–790.

Carlson, C. L., & Alexander, D. K. (1993, February). *Effects of variations in reinforcement and feedback strategies on the performance and intrinsic motivation of ADHD children.* Paper presented at the meeting of the Society for Research in Child and Adolescent Psychopathology, Sante Fe, NM.

Carte, E. T., Nigg, J. T., & Hinshaw, S. P. (in press). Neuropsychological functioning, motor speed, and language processing in boys with and without ADHD. *Journal of Abnormal Child Psychology.*

Caspi, A., & Silva, P. A. (1995). Temperamental qualities at age three predict personality traits in young adulthood: Longitudinal evidence from a birth cohort. *Child Development, 66*, 486–498.

Castellanos, F. X., Giedd, J. N., Eckburg, P., Marsh, W. L., Vaituzis, C., Kaysen, D., Hamburger, S. D., & Rapoport, J. L. (1994). Quantitative morphology of the caudate nucleus in attention deficit hyperactivity disorder. *American Journal of Psychiatry, 151*, 1791–1796.

Cerutti, D. T. (1989). Discrimination theory of rule-governed behavior. *Journal of the Experimental Analysis of Behavior, 51*, 259–276.

Chee, P., Logan, G., Schachar, R., Lindsay, P., & Wachsmuth, R. (1989). Effects of event rate and display time on sustained attention in hyperactive, normal, and control children. *Journal of Abnormal Child Psychology, 17*, 371–391.

Chess, S. (1960). Diagnosis and treatment of the hyperactive child. *New York State Journal of Medicine, 60*, 2379–2385.

Cohen, N. J., Weiss, G., & Minde, K. (1972). Cognitive styles in adolescents previously diagnosed as hyperactive. *Journal of Child Psychology and Psychiatry, 13*, 203–209.

Cole, P. M., Zahn-Waxler, C., & Smith, D. (1994). Expressive control during a disappointment: Variations related to preschoolers' behavior problems. *Developmental Psychology, 30*, 835–846.

Conte, R., & Regehr, S. M. (1991). Learning and transfer of inductive reasoning rules in overactive children. *Cognitive Therapy and Research, 15*, 129–139.

Copeland, A. P. (1979). Types of private speech produced by hyperactive and nonhyperactive boys. *Journal of Abnormal Child Psychology, 7*, 169–177.

Copeland, A. P., & Weissbrod, C. (1978). Behavioral correlates of the hyperactivity factor of the Conners Teacher Questionnaire. *Journal of Abnormal Child Psychology, 6*, 339–343.

Corkum, P. V., & Siegel, L. S. (1993). Is the continuous performance task a valuable research tool for use with children with attention-deficit-hyperactivity disorder? *Journal of Child Psychology and Psychiatry, 34*, 1217–1239.

Cunningham, S. J., & Knights, R. M. (1978). The performance of hyperactive and normal boys under differing reward and punishment schedules. *Journal of Pediatric Psychology, 3*, 195–201.

Cunningham, C. E., & Siegel, L. S. (1987). Peer interactions of normal and attention-deficit disordered boys during free-play, cooperative task, and simulated classroom situations. *Journal of Abnormal Child Psychology, 15*, 247–268.

Danforth, J. S., Barkley, R. A., & Stokes, T. F. (1991). Observations of parent–child interactions with hyperactive children: Research and clinical implications. *Clinical Psychology Review, 11*, 703–727.

Delis, D. C., Squire, L. R., Bihrle, A., & Massman, P. (1992). Componential analysis of problem-solving ability: Performance of patients with frontal lobe damage and amnesic patients on a new sorting test. *Neuropsychologia, 30*, 683–697.

Denckla, M. B. (1985). Motor coordination in dyslexic children: Theoretical and clinical implications. In F. H. Duffy & N. Geschwind (Eds.), *Dyslexia: A neuroscientific approach to clinical evaluation* (pp. 187–195). Boston: Little, Brown.

Denckla, M. B. (1994). Measurement of executive function. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learning disabilities: New views on measurement issues* (pp. 117–142). Baltimore: Paul H. Brookes.

Denckla, M. B. (1995). A theory and model of executive function: A neuropsychological perspective. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 263–277). Baltimore: Paul H. Brookes.

Denckla, M. B., & Rudel, R. G. (1978). Anomalies of motor development in hyperactive boys. *Annals of Neurology, 3*, 231–233.

Denckla, M. B., Rudel, R. G., Chapman, C., & Krieger, J. (1985). Motor proficiency in dyslexic children with and without attentional disorders. *Archives of Neurology, 42*, 228–231.

D'Esposito, M., Detre, J. A., Alsop, D. C., Shin, R. K., Atlas, S., & Grossman, M. (1995). The neural basis of the central executive system of working memory. *Nature, 378*, 279–281.

Diamond, A., Cruttenden, L., & Neiderman, D. (1994). A$\bar{B}$ with multiple wells: 1. Why are multiple wells sometimes easier than two wells? 2. Memory or memory + inhibition? *Developmental Psychology, 30*, 192–205.

Dimasio, A. R. (1994). *Descartes' error: Emotion, reason, and the human brain.* New York: Putnam.

Douglas, V. I. (1972). Stop, look, and listen: The problem of sustained attention and impulse control in hyperactive and normal children. *Canadian Journal of Behavioural Science, 4*, 259–282.

Douglas, V. I. (1980). Higher mental processes in hyperactive children: Implications for training. In R. Knights & D. Bakker (Eds.), *Treatment of hyperactive and learning disordered children* (pp. 65–92). Baltimore: University Park Press.

Douglas, V. I. (1983). Attention and cognitive problems. In M. Rutter (Ed.), *Developmental neuropsychiatry* (pp. 280–329). New York: Guilford Press.

Douglas, V. I. (1988). Cognitive deficits in children with attention deficit disorder with hyperactivity. In L. M. Bloomingdale & J. A. Sergeant

(Eds.), *Attention deficit disorder: Criteria, cognition, intervention* (pp. 65–82). London: Pergamon.

Douglas, V. I., & Benezra, E. (1990). Supraspan verbal memory in attention deficit disorder with hyperactivity, normal, and reading disabled boys. *Journal of Abnormal Child Psychology, 18,* 617–638.

Douglas, V. I., & Parry, P. A. (1983). Effects of reward on delayed reaction time task performance of hyperactive children. *Journal of Abnormal Child Psychology, 11,* 313–326.

Douglas, V. I., & Parry, P. A. (1994). Effects of reward and non-reward on attention and frustration in attention deficit disorder. *Journal of Abnormal Child Psychology, 22,* 281–302.

Douglas, V. I., & Peters, K. G. (1979). Toward a clearer definition of the attentional deficit of hyperactive children. In G. A. Hale & M. Lewis (Eds.), *Attention and the development of cognitive skills* (pp. 173–248). New York: Plenum.

Dykman, R. A., & Ackerman, P. T. (1992). Attention deficit disorder and specific reading disability: Separate but often overlapping disorders. In S. Shaywitz & B. A. Shaywitz (Eds.), *Attention deficit disorder comes of age: Toward the twenty-first century* (pp. 165–184). Austin, TX: Pro-Ed.

Eisenberg, N., Fabes, R. A., Bernzweig, J., Karbon, M., Poulin, R., & Hanish, L. (1993). The relations of emotionality and regulation to preschoolers' social skills and sociometric status. *Child Development, 64,* 1418–1438.

Epstein, M. A., Shaywitz, S. E., Shaywitz, B. A., & Woolston, J. L. (1992). The boundaries of attention deficit disorder. In S. Shaywitz & B. A. Shaywitz (Eds.), *Attention deficit disorder comes of age: Toward the twenty-first century* (pp. 197–219). Austin, TX: Pro-Ed.

Ernst, M., Liebenauer, L. L., King, A. C., Fitzgerald, G. A., Cohen, R. M., & Zametkin, A. J. (1994). Reduced brain metabolism in hyperactive girls. *Journal of the American Academy of Child and Adolescent Psychiatry, 33,* 858–868.

Felton, R. H., Wood, F. B., Brown, I. S., Campbell, S. K., & Harter, M. R. (1987). Separate verbal memory and naming deficits in attention deficit disorder and reading disability. *Brain and Language, 31,* 171–184.

Fischer, M., Barkley, R. A., Edelbrock, C. S., & Smallish, L. (1990). The adolescent outcome of hyperactive children diagnosed by research criteria. II: Academic, attentional, and neuropsychological status. *Journal of Consulting and Clinical Psychology, 58,* 580–588.

Flavell, J. H., Miller, P. H., & Miller, S. A. (1993). *Cognitive development.* Englewood Cliffs, NJ: Prentice Hall.

Frauenglass, M. H., & Diaz, R. M. (1985). Self-regulatory functions of children's private speech: A critical analysis and recent challenges to Vygotsky's theory. *Developmental Psychology, 21,* 357–364.

Freeman, R. J., & Kinsbourne, M. (1990). *A stimulant-correctible incidental passive avoidance deficit in attention deficit hyperactivity disorder.* Unpublished manuscript, Simon Fraser University, Burnaby, British Columbia, Canada.

Freibergs, V., & Douglas, V. I. (1969). Concept learning in hyperactive and normal children. *Journal of Abnormal Psychology, 74,* 388–395.

Frost, L. A., Moffitt, T. E., & McGee, R. (1989). Neuropsychological correlates of psychopathology in an unselected cohort of young adolescents. *Journal of Abnormal Psychology, 98,* 307–313.

Funk, J. B., Chessare, J. B., Weaver, M. T., & Exley, A. R. (1993). Attention deficit hyperactivity disorder, creativity, and the effects of methylphenidate. *Pediatrics, 91,* 816–819.

Fuster, J. M. (1989). *The prefrontal cortex.* New York: Raven Press.

Fuster, J. M. (1995). Memory and planning: Two temporal perspectives of frontal lobe function. In H. H. Jasper, S. Riggio, & P. S. Goldman-Rakic (Eds.), *Epilepsy and the functional anatomy of the frontal lobe* (pp. 9–18). New York: Raven Press.

Garber, J., & Dodge, K. A. (1991). (Eds.). *The development of emo-*

tional regulation and dysregulation. Cambridge, England: Cambridge University Press.

Gayton, W. F., Bailey, C., Wagner, A., & Hardesty, V. A. (1986). Relationship between childhood hyperactivity and accident proneness. *Perceptual and Motor Skills, 63,* 801–802.

Gerbing, D. W., Ahadi, S. A., & Patton, J. H. (1987). Toward a conceptualization of impulsivity: Components across the behavioral and self-report domains. *Multivariate Behavioral Research, 22,* 357–379.

Gershberg, F. B., & Shimamura, A. P. (1995). Impaired use of organizational strategies in free recall following frontal lobe damage. *Neuropsychologia, 33,* 1305–1333.

Glow, P. H., & Glow, R. A. (1979). Hyperkinetic impulse disorder: A developmental defect of motivation. *Genetic Psychology Monographs, 100,* 159–231.

Godbout, L., & Doyon, J. (1995). Mental representation of knowledge following frontal-lobe or post-rolandic lesions. *Neuropsychologia, 33,* 1671–1696.

Goel, V., & Grafman, J. (1995). Are the frontal lobes implicated in "planning" functions? Interpreting data from the Tower of Hanoi. *Neuropsychologia, 33,* 623–642.

Goldberg, E., & Podell, K. (1995). Lateralization in the frontal lobes. In H. H. Jasper, S. Riggio, & P. S. Goldman-Rakic (Eds.), *Epilepsy and the functional anatomy of the frontal lobe* (pp. 85–96). New York: Raven Press.

Goldman-Rakic, P. S. (1995). Anatomical and functional circuits in prefrontal cortex of nonhuman primates: Relevance to epilepsy. In H. H. Jasper, S. Riggio, & P. S. Goldman-Rakic (Eds.), *Epilepsy and the functional anatomy of the frontal lobe* (pp. 51–62). New York: Raven Press.

Gomez, R., & Sanson, A. V. (1994). Effects of experimenter and mother presence on the attentional performance and activity of hyperactive boys. *Journal of Abnormal Child Psychology, 22,* 517–529.

Goodyear, P., & Hynd, G. (1992). Attention deficit disorder with (ADD/H) and without (ADD/WO) hyperactivity: Behavioral and neuropsychological differentiation. *Journal of Clinical Child Psychology, 21,* 273–304.

Gordon, M. (1979). The assessment of impulsivity and mediating behaviors in hyperctive and nonhyperactive children. *Journal of Abnormal Child Psychology, 7,* 317–326.

Goyette, C. H., Conners, C. K., & Ulrich, R. F. (1978). Normative data on revised Conners Parent and Teacher Rating Scales. *Journal of Abnormal Child Psychology, 6,* 221–236.

Gray, J. A. (1982). *The neuropsychology of anxiety.* New York: Oxford University Press.

Grodzinsky, G. M., & Diamond, R. (1992). Frontal lobe functioning in boys with attention-deficit hyperactivity disorder. *Developmental Neuropsychology, 8,* 427–445.

Haenlein, M., & Caul, W. F. (1987). Attention deficit disorder with hyperactivity: A specific hypothesis of reward dysfunction. *Journal of the American Academy of Child and Adolescent Psychiatry, 26,* 356–362.

Halverson, C. F., & Waldrop, M. F. (1976). Relations between preschool activity and aspects of intellectual and social behavior at age 7½. *Developmental Psychology, 12,* 107–112.

Hamlett, K. W., Pellegrini, D. S., & Conners, C. K. (1987). An investigation of executive processes in the problem-solving of attention deficit disorder-hyperactive children. *Journal of Pediatric Psychology, 12,* 227–240.

Hart, E. L., Lahey, B. B., Loeber, R., Applegate, B., & Frick, P. J. (1995). Developmental changes in attention-deficit hyperactivity disorder in boys: A four-year longitudinal study. *Journal of Abnormal Child Psychology, 23,* 729–750.

Hartsough, C. S., & Lambert, N. M. (1985). Medical factors in hyperac-

tive and normal children: Prenatal, developmental, and health history findings. *American Journal of Orthopsychiatry, 55,* 190–210.

Hastings, J., & Barkley, R. A. (1978). A review of psychophysiological research with hyperactive children. *Journal of Abnormal Child Psychology, 7,* 413–337.

Hayes, S. (1989). *Rule-governed behavior.* New York: Plenum.

Heilman, K. M., Voeller, K. K. S., & Nadeau, S. E. (1991). A possible pathophysiological substrate of attention deficit hyperactivity disorder. *Journal of Child Neurology, 6,* 74–79.

Hinshaw, S. P. (1987). On the distinction between attentional deficits/hyperactivity and conduct problems/aggression in child psychopathology. *Psychological Bulletin, 101,* 443–463.

Hinshaw, S. P. (1992). Externalizing behavior problems and academic underachievement in childhood and adolescence: Causal relationships and underlying mechanisms. *Psychological Bulletin, 111,* 127–155.

Hinshaw, S. P. (1994). *Attention deficits and hyperactivity in children.* Thousand Oaks, CA: Sage.

Hinshaw, S. P., Heller, T., & McHale, J. P. (1992). Covert antisocial behavior in boys with attention-deficit hyperactivity disorder: External validation and effects of methylphenidate. *Journal of Consulting and Clinical Psychology, 60,* 274–281.

Hinshaw, S. P., Herbsman, C., Melnick, S., Nigg, J., & Simmel, C. (1993, February). *Psychological and familial processes in ADHD: Continuous or discontinuous with those in normal comparison children?* Paper presented at the meeting of the Society for Research in Child and Adolescent Psychopathology, Santa Fe, NM.

Hinshaw, S. P., Simmel, C., & Heller, T. L. (1995). Multimethod assessment of covert antisocial behavior in children: Laboratory observations, adult ratings, and child self-report. *Psychological Assessment, 7,* 209–219.

Hoffman, M. L. (1970). Moral development. In P. H. Mussen (Ed.), *Handbook of child psychology* (Vol. 2, pp. 261–293). New York: Wiley.

Hoy, E., Weiss, G., Minde, K., & Cohen, N. (1978). The hyperactive child at adolescence: Cognitive, emotional, and social functioning. *Journal of Abnormal Child Psychology, 6,* 311–324.

Iaboni, F., Douglas, V. I., & Baker, A. G. (1995). Effects of reward and response costs on inhibition in ADHD children. *Journal of Abnormal Psychology, 104,* 232–240.

Iversen, S. D., & Dunnett, S. B. (1990). Functional organization of striatum as studied with neural grafts. *Neuropsychologia, 28,* 601–626.

Kagan, J., Reznick, S., & Snidman, N. (1988, April 8). Biological bases of childhood shyness. *Science, 240,* 167–171.

Kanfer, F. H., & Karoly, P. (1972). Self-control: A behavioristic excursion into the lion's den. *Behavior Therapy, 3,* 398–416.

Kaufman, A. S., & Kaufman, N. L. (1983). *Kaufman Assessment Battery for Children.* Circle Pines, MN: American Guidance Services.

Keogh, B. K., & Margolis, J. S. (1976). A component analysis of attentional problems of educationally handicapped boys. *Journal of Abnormal Child Psychology, 4,* 349–359.

Kesner, R. P., Hopkins, R. O., & Fineman, B. (1994). Item and order dissociation in humans with prefrontal cortex damage. *Neuropsychologia, 32,* 881–891.

Klein, R., & Mannuzza, S. (1991). Long-term outcome of hyperactive children: A review. *Journal of the American Academy of Child and Adolescent Psychiatry, 30,* 383–387.

Klorman, R. (1992). Cognitive event-related potentials in attention deficit disorder. In S. E. Shaywitz & B. A. Shaywitz (Eds.), *Attention deficit disorder comes of age: Toward the twenty-first century* (pp. 221–244). Austin, TX: Pro-Ed.

Klorman, R., Brumaghim, J. T., Coons, H. W., Peloquin, L., Strauss, J., Lewine, J. D., Borgstedt, A. D., & Goldstein, M. G. (1988). The contributions of event-related potentials to understanding effects of stimulants on information processing in attention deficit disorder. In L. M. Bloomingdale & J. A. Sergeant (Eds.), *Attention deficit disorder: Criteria, cognition, intervention* (pp. 199–218). London: Pergamon.

Knights, R. T., Grabowecky, & Scabini, D. (1995). Role of human prefrontal cortex in attention control. In H. H. Jasper, S. Riggio, & P. S. Goldman-Rakic (Eds.), *Epilepsy and the functional anatomy of the frontal lobe* (pp. 21–34). New York: Raven Press.

Kochanska, G., DeVet, K., Goldman, M., Murray, K., & Putnam, S. P. (1994). Maternal reports of conscience development and temperament in young children. *Child Development, 65,* 852–868.

Kohlberg, L., Yaeger, J., & Hjertholm, E. (1968). Private speech: Four studies and a review of theories. *Child Development, 39,* 691–736.

Koplowicz, S., & Barkley, R. A. (1995). *Sense of time in children with attention deficit hyperactivity disorder and normal children.* Unpublished manuscript, University of Massachusetts Medical Center, Worcester, MA.

Kopp, C. B. (1982). Antecedents of self-regulation: A developmental perspective. *Developmental Psychology, 18,* 199–214.

Kopp, C. B. (1989). Regulation of distress and negative emotions: A developmental view. *Developmental Psychology, 25,* 343–354.

Krener, P., Carter, C., Chaderjian, M., Wolfe, V., & Northcutt, C. (1993, October). *Executive function in children with ADHD and controls.* Paper presented at the meeting of the American Academy of Child and Adolescent Psychiatry, San Antonio, TX.

Kupietz, S. S., Camp, J. A., & Weissman, A. D. (1976). Reaction time performance of behaviorally deviant children: Effects of prior preparatory interval and reinforcement. *Journal of Child Psychology and Psychiatry, 17,* 123–131.

Lahey, B. B., Applegate, B., McBurnett, K., Biederman, J., Greenhill, L., Hynd, G. W., Barkley, R. A., Newcorn, J., Jensen, P., Richters, J., Garfinkel, B., Kerdyk, L., Frick, P. J., Ollendick, T., Perez, D., Hart, E. L., Waldman, I., & Shaffer, D. (1994). DSM–IV field trials for attention deficit/hyperactivity disorder in children and adolescents. *American Journal of Psychiatry, 151,* 1673–1685.

Lahey, B. B., & Carlson, C. L. (1992). Validity of the diagnostic category of attention deficit disorder without hyperactivity: A review of the literature. In S. E. Shaywitz & B. Shaywitz (Eds.), *Attention deficit disorder comes of age: Toward the twenty-first century* (pp. 119–144). Austin, TX: Pro-Ed.

Lahey, B. B., Pelham, W. E., Schaughency, E. A., Atkins, M. S., Murphy, H. A., Hynd, G. W., Russo, M., Hartdagen, S., & Lorys-Vernon, A. (1988). Dimensions and types of attention deficit disorder with hyperactivity in children: A factor and cluster-analytic approach. *Journal of the American Academy of Child and Adolescent Psychiatry, 27,* 330–335.

Landau, S., Lorch, E. P., & Milich, R. (1992). Visual attention to and comprehension of television in attention deficit hyperactivity disordered and normal boys. *Child Development, 63,* 928–937.

Lang, P. J. (1995). The emotion probe: Studies of motivation and attention. *American Psychologist, 50,* 372–385.

Laufer, M., & Denhoff, E. (1957). Hyperkinetic behavior syndrome in children. *Journal of Pediatrics, 50,* 463–474.

Lee, M., Vaughn, B. E., & Kopp, C. B. (1983). The role of self-control in young children's performance on a delayed response memory for location task. *Developmental Psychology, 19,* 40–44.

Leung, P. W. L., & Connolly, K. J. (1996). Distractibility in hyperactive and conduct-disordered children. *Journal of Child Psychology and Psychiatry, 37,* 305–312.

Levin, H. S., Culhane, K. A., Hartmann, J., Evankovich, K., Mattson, A. J., Harward, H., Ringholz, G., Ewing-Cobbs, L., & Fletcher, J. M.

(1991). Developmental changes in performance on tests of purported frontal lobe functions. *Developmental Neuropsychology, 7,* 377–396.

Levin, H. S., Mendelsohn, D., Lilly, M. A., Fletcher, J. M., Culhane, K. A., Chapman, S. B., Harward, H., Kusnerik, L., Bruce, D., & Eisenberg, H. M. (1994). Tower of London performance in relation to magnetic resonance imaging following closed head injury in children. *Neuropsychology, 8,* 171–179.

Levy, F., & Hobbes, G. (1989). Reading, spelling, and vigilance in attention deficit and conduct disorder. *Journal of Abnormal Child Psychology, 17,* 291–298.

Loeber, R., Green, S. M., Lahey, B. B., Christ, M. A. G., & Frick, P. J. (1992). Developmental sequences in the age of onset of disruptive child behaviors. *Journal of Child and Family Studies, 1,* 21–41.

Loge, D. V., Staton, R. D., & Beatty, W. W. (1990). Performance of children with ADHD on tests sensitive to frontal lobe dysfunction. *Journal of the American Academy of Child and Adolescent Psychiatry, 29,* 540–545.

Lou, H. C., Henriksen, L., & Bruhn, P. (1984). Focal cerebral hypoperfusion in children with dysphasia and/or attention deficit disorder. *Archives of Neurology, 41,* 825–829.

Lou, H. C., Henriksen, L., Bruhn, P., Borner, H., & Nielsen, J. B. (1989). Striatal dysfunction in attention deficit and hyperkinetic disorder. *Archives of Neurology, 46,* 48–52.

Ludlow, C., Rapoport, J., Bassich, C. J., & Mikkelson, E. (1980). The differential effects of dextroamphetamine on the language performance of hyperactive and normal boys. In R. Knights & D. Bakker (Eds.), *Treatment of hyperactive and learning disordered children* (pp. 185–217). Baltimore: University Park Press.

Lufi, D., Cohen, A., & Parish-Plass, J. (1990). Identifying ADHD with the WISC–R and the Stroop Color and Word Test. *Psychology in the Schools, 27,* 28–34.

Luk, S. (1985). Direct observations studies of hyperactive behaviors. *Journal of the American Academy of Child and Adolescent Psychiatry, 24,* 338–344.

Malone, M. A., & Swanson, J. M. (1993). Effects of methylphenidate on impulsive responding in children with attention deficit hyperactivity disorder. *Journal of Child Neurology, 8,* 157–163.

Mariani, M., & Barkley, R. A. (in press). Neuropsychological and academic functioning in preschool children with attention deficit hyperactivity disorder. *Developmental Neuropsychology.*

Mattes, J. A. (1980). The role of frontal lobe dysfunction in childhood hyperkinesis. *Comprehensive Psychiatry, 21,* 358–369.

McBurnett, K., Harris, S. M., Swanson, J. M., Pfiffner, L. J., Tamm, L., & Freeland, D. (1993). Neuropsychological and psychophysiological differentiation of inattention/overactivity and aggression/defiance symptom groups. *Journal of Clinical Child Psychology, 22,* 165–171.

McGee, R., Williams, S., & Feehan, M. (1992). Attention deficit disorder and age of onset of problem behaviors. *Journal of Abnormal Child Psychology, 20,* 487–502.

McGee, R., Williams, S., Moffitt, T., & Anderson, J. (1989). A comparison of 13-year-old boys with attention deficit and/or reading disorder on neuropsychological measures. *Journal of Abnormal Child Psychology, 17,* 37–53.

McMahon, S. A., & Greenberg, L. M. (1977). Serial neurologic examination of hyperactive children. *Pediatrics, 59,* 584–587.

Methany, A. P., Jr., & Fisher, J. E. (1984). Behavioral perspectives on children's accidents. In M. Wolraich & D. K. Routh (Eds.), *Advances in behavioral pediatrics* (Vol. 5, pp. 221–263). Greenwich, CT: JAI Press.

Michon, J. (1985). Introduction. In J. Michon & T. Jackson (Eds.), *Time, mind, & behavior.* Berlin, Germany: Springer-Verlag.

Milich, R. (in press). The response of children with ADHD to failure: If at first you don't succeed, do you try, try again? *School Psychology Review.*

Milich, R., Hartung, C. M., Martin, C. A., & Haigler, E. D. (1994). Behavioral disinhibition and underlying processes in adolescents with disruptive behavior disorders. In D. K. Routh (Ed.), *Disruptive behavior disorders in childhood* (pp. 109–138). New York: Plenum.

Milich, R., & Kramer, J. (1985). Reflections on impulsivity: An empirical investigation of impulsivity as a construct. In K. Gadow & I. Bialer (Eds.), *Advances in learning and behavioral disabilities* (Vol. 3, pp. 57–94). Greenwich, CT: JAI.

Milich, R. S., Landau, S., Kilby, G., & Whitten, P. (1982). Preschool peer perceptions of the behavior of hyperactive and aggressive children. *Journal of Abnormal Child Psychology, 10,* 497–510.

Milich, R., & Loney, J. (1979). The factor composition of the WISC for hyperkinetic/MBD males. *Journal of Learning Disabilities, 12,* 67.

Milner, B. (1995). Aspects of human frontal lobe function. In H. H. Jasper, S. Riggio, & P. S. Goldman-Rakic (Eds.), *Epilepsy and the functional anatomy of the frontal lobe* (pp. 67–81). New York: Raven Press.

Mischel, W., Shoda, Y., & Peake, P. K. (1988). The nature of adolescent competencies predicted by preschool delay of gratification. *Journal of Personality and Social Psychology, 54,* 687–696.

Mischel, W., Shoda, Y., & Rodriguez, M. I. (1989, May 26). Delay of gratification in children. *Science, 244,* 933–938.

Moffitt, T. E. (1990). Juvenile delinquency and attention deficit disorder: Boys' developmental trajectories from age 3 to 15. *Child Development, 61,* 893–910.

Moffitt, T. E., & Silva, P. A. (1988). Self-reported delinquency, neuropsychological deficit, and history of attention deficit disorder. *Journal of Abnormal Child Psychology, 16,* 553–569.

Mori, L., & Peterson, L. (1995). Knowledge of safety of high and low active–impulsive boys: Implications for child injury prevention. *Journal of Clinical Child Psychology, 24,* 370–376.

Morris, R. G., Ahmed, S., Syed, G. M., & Toone, B. K. (1993). Neural correlates of planning ability: Frontal lobe activation during the Tower of London Test. *Neuropsychologia, 31,* 1367–1378.

Munir, K., Biederman, J., & Knee, D. (1987). Psychiatric comorbidity in patients with attention deficit disorder: A controlled study. *Journal of the American Academy of Child and Adolescent Psychiatry, 26,* 844–848.

Murphy, K. R., & Barkley, R. A. (in press). ADHD adults: Comorbidities and adaptive impairments. *Comprehensive Psychiatry.*

Nadeau, K. (1995). *Attention deficit hyperactivity disorder in adults: A handbook.* New York: Brunner/Mazel.

Narhi, V., & Ahonen, T. (1995). Reading disability with or without attention deficit hyperactivity disorder: Do attentional problems make a difference? *Developmental Neuropsychology, 11,* 337–349.

Nucci, L. P., & Herman, S. (1982). Behavioral disordered children's conceptions of moral, conventional, and personal issues. *Journal of Abnormal Child Psychology, 10,* 411–426.

Olson, S. L. (1989). Assessment of impulsivity in preschoolers: Cross-measure convergences, longitudinal stability, and relevance to social competence. *Journal of Clinical Child Psychology, 18,* 176–183.

Oosterlaan, J., & Sergeant, J. A. (1995). Response choice and inhibition in ADHD, anxious, and aggressive children: The relationship between S–R compatibility and the stop signal task. In J. A. Sergeant (Ed.), *Eunethydis: European approaches to hyperkinetic disorder* (pp. 225–240). Amsterdam: Editor.

Parry, P. A., & Douglas, V. I. (1983). Effects of reinforcement on concept identification in hyperactive children. *Journal of Abnormal Child Psychology, 11,* 327–340.

Passler, M. A., Isaac, W., & Hynd, G. W. (1985). Neuropsychological

development of behavior attributed to frontal lobe functioning in children. *Developmental Neuropsychology, 1,* 349–370.

Patterson, G. R. (1982). *Coercive family process.* Eugene, OR: Castalia.

Patterson, G. R. (1986). Performance models for antisocial boys. *American Psychologist, 41,* 432–444.

Pelham, W. E., & Bender, M. E. (1982). Peer relationships in hyperactive children: Description and treatment. In K. D. Gadow & J. Bialer (Eds.), *Advances in learning and behavioral disabilities* (Vol. 1, pp. 365–436). Greenwich, CT: JAI Press.

Pelham, W. E., Milich, R., & Walker, J. L. (1986). Effects of continuous and partial reinforcement and methylphenidate on learning in children with attention deficit disorder. *Journal of Abnormal Psychology, 95,* 319–325.

Pennington, B. F., Grossier, D., & Welsh, M. C. (1993). Contrasting cognitive deficits in attention deficit disorder versus reading disability. *Developmental Psychology, 29,* 511–523.

Pennington, B. F., & Ozonoff, S. (1996). Executive functions and developmental psychopathology. *Journal of Child Psychology and Psychiatry, 37,* 51–87.

Porrino, L. J., Rapoport, J. L., Behar, D., Sceery, W., Ismond, D. R., & Bunney, W. E., Jr. (1983). A naturalistic assessment of the motor activity of hyperactive boys. *Archives of General Psychiatry, 40,* 681–687.

Quay, H. C. (1988a). Attention deficit disorder and the behavioral inhibition system: The relevance of the neuropsychological theory of Jeffrey A. Gray. In L. M. Bloomingdale & J. Sergeant (Eds.), *Attention deficit disorder: Criteria, cognition, intervention* (pp. 117–126). New York: Pergamon.

Quay, H. C. (1988b). The behavioral reward and inhibition systems in childhood behavior disorder. In L. M. Bloomingdale (Ed.), *Attention deficit disorder III: New research in treatment, psychopharmacology, and attention* (pp. 176–186). New York: Pergamon.

Quay, H. C. (1996, January). *Gray's behavioral inhibition in ADHD: An update.* Paper presented at the annual meeting of the International Society for Research in Child and Adolescent Psychopathology, Los Angeles, CA.

Rapoport, J. L. (1996, January). *Anatomic magnetic resonance imaging in attention deficit/hyperactivity disordered boys.* Paper presented at the annual meeting of the International Society for Research in Child and Adolescent Psychopathology, Los Angeles, CA.

Rapport, M. D., Tucker, S. B., DuPaul, G. J., Merlo, M., & Stoner, G. (1986). Hyperactivity and frustration: The influence of control over and size of rewards in delaying gratification. *Journal of Abnormal Child Psychology, 14,* 181–204.

Robins, P. M. (1992). A comparison of behavioral and attentional functioning in children diagnosed as hyperactive or learning-disabled. *Journal of Abnormal Child Psychology, 20,* 65–82.

Rolls, E. T., Hornak, J., Wade, D., & McGrath, J. (1994). Emotion-related learning in patients with social and emotional changes associated with frontal lobe damage. *Journal of Neurology, Neurosurgery, and Psychiatry, 57,* 1518–1524.

Rosenbaum, M., & Baker, E. (1984). Self-control behavior in hyperactive and nonhyperactive children. *Journal of Abnormal Child Psychology, 12,* 303–318.

Rosenthal, R. H., & Allen, T. W. (1978). An examination of attention, arousal, and learning dysfunctions of hyperkinetic children. *Psychological Bulletin, 85,* 689–715.

Rosenthal, R. H., & Allen, T. W. (1980). Intratask distractibility in hyperkinetic and nonhyperkinetic children. *Journal of Abnormal Child Psychology, 8,* 175–187.

Ross, R. G., Hommer, D., Breiger, D., Varley, C., & Radant, A. (1994). Eye movement task related to frontal lobe functioning in children with

attention deficit disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 33,* 869–874.

Rothenberger, A. (1995). Electrical brain activity in children with hyperkinetic syndrome: Evidence of a frontal cortical dysfunction. In J. A. Sergeant (Ed.), *Eunethydis: European approaches to hyperkinetic disorder* (pp. 255–270). Amsterdam: Editor.

Routh, D. K., & Schroeder, C. S. (1976). Standardized playroom measures as indices of hypercativity. *Journal of Abnormal Child Psychology, 4,* 199–207.

Sagvolden, T., Wultz, B., Moser, E. I., Moser, M., & Morkrid, L. (1989). Results from a comparative neuropsychological research program indicate altered reinforcement mechanisms in children with ADD. In T. Sagvolden & T. Archer (Eds.), *Attention deficit disorder: Clinical and basic research* (pp. 261–286). Hillsdale, NJ: Erlbaum.

Schachar, R. J. (1986). Hyperkinetic syndrome: Historical development of the concept. In E. Taylor (Ed.), *The overactive child* (pp. 19–40). Philadelphia: Lippincott.

Schachar, R. J., & Logan, G. D. (1990). Impulsivity and inhibitory control in normal development and childhood psychopathology. *Developmental Psychology, 26,* 710–720.

Schachar, R. J., Tannock, R., & Logan, G. (1993). Inhibitory control, impulsiveness, and attention deficit hyperactivity disorder. *Clinical Psychology Review, 13,* 721–739.

Schachar, R. J., Tannock, R., Marriott, M., & Logan, G. (1995). Deficient inhibitory control in attention deficit hyperactivity disorder. *Journal of Abnormal Child Psychology, 23,* 411–438.

Schweitzer, J. B., & Sulzer-Azaroff, B. (1995). Self-control in boys with attention-deficit hyperactivity disorder: Effects of added stimulation and time. *Journal of Child Psychology and Psychiatry, 36,* 671–686.

Seidman, L. J., Biederman, J., Faraone, S. V., Milberger, S., Norman, D., Seiverd, K., Benedict, K., Guite, J., Mick, E., & Kiely, K. (1995). Effects of family history and comorbidity on the neuropsychological performance of children with ADHD: Preliminary findings. *Journal of the American Academy of Child and Adolescent Psychiatry, 34,* 1015–1024.

Seidman, L. J., Biederman, J., Faraone, S. V., Milberger, S., Seiverd, K., Benedict, K., Bernstein, J. H., Weber, W., & Ouellette, C. (1996). *Towards defining a neuropsychology of ADHD: Performance of children and adolescents from a large clinically referred sample.* Manuscript submitted for publication, Massachusetts General Hospital, Boston, MA.

Sergeant, J. A. (1995a). Hyperkinetic disorder revisited. In J. A. Sergeant (Ed.), *Eunethydis: European approaches to hyperkinetic disorder* (pp. 7–17). Amsterdam: Author.

Sergeant, J. A. (1995b). A theory of attention: An information processing perspective. In G. R. Lyon & N. A. Krasnegor (Eds.), *Attention, memory, and executive function* (pp. 57–69). Baltimore: Paul H. Brookes.

Sergeant, J. A. (1996, January). *The cognitive–energetic model of ADHD.* Paper presented at the annual meeting of the International Society for Research in Child and Adolescent Psychopathology, Los Angeles, CA.

Sergeant, J. A., & van der Meere, J. (1988). What happens when the hyperactive child commits an error? *Psychiatry Research, 24,* 157–164.

Shapiro, E. G., Hughes, S. J., August, G. J., & Bloomquist, M. L. (1993). Processing emotional information in children with attention deficit hyperactivity disorder. *Developmental Neuropsychology, 9,* 207–224.

Shaw, G. A., & Brown, G. (1990). Laterality and creativity concomitants of attention problems. *Developmental Neuropsychology, 6,* 39–57.

Shaw, G. A., & Giambra, L. (1993). Task-unrelated thoughts of college students diagnosed as hyperactive in childhood. *Developmental Neuropsychology, 9*, 17–30.

Shaywitz, S. E., & Shaywitz, B. A. (1984). Diagnosis and management of attention deficit disorder: A pediatric perspective. *Pediatric Clinics of North America, 31*, 429–457.

Shoda, Y., Mischel, W., & Peake, P. K. (1990). Predicting adolescent cognitive and self-regulatory competencies from preschool delay of gratification: Identifying diagnostic conditions. *Developmental Psychology, 26*, 978–986.

Shue, K., & Douglas, V. I. (1989). Attention deficit hyperactivity disorder, normal development, and frontal lobe syndrome [Abstract]. *Canadian Psychology, 30*, 498.

Sieg, K. G., Gaffney, G. R., Preston, D. F., & Hellings, J. A. (1995). SPET brain imaging abnormalities in attention deficit hyperactivity disorder. *Clinical Nuclear Medicine, 20*, 55–60.

Silverman, I. W., & Ragusa, D. M. (1991). Child and maternal correlates of impulse control in 24-month old children. *Genetic, Social, and General Psychology Monographs, 116*, 435–473.

Silverman, I. W., & Ragusa, D. M. (1992). A short-term longitudinal study of the early development of self-regulation. *Journal of Abnormal Child Psychology, 20*, 415–435.

Skinner, B. F. (1953). *Science and human behavior.* New York: Macmillan.

Sleator, E. K., & Pelham, W. E. (1986). *Attention deficit disorder.* Norwalk, CT: Appleton-Century-Crofts.

Solanto, M. V. (1990). The effects of reinforcement and response-cost on a delayed response task in children with attention deficit hyperactivity disorder: A research note. *Journal of Child Psychology and Psychiatry, 31*, 803–808.

Sonuga-Barke, E. J. S., Taylor, E., & Hepinstall, E. (1992). Hyperactivity and delay aversion—II. The effect of self versus externally imposed stimulus presentation periods on memory. *Journal of Child Psychology and Psychiatry, 33*, 399–409.

Sonuga-Barke, E. J. S., Taylor, E., Sembi, S., & Smith, J. (1992). Hyperactivity and delay aversion—I. The effect of delay on choice. *Journal of Child Psychology and Psychiatry, 33*, 387–398.

Steinkamp, M. W. (1980). Relationships between environmental distractions and task performance of hyperactive and normal children. *Journal of Learning Disabilities, 13*, 40–45.

Stewart, M. A., Pitts, F. N., Craig, A. G., & Dieruf, W. (1966). The hyperactive child syndrome. *American Journal of Orthopsychiatry, 36*, 861–867.

Stifter, C. A., & Braungart, J. M. (1995). The regulation of negative reactivity in infancy: Function and development. *Developmental Psychology, 31*, 448–455.

Still, G. F. (1902). Some abnormal psychical conditions in children. *Lancet, 1*, 1008–1012, 1077–1082, 1163–1168.

Stuss, D. T., & Benson, D. F. (1986). *The frontal lobes.* New York: Raven Press.

Stuss, D. T., Gow, C. A., & Hetherington, C. R. (1992). "No longer gage": Frontal lobe dysfunction and emotional changes. *Journal of Consulting and Clinical Psychology, 60*, 349–359.

Szatmari, P. (1992). The epidemiology of attention-deficit hyperactivity disorders. In G. Weiss (Ed.), *Child and adolescent psychiatry clinics of North America: Attention deficit disorder* (pp. 361–372). Philadelphia: W. B. Saunders.

Szatmari, P., Offord, D. R., & Boyle, M. H. (1989). Correlates, associated impairments, and patterns of service utilization of children with attention deficit disorders: Findings from the Ontario Child Health Study. *Journal of Child Psychology and Psychiatry, 30*, 205–217.

Tannock, R. (1996, January). *Discourse deficits in ADHD: Executive dysfunction as an underlying mechanism?* Paper presented at the an-

nual meeting of the International Society for Research in Child and Adolescent Psychopathology, Los Angeles, CA.

Tannock, R., Purvis, K. L., & Schachar, R. J. (1992). Narrative abilities in children with attention deficit hyperactivity disorder and normal peers. *Journal of Abnormal Child Psychology, 21*, 103–117.

Tant, J. L., & Douglas, V. I. (1982). Problem-solving in hyperactive, normal, and reading-disabled boys. *Journal of Abnormal Child Psychology, 10*, 285–306.

Taylor, E. (1996, January). *Discussion of current theories of ADHD.* Paper presented at the annual meeting of the International Society for Research in Child and Adolescent Psychopathology, Los Angeles, CA.

Taylor, E., Sandberg, S., Thorley, G., & Giles, S. (1991). *The epipdemiology of childhood hyperactivity.* London: Institute of Psychiatry.

Thoresen, C. E., & Mahoney, M. J. (1974). *Behavioral self-control.* New York: Holt, Rinehart, & Winston.

Torgesen, J. K. (1994). Issues in the assessment of executive function: An information-processing perspective. In G. R. Lyon (Ed.), *Frames of reference for the assessment of learning disabilities: New views on measurement issues* (pp. 143–162). Baltimore: Paul H. Brookes.

Trommer, B. L., Hoeppner, J. B., Lorber, R., & Armstrong, K. (1988). Pitfalls in the use of a continuous performance test as a diagnostic tool in attention deficit disorder. *Developmental and Behavioral Pediatrics, 9*, 339–346.

Ullman, D. G., Barkley, R. A., & Brown, H. W. (1978). The behavioral symptoms of hyperkinetic children who successfully responded to stimulant drug treatment. *American Journal of Orthopsychiatry, 48*, 425–437.

van der Meere, J. (in press). The role of attention. In S. Sandberg (Ed.), *Monographs on child and adolesent psychiatry: Hyperactivity disorders* (pp. 109–146). London: Cambridge University Press.

van der Meere, J., Hughes, K. A., Borger, N., & Sallee, F. R. (1995). The effect of reward on sustained attention in ADHD children with and without CD. In J. A. Sergeant (Ed.), *Eunethydis: European approaches to hyperkinetic disorder* (pp. 241–253). Amsterdam: Editor.

van der Meere, J., & Sergeant, J. (1988a). Acquisition of attention skill in pervasively hyperactive children. *Journal of Child Psychology and Psychiatry, 29*, 301–310.

van der Meere, J., & Sergeant, J. (1988b). Controlled processing and vigilance in hyperactivity: Time will tell. *Journal of Abnormal Child Psychology, 16*, 641–656.

van der Meere, J., & Sergeant, J. (1988c). Focused attention in pervasively hyperactive children. *Journal of Abnormal Child Psychology, 16*, 627–640.

van der Meere, J., Shalev, R., Borger, N., & Gross-Tsur, V. (1995). Sustained attention, activation and MPH in ADHD: A research note. *Journal of Child Psychology and Psychiatry, 36*, 697–703.

van der Meere, J., van Baal, M., & Sergeant, J. (1989). The additive factor method: A differential diagnostic tool in hyperactivity and learning disability. *Journal of Abnormal Child Psychology, 17*, 409–422.

van der Meere, J., Vreeling, H. J., & Sergeant, J. (1992). A motor presetting study in hyperactive, learning disabled and control children. *Journal of Child Psychology and Psychiatry, 33*, 1347–1354.

van der Meere, J., Wekking, E., & Sergeant, J. (1991). Sustained attention and pervasive hyperactivity. *Journal of Child Psychology and Psychiatry, 32*, 275–284.

Vendrell, P., Junque, C., Pujol, J., Jurado, M. A., Molet, J., & Grafman, J. (1995). The role of prefrontal regions in the Stroop task. *Neuropsychologia, 33*, 341–352.

Verin, M., Partiot, A., Pillon, P. B., Malapani, C., Agid, Y., & Dubois, B. (1993). Delayed response tasks and prefrontal lesions in man: Evidence for self-generated patterns of behaviour with poor environmental modulation. *Neuropsychologia, 31*, 1379–1396.

Voelker, S. L., Carter, R. A., Sprague, D. J., Gdowski, C. L., & Lachar,

D. (1989). Developmental trends in memory and metamemory in children with attention deficit disorder. *Journal of Pediatric Psychology, 14,* 75–88.

Voeller, K. K. S., & Heilman, K. M. (1988). Motor impersistence in children with attention deficit hyperactivity disorder: Evidence for right hemisphere dysfunction. *Annals of Neurology, 24,* 323.

Vygotsky, L. S. (1978). *Mind in society.* Cambridge, MA: Harvard University Press.

Vygotsky, L. S. (1987). Thinking and speech. In L. S. Vygotsky, R. W. Rieber (Series Eds.), & A. S. Carton (Vol. Ed.), *The collected works of L. S. Vygotsky. Vol. 1: Problems in general psychology* (N. Minick, Trans.). New York: Plenum.

Weiss, G., & Hechtman, L. (1993). *Hyperactive children grown up.* New York: Guilford Press.

Weithorn, C. J., & Kagen, E. (1984). Verbal mediation in high-active and cognitively impulsive second graders. *Journal of Learning Disabilities, 17,* 82–88.

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

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

Werry, J. S. (1988). Differential diagnosis of attention deficits and conduct disorders. In L. M. Bloomingdale & J. A. Sergeant (Eds.), *Attention deficit disorder: Criteria, cognition, intervention* (pp. 83–96). London: Pergamon.

Werry, J. S. (1992). History, terminology, and manifestations at different ages. In G. Weiss (Ed.), *Child and adolescent psychiatry clinics of North America: Attention deficit disorder* (pp. 297–310). Philadelphia: W. B. Saunders.

Werry, J. S., Elkind, G. S., & Reeves, J. S. (1987). Attention deficit, conduct, oppositional, and anxiety disorders in children: III. Laboratory differences. *Journal of Abnormal Child Psychology, 15,* 409–428.

Werry, J. S., Minde, K., Guzman, A., Weiss, G., Dogan, K., & Hoy, E. (1972). Studies on the hyperactive child: VII. Neurological status compared with neurotic and normal children. *American Journal of Orthopsychiatry, 42,* 441–451.

Weyandt, L. L., & Willis, W. G. (1994). Executive functions in school-aged children: Potential efficacy of tasks in discriminating clinical groups. *Developmental Neuropsychology, 19,* 27–38.

Whalen, C. K., Henker, B., Collins, B. E., McAuliffe, S., & Vaux, A.

(1979). Peer interaction in structured communication task: Comparisons of normal and hyperactive boys and of methylphenidate (Ritalin) and placebo effects. *Child Development, 50,* 388–401.

White, J. L., Moffitt, T. E., Caspi, A., Bartusch, D. J., Needles, D. J., & Stouthamer-Loeber, M. (1994). Measuring impulsivity and examining its relationship to delinquency. *Journal of Abnormal Psychology, 103,* 192–205.

Wilkison, P. C., Kircher, J. C., McMahon, W. M., & Sloane, H. N. (1995). Effects of methylphenidate on reward strength in boys with attention-deficit hyperactivity disorder. *Journal of the American Academy of Child and Adolescent Psychiatry, 34,* 877–885.

Williams, G. V., & Goldman-Rakic, P. S. (1995). Modulation of memory fields by dopamine D1 receptors in prefrontal cortex. *Nature, 376,* 572–575.

Zahn, T. P., Krusei, M. J. P., & Rapoport, J. L. (1991). Reaction time indices of attention deficits in boys with disruptive behavior disorders. *Journal of Abnormal Child Psychology, 19,* 233–252.

Zakay, D. (1992). The role of attention in children's time perception. *Journal of Experimental Child Psychology, 54,* 355–371.

Zametkin, A. J., Liebenauer, L. L., Fitzgerald, G. A., King, A. C., Minkunas, D. V., Herscovitch, P., Yamada, E. M., & Cohen, R. M. (1993). Brain metabolism in teenagers with attention-deficit hyperactivity disorder. *Archives of General Psychiatry, 50,* 333–340.

Zametkin, A. J., Nordahl, T. E., Gross, M., King, A. C., Semple, W. E., Rumsey, J., Hamburger, S., & Cohen, R. (1990). Cerebral glucose metabolism in adults with hyperactivity of childhood onset. *New England Journal of Medicine, 323,* 1361–1366.

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

Zentall, S. S. (1985). A context for hyperactivity. In K. D. Gadow & I. Bialer (Eds.), *Advances in learning and behavioral disabilities* (Vol. 4, pp. 273–343). Greenwich, CT: JAI Press.

Zentall, S. S. (1988). Production deficiencies in elicited language but not in the spontaneous verbalizations of hyperactive children. *Journal of Abnormal Child Psychology, 16,* 657–673.

Zentall, S. S., & Smith, Y. S. (1993). Mathematical performance and behavior of children with hyperactivity with and without coexisting aggression. *Behavior Research and Therapy, 31,* 701–710.