Handbook of Self-Regulation

Research, Theory, and Applications

Edited by

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Attention-Deficity/Hyperactivity Disorder and Self-Regulation

Taking an Evolutionary Perspective on Executive Functioning

RUSSELL A. BARKLEY

Current psychiatric taxonomy describes attention-deficit/hyperactivity disorder, or ADHD, as involving developmentally inappropriate degrees of inattention and hyperactive–impulsive behavior. These symptoms frequently arise in early childhood, are relatively pervasive or cross-situational in nature, may persist into adolescence and even adulthood in the majority of clinically diagnosed cases, and result in impairment in major life activities, such as family functioning, developing self-sufficiency, peer relations, and educational and occupational functioning, among others (American Psychiatric Association, 1994; Barkley, 1998). This perspective emphasizes problems in the realms of attention, impulsiveness, and activity level as being central to the disorder. But children with ADHD often demonstrate deficiencies in many other motor and cognitive abilities.

Among these are difficulties with (1) physical fitness, gross and fine motor coordination, and motor sequencing (Breen, 1989; Kadesjo & Gillberg, 2001; Mariani & Barkley, 1997); (2) speed of color naming (Tannock, Martinussen, & Frijters, 2000); (3) verbal and nonverbal working memory and mental computation (Mariani & Barkley, 1997; Murphy, Barkley, & Bush, 2001; Zentall & Smith, 1993); (4) story recall (Lorch et al., 2000); (5) planning and anticipation (Grodzinsky & Diamond, 1992; Klorman et al., 1999); (6) verbal fluency and confrontational communication (Grodzinsky & Diamond, 1992; Zentall, 1988); (5) effort allocation (Douglas, 1983); (6) developing, applying, and self-monitoring organizational strategies (Hamlett, Pellegrini, & Conners, 1987; Purvis & Tannock, 1997); (7) internalization of self-directed speech (Berk & Potts, 1991; Winsler, Diaz, Atencio, McCarthy, & Chabay, 2000); (8) adhering to restrictive instructions (Danforth, Barkley, & Stokes, 1991; Roberts, 1990); and (9) self-regulation of emotion (Braaten & Rosen, 2000; Hinshaw, Buhrmeister, & Heller, 1989; Maedgen &

Carlson, 2000). Several studies have also demonstrated that ADHD may be associated with less mature or diminished moral development (Hinshaw, Herbsman, Melnick, Nigg, & Simmel, 1993; Simmel & Hinshaw, 1993). Many of these cognitive difficulties appear to be specific to ADHD and are not a function of its commonly comorbid disorders, such as learning disabilities, depression, anxiety, or oppositional defiant/conduct disorder (Barkley, Edwards, Lanieri, & Metevia, 2001; Klorman et al., 1999; Murphy et al., 2001; Nigg, 1999; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002).

The commonality among most or all of these seemingly disparate abilities is that all have been considered to fall within the domain of "executive functions" in the field of neuropsychology (Barkley, 1997b; Denckla, 1996) or "metacognition" in developmental psychology (Flavell, 1970; Torgesen, 1994; Welsh & Pennington, 1988), or to be affected by these functions. All seem to be mediated, at least in part, by the frontal cortex, and particularly the prefrontal lobes (Fuster, 1997; Stuss & Benson, 1986). Theorists and clinical scientists have long speculated that problems with executive functioning specifically and self-regulation more generally are at the heart of this disorder and give rise to the more superficial and surface symptoms represented in clinical diagnostic criteria (Barkley, 1997a; Cantwell, 1975; Douglas, 1983; Still, 1902).

As appealing as these speculations have been about ADHD and self-control in seeming to square better with the behavior of children with ADHD, they necessitate that one have a reasonable account of how normal self-regulation develops in children and of how ADHD acts to disrupt that normal developmental process. These necessities have led me to spend the better part of the past decade conceptualizing and investigating the nature of self-control in children and adults with and without ADHD (Barkley, 1997a) and, more recently, conjecturing about the possible adaptive advantages that psychological modules for self-regulation and executive functioning may have served in the course of human evolution (Barkley, 2001b). As I discuss later, such conjecture can serve to suggest testable hypotheses for future research concerning the nature and purposes of self-regulation, and broaden the scope of social domains that developmental disorders such as ADHD, or acquired disorders such as frontal lobe injuries, may disrupt. Space constraints limit this chapter to providing merely an overview of the self-control problems experienced by children and adults with ADHD, and the course I have taken in developing a theory of self-control to try to explain that disorder. Greater coverage of these issues can be found in other sources (Barkley, 1997a, 1997b, 1998, 2001b). Good science and scholarship demand that we define our terms in as operational a way as possible, if we are to avoid conceptual or semantic confusion. Of relevance here, the terms "behavioral inhibition," "self-control," and "executive functioning," which have been employed frequently in the fields of developmental psychology, neuropsychology, and child psychopathology, need some pinning down if we are to get some idea of what they represent and how their functions may be disturbed in individuals with ADHD.

DEFINING INHIBITION, SELF-CONTROL, AND EXECUTIVE FUNCTION

From the perspective taken here, the terms "behavioral" or "response inhibition," "self-control" or "self-regulation," and "executive functioning" define overlapping and interacting human abilities. Defining them carefully shows their interconnectedness. The definitions used here are behavioral rather than cognitive terms, which at least permits them to be more operationally defined, more easily observed and understood, and potentially

more easily examined in research. Behavioral terms also make more evident the possible evolutionary continuity or transition from the rudimentary appearance of some aspects of inhibition, self-control, and executive functions (EFs) observed in a few other primates (e.g., nonverbal working memory in rhesus monkeys and chimpanzees) to the complex executive system ascribed to humans. To describe these terms operationally relative to their manifest behavioral equivalents also may clarify their possible path of gradual evolution and their adaptive purpose(s). In this chapter, I take the stance that the initial and overarching purpose of self-control and executive functioning is inherently social. That purpose arose out of the group-living niche that humans occupy, particularly out of social groups comprised of genetically unrelated, or distantly related, individuals who came to depend on forms of reciprocal exchange or altruism and the formation of cooperative coalitions for orchestrating non-zero-sum activities on which their survival likely depended. The essence of such non-zero-sum coalitions is that they attain economic and other survival benefits that cannot be achieved by individuals acting alone (Wright, 2000). From this perspective, nonsocial organisms that live relatively independently of other members of their species (other than for mating/reproductive activities) do not need self-control or the executive system that permits it.

The term "response inhibition," as I use it here, refers to three overlapping yet somewhat distinct processes:

1. Inhibiting the initial prepotent response to an event, so as to create a delay in responding.
2. Interrupting an ongoing response that proves ineffective, thereby permitting a delay in and reevaluation of the decision to continue responding (a sensitivity to error).
3. Protecting not only the self-directed (executive) responses that occur within the delay but also the goal-directed behavior they generate from disruption by competing events and responses (interference control or resistance to distraction) (Barkley, 1997a, 1997b; Fuster, 1997).

I view the first process as the most important, for without a delay in the prepotent response (stopping), any thinking and related goal-directed actions pertinent to that situation are pointless, if they can occur at all (Barkley, 1997a; Bronowski, 1967/1977). It is not only the response that is delayed but also the decision about a response (Bronowski, 1967/1977, 1976). The prepotent response is that response for which immediate reinforcement (positive or negative) is available within a particular context, or which has been previously associated with that context (Barkley, 1997b). Both forms of reinforcement—positive and negative—must be considered in defining a response as being prepotent. Whereas some forms of impulsive behavior function to achieve an immediate reward, others serve to escape or avoid immediate aversive, punitive, or otherwise undesirable events (negative reinforcement). Such escape/avoidance responses are just as much a part of immediate gratification as are responses that result in immediate reward. Both forms of prepotent response will require inhibition if executive functioning, or thinking, and self-regulation are to occur and to be effective.

I employ the definition of "self-control" used in behavior analysis: *Self-control is a response (or series of responses) by the individual that functions to alter the probability of a subsequent response to an event, thereby changing the likelihood of a later consequence related to that event* (Barkley, 1997a, 1997b; Kanfer & Karoly, 1972; Mischel, Shoda, & Rodriguez, 1989; Skinner, 1953). In other words, self-control is any action by

individuals directed toward themselves, so as to change their behavior and therein alter future rather than merely immediate consequences. Some have considered self-control to be the choice of a delayed, larger reward over a more immediate, smaller one (Ainslie, 1974; Burns & Powers, 1975; Logue, 1988; Mischel, 1983; Navarick, 1986). But this ignores the self-directed actions in which the individual must engage, so as to value the delayed over the immediate reward and to pursue that delayed consequence.

What then is executive functioning? Neuropsychology seems to view it as being largely comprised of unobservable "cognitive" or mentalistic events mediated chiefly by the prefrontal cortex. That literature is typified by descriptions of various activities thought to be involved in executive functioning, whereas the construct itself goes undefined. For instance, the term "executive function" has been used to encompass the actions of planning, inhibiting responses, developing and using strategy, flexible sequencing of actions, maintaining a behavioral set, resisting interference, and so on (Denckla, 1996; Morris, 1996; Spreen, Risser, & Edgell, 1995). Others simply concluded that the EFs are what the frontal lobes do (Stuss & Benson, 1986). Denckla (1994) defined executive functioning by its components: interference control, effortful and flexible organization, and strategic planning or anticipatory, goal-directed preparedness to act. Dennis (1991) did likewise, recognizing the components of regulatory (mental attention), executive (planning), and social discourse (productive verbal interaction with others). And so did Spreen and colleagues (1995) in their description of EFs as inhibition, planning, organized searching, self-monitoring, and flexibility of thought and action. The underlying theme of EFs seems to be this future orientation as conjectured by Denckla, and which the philosopher Daniel Dennett (1995) has called "the intentional stance." Goal-directed behaviors require a capacity for understanding the temporal ordering of events and of requisite responses to them (Shimamura, Janowsky, & Squire, 1990), including the hierarchical staging of behavior into arrangements of goal–subgoal components (Goel & Grafman, 1995). Those arrangements may form part of a larger capacity for the formation of social scripts (Sirigu et al., 1995) that involve the generation of the sequential steps needed to complete a social goal, such as shopping for groceries, planning a wedding, and so on. As Sirigu and colleagues (1995) found, these scripts are impaired in patients with frontal lobe injuries. Yet all such efforts to describe the EFs seem to fall short of the mark. They merely invite the question of what underlying theme binds these descriptions together.

Neuropsychology has opted for a "cognitive" or mentalistic view of executive functioning, founded on the computer as a metaphor for brain–behavior functioning. This view is incorrect, I believe, for two reasons. First, as I assert later, the EFs are not mental in some impossibly undetectable, otherworldly sense that they take place in something called a mind on some higher than physical plane. *The EFs comprise the principal classes of behavior that we use toward ourselves for purposes of self-regulation (changing our future).* An "executive act" is any act toward oneself that functions to modify one's own behavior, so as to change one's future outcomes. Such actions may be covert but need not be so to be classified as "executive" actions here. The term "covert" merely means that the outward, publicly observable (musculoskeletal) manifestations of such behavior have been made very difficult to detect by others over the course of human evolution. But those actions still occur, and they can still be thought of as forms of behavior. Second, developments in the technology of neuroimaging and the fine-grained recording of shifts in muscle potential now suggest that this covert behavior-to-the-self is capable of being measured (D'Esposito et al., 1997; Livesay, Liebke, Samaras, & Stanley, 1996; Livesay & Samaras, 1998; Ryding, Bradvik, & Ingvar, 1996). As these studies suggest, when we en-

gage in verbal thought (covert self-speech) and imagined actions, the peripheral muscles and brain substrates ordinarily associated with the public display of these same actions continue to be activated. But the movements of the peripheral muscles are largely imperceptible to others, being reflected chiefly through small changes in muscle electrical potentials at those sites. Thinking is behaving to the self, with the peripheral muscle apparatus being largely suppressed.

The conceptual linkage of inhibition with self-regulation, and of both constructs with executive functioning is now obvious. Response inhibition is a prerequisite to self-regulation, because one cannot direct actions or behavior toward oneself if one has already responded impulsively to an immediate event. The EFs are the general forms or classes of self-directed actions that humans use in self-regulation. I have identified at least four such classes below. The EFs and the self-regulation they create produce a net overall maximization of social consequences when considering both the immediate and delayed outcomes of certain response alternatives. Self-regulation and the EFs that comprise it, in short, function to maximize future consequences over immediate ones, and so are instrumental to purposive, intentional behavior. As I argued earlier, that future is a social one. This resembles the view of Lezak (1995), who described the EFs as "those capacities that enable a person to engage successfully in independent, purposive, self-serving behavior," (p. 42) or that of Denckla (1994), noted earlier, who described them as attention and intention toward the future. Regrettably, neither author specified the nature of those EFs with any precision.

Often unstated is the fact that self-control is nearly impossible if there is not some means by which the individual is capable of perceiving and valuing future over immediate outcomes: No sense of the future—no self-control. A longer term outcome may have greater reward value than a short-term reward, if the two are compared to each other without regard to time. But arranged temporally, as they are, the reward value of the longer term outcome will be discounted by all organisms as a function of the length of the temporal delay involved to get it (Mazur, 1993). Humans demonstrate a remarkable shift over the first three decades of life toward a greater preference for larger, delayed versus smaller, more immediate rewards (Green, Meyerson, Lichtman, Rosen, & Fry, 1996). They discount future outcomes less steeply with age than do younger individuals or other species. This requires some neuropsychological capacity to sense the future, that is, to construct hypothetical futures, particularly for social consequences. It also simultaneously involves the weighing of alternative responses and their temporally proximal and distal outcomes—a calculation of risk–benefit ratios over time. Some neuropsychological mechanism must have evolved that permitted this relatively rapid construction of hypothetical social futures, while engaging in an economic analysis of immediate versus delayed outcomes. Without such an evolved mental mechanism, self-control would not occur. As I discuss below, the first EF to develop in children provides the capacity for just such a cross-temporal economic spreadsheet—visual imagery.

CONSTRUCTING A THEORY OF THE EXECUTIVE FUNCTIONS AND SELF-CONTROL

I have suggested that humans have at least four means of self-control—four classes of action that they direct toward themselves to change themselves to improve their future. The details of this model of EFs can be found in previous publications (Barkley, 1997a, 1997b), along with the evidence that seems to support their existence. That evidence

comes from developmental psychology, neuropsychological studies into the underlying factors or dimensions of executive functioning, and neuroimaging research on the apparent localization of these EFs within the prefrontal lobes. It also comes from a substantial amount of research on executive functioning in children and adults with ADHD, a disorder of inhibition believed to originate in the prefrontal–striatal–cerebellar network (Castellanos et al., 1996; Filipek et al., 1997).

The initial structure of this model is taken from Bronowski (1967/1977), who first proposed it in his discussion of the unique properties of human language that he attributed to the prefrontal cortex. I further elaborated this framework by drawing heavily from Fuster's insights into the functioning of the prefrontal cortex (Fuster, 1995, 1997). To this, I added the findings of Goldman-Rakic (1995) and others on working memory, and also those of Damasio (1994, 1995) on the somatic marker system and the rapid economic (motivational) analysis of hypothetical outcomes it affords. The model of EFs offered here is thereby a hybrid one.

The EFs model is graphically depicted in Figure 15.1. Space here permits only a very brief summary of it; far greater detail is provided elsewhere (Barkley, 1997a, 1998). In this model, inhibition sets the occasion for the occurrence of the EFs and provides the protection from interference that those EFs will require to construct hypothetical futures and direct behavior toward them. Despite being relatively distinct, the three inhibitory functions and the four EFs are interactive in their natural state and share a common pur-

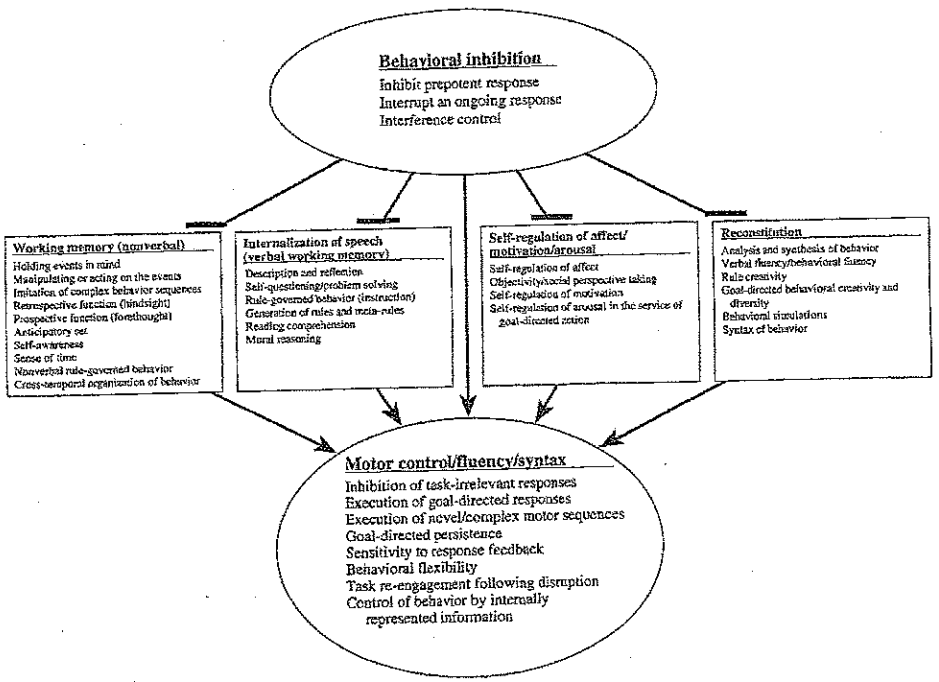

FIGURE 15.1. A schematic model of the relationship of inhibition to four executive functions and the motor control they govern. From Barkley (1997b). Copyright 1997 by The Guilford Press. Reprinted by permission.

pose. That purpose is to "internalize," or make private, certain self-directed behavior, so as to anticipate and prepare for the future, especially the social future. Why such self-directed behaviors had to become covert in form is be noted later. For now, the ultimate utility of the EFs is to maximize net long-term versus short-term social outcomes.

I view the four EFs as developing by a common process. I have borrowed Vygotsky's process for the internalization of speech (Diaz & Berk, 1992; Vygotsky, 1978; Vygotsky & Luria, 1994), which I ascribe to the second EF, and extended it to three other forms of behavior that become self-directed and eventually covert or internalized. All four EFs represent private, covert forms of behavior that at one time in early child development (and in human evolution) were entirely publicly observable and directed toward others and the external world at large. With maturation, this outer-directed behavior becomes turned on the self as a means to control one's own behavior. Such self-behaving then becomes increasingly less observable to others as the suppression of the public musculoskeletal aspects of the behavior progresses. This progressively greater capacity to suppress the publicly observable aspects of behavior is what is meant here by the terms "covert, privatized, or internalized."

Sensing to the Self (Nonverbal Working Memory)

The first executive function has been called nonverbal working memory by others. It is akin to Baddeley's visuospatial sketchpad in his information-processing rendition of working memory (Baddeley, 1986). It originates in the privatization of sensorimotor actions—it is sensing to the self (literally, re-sensing to the self). The most important of the senses to humans are vision and audition, so this executive function may be chiefly comprised of visual imagery and covert audition—seeing and hearing to the self.

This EF has both retrospective (sensory or resensing) and prospective (preparatory motor) elements (Fuster, 1997; Goldman-Rakic, 1995), and requires interference control for its effective performance. Here, then, arises the mental module for sensing the hypothetical future from the experienced past. This serves to generate the private or mental representations (images, auditions, etc.) that bridge the cross-temporal elements within a contingency arrangement (event–response–outcome) that is so crucial for self-control toward the future. Pierce (1897/1955), and later Deacon (1997) and Donald (1993), noted that such private sensorimotor representations are prerequisites for symbolization. They constitute mental icons that can be linked with others to form indexical relations (e.g., smell smoke → iconic smoke → iconic fire → escape) (Deacon, 1997). Symbols can then arise as means of linking such indexical relations to each other (Deacon, 1997). Both private sensory representations (nonverbal working memory) and symbolization (language and verbal working memory) are among the prerequisites for culture (Deacon, 1997; Donald, 1993; Durham, 1991; Lumsden & Wilson, 1982).

Speech to the Self (Verbal Working Memory)

The second EF, verbal working memory, is similar to Baddeley's (Baddeley & Hitch, 1994) construct of the same name. It originates in the developmental internalization of speech. The individual is capable of activating the central or cortical aspects of speech without engaging the actual motor execution of that speech. Such self-speech permits self-description and reflection, self-instruction, self-questioning and problem solving, as well as the invention of rules and metarules to be applied to oneself (Diaz & Berk, 1992). Therefore, it contributes not only to a major form of self-control via language but also

likely provides the basis for moral conduct. It also makes possible reading comprehension through silent reading (self-speech) that must be held in mind for the extraction of its semantic (nonverbal) content.

Emotion to the Self (Self-Regulation of Affect–Motivation–Arousal Emotion)

This EF may occur initially as a mere consequence of the first two (private sensing and speech). Those EFs involve covertly re-presenting forms of visual and verbal information to oneself. These mentally represented events have associated affective and motivational properties or valences, which Damasio (1994, 1995) called "somatic markers." Initially, those affective and motivational valences may have publicly visible counterparts, emotional displays, such as when we laugh out loud in response to a mentally visualized incident. Eventually, though, these affective displays are kept private or covert in form. Hence, originates the third EF of privatizing affect and its motivational properties. In brief, it is feeling (emoting–motivating) to the self. This model argues that this EF forms the wellspring of intrinsic motivation (willpower) so necessary to support future-directed behavior.

Self-Play (Reconstitution)

The fourth EF is self-directed, private (covert) play, or reconstitution. "Fluency," "flexibililty," and "generativity" are some other terms by which this EF is known in neuropsychology. It serves to generate a diversity of new combinations of behavioral units out of old ones through a two-step process: analysis and synthesis. In analysis, old behavior sequences are broken down into smaller units. These units are then recombined (synthesized) into new sequences that can be tested against the requirements of the problem to be solved (Corballis, 1989; Fuster, 1997). It is hypothesized here to arise from the internalization of play (both sensorimotor and symbolic) and serves to create novel future-directed actions. Such novel actions will be needed when obstacles to a goal are encountered (problems), in order to overcome them and successfully attain the goal. The generation of such novel responses has been shown to be especially problematic for patients with frontal lobe injuries (Godefroy & Rosseaux, 1997). It has been blamed on their inability to form and sustain mental referents from instructions, so as to manipulate them to discover a means to achieve a goal. And that, as I have argued, is simply covert play to one's self.

This EF may be subdivided further into verbal and nonverbal components comparable to the working memory system (verbal or nonverbal) on which it acts. Fluency tasks are one means of assessing this function. Recent neuroimaging studies suggest that verbal and nonverbal (design) fluency are mediated by separate (left vs. right) regions of the dorsolateral frontal cortex (Lee et al., 1997; Stuss et al., 1998). That would imply that a bivariate subdivision of this executive function might be useful. However, prior factor-analytic studies of EF measures have found only a single dimension representing both verbal and nonverbal fluency (Levin et al., 1996).

Further Implications of the Theory

Each executive function is also hypothesized to contribute to the following developmental shifts in the sources of control over human behavior:

- From external events to mental representations related to those events.
- From control by others to control by the self.
- From immediate reinforcement to delayed gratification.
- From the temporal now to the conjectured social future.

With maturation, the individual progressively comes to be guided more by covert representations that permit self-control, deferred gratification, and goal-directed actions toward conjectured social futures.

Briefly put, the internalization of sensorimotor action, self-speech, and emotion–motivation, along with the internalization of play (reconstitution), provides an exceptionally powerful set of mind tools that greatly facilitate adaptive functioning. In a sense, these EFs permit the private simulation of actions within specific settings that can be tested out mentally for their probable consequences (somatic markers) before a response is selected for eventual public execution. This, as Karl Popper noted, allows our ideas to die in our place (see Dennett, 1995). It constitutes a form of mental trial-and-error learning that is devoid of real world consequences for one's mistakes.

This use of the EFs for private simulation has led me to consider what might be the ultimate adaptive advantage or evolutionary function for which self-control and the executive system arose in humans (Barkley, 2001b). Why give consideration to an evolutionary perspective on self-control? Because it can be a rich source of testable hypotheses about a set of mental functions and the disorders associated with them, if properly done (Buss, Haselton, Shackelford, Bleske, & Wakefield, 1998).

EVOLUTIONARY CONSIDERATIONS

The importance of taking an evolutionary stance toward child psychopathologies rests in three interrelated ideas. The first derives from the criteria that may be used to define a mental disorder. Wakefield (1999) has championed a simple yet elegant set of useful requirements that must be met for a condition to be considered a valid disorder. These requirements are based, in part, on the definition of a "biological adaptation." For a disorder to be considered as such from this perspective, it must be a "harmful dysfunction." In the first part of these criteria, existent scientific evidence must demonstrate that those experiencing the disorder have a failure or extreme deficiency in a biological adaptation. Adaptations are universal functional mechanisms found in all members of that species under their typical species range or environmental circumstances. Like hearts, lungs, and eyes, brains are an adaptation. But such adaptations are not only physical but also psychological (Barkow, Cosmides, & Tooby, 1992). In a sense, the human brain comes with a large number of inborn psychological adaptations, or mental modules (Pinker, 1997). Mental disorders are therefore defined, in part, as failures or extreme deficiencies in psychological adaptations. The second part of these criteria is the requirement that harm result from the failing adaptation. Harm can consist of increased mortality, morbidity, or substantial impairment in major life activities. This view of disorders requires that a relatively clear understanding of the psychological mechanism exists, along with evidence that it is disrupted in those possessing the disorder. Only evolution provides a means by which to understand the basis for the psychological adaptation, or its adaptive purpose(s). There is no question that ADHD is associated with a significant deficit in a psychological adaptation (response inhibition) and significant impairment in daily life activities (Barkley, 1998). It also contributes to increased morbidity through accidental injury

(Barkley, 2001a) and may result in decreased life expectancy, though the latter is rather speculative at this time (Barkley, 1998).

This raises the second rationale for an evolutionary approach to psychopathology. If disorders are failures of adaptations, then the more one understands the evolutionary history of that adaptation, and especially what functions it serves, the deeper the appreciation for what the disorder has disrupted in the psychological functioning of those so afflicted. Adaptations arise from evolution as a consequence of their solving adaptive problems for the species (Ridley, 1996). To fully understand the adaptation, then, one needs to consider the nature of these problems and how the adaptive mechanism contributes to their reduction or resolution. For instance, I have speculated that behavioral inhibition, and especially the associated executive functions, may have arisen for purposes of reciprocal exchange (delayed altruism), the formation of cooperative coalitions that engage in non-zero-sum activities, and, eventually, imitation and vicarious learning (Barkley, 2001b). By approaching the disorder from the standpoint of evolution, a person is better able to appreciate the purposes of the adaptation and how its failure via the disorder may disrupt normal functioning. Returning to ADHD, an evolutionary analysis would raise the hypothesis that those with ADHD will have substantial difficulty in social realms that involve reciprocal exchange or altruism, development of cooperative coalitions to achieve greater benefits than can be attained by acting alone, and use of vicarious learning for self-management and improvement. None of these directions for future research would have arisen from the purely descriptive and taxonomic view of ADHD as an attention disorder (American Psychiatric Association, 1994).

The third basis for considering an evolutionary stance to disorders comes from the fact that much of a species' development is governed by heritable patterns of structural and functional change. Both the physical and psychological molding of a species to its relatively recognizable and uniform body plan and set of behavioral predispositions have been, to varying degrees, determined by natural selection acting on heritable, recurring patterns of structural and functional development (Barkow, Cosmides, & Tooby, 1992). In short, not only do adaptations arise through the process of natural selection, but so also do their pattern and sequence of development. This being so, one must consider the pattern and sequence for the normal development of an adaptation, including psychological ones, if one is to understand better how they are disrupted by or within a particular form of psychopathology or developmental disability. Just as an evolutionary perspective raises interesting hypotheses about the end purpose of an adaptation, so too can it raise equally interesting hypotheses about the development of that functional mechanism. For ADHD, an evolutionary developmental perspective would provide a fuller account of ADHD through its implications for the pattern and sequence in which normal inhibition and self-regulation emerge in children, and what ADHD may be doing to them.

As noted earlier, I believe that there is little question that self-regulation arose for a social function; thus, self-control is directly related to social relations (see Vohs & Ciarocco, Chapter 20, this volume). I discuss two among several possible adaptive social advantages for which self-control and an executive system might be useful (see Barkley, 2001b, for others).

Reciprocal Altruism (Social Exchange) and Coalition Formation

Among human universal social attributes, reciprocal altruism with nonkin (others with whom one does not share genetic self-interest) stands out as among our most unique behavioral features relative to other species. Humans exchange goods or services now for

other ones later, despite having no common genetic self-interests with those with whom they engage in such exchanges. They do it nearly all the time, forming the backbone of human economic systems (Ridley, 1997). Although Williams (1966/1996) prefers the less emotive term "social donors" for those engaged in this practice to Haldane's term "altruism," the point is the same. Genetically unrelated humans live within a social group and frequently exchange benefits and costs now for benefits and costs later. The exchanges are reciprocated, and those reciprocations are delayed in time. Such a delayed exchange of costs and benefits between nonkin constitutes a promise or a social contract. Darwin (see Williams, 1966/1996, p. 94) was apparently well aware of the fact that a group-living species might well come to evolve a form of social exchange (what he termed as "the lowly motive"). He also appreciated that such exchange was an important factor to consider in understanding the evolution of not only human mental functions but also friendship and culture.

Reciprocal exchange, particularly when it is delayed, constitutes a prime candidate for the initial adaptive function of the prefrontal cortex. It requires both inhibition and a representational memory system for sensing past and future occasions—the foundation of self-control, as discussed earlier. Just as with any other form of adaptation, the mental mechanisms affording self-control exact a biological cost to the individual. That cost must be outweighed by some benefit, and such benefit need not be for the good of the species, or even the group, in order to evolve. It must be for the good of the individual and, specifically, the individual's genes. Yet humans voluntarily subject themselves to periods of self-deprivation (as in sharing or even dieting), deferred gratification (such as saving, investing, and education), and even aversiveness (as in getting inoculations against diseases). From the standpoint of selfish gene theory and its related kin, selection theory (Ridley, 1997), these actions make little sense in the context of the moment. According to those theories, individuals should seek as much benefit and advantage now for themselves and their genetic relatives, if only because others will do so if they do not, leaving the former at a disadvantage. Such personal greed is certainly evident in humans and can result in a sort of Tragedy of the Commons, whereby publicly held resources are depleted by self-interested individuals, even if the long-term depletion of the asset is not in those individuals' best interests (Ridley, 1997). In such instances, acts of self-control are losing strategies. The costs of reciprocal altruism and self-control can be substantial, and the individual employing it can be easily cheated out of or outcompeted for the immediate resources. The existence of reciprocal altruism requires that there be some advantage to the self-interested motives of individuals involved in those exchanges.

Delayed reciprocal exchange requires a capacity to perceive long-term sequences of events and their outcomes for one's self and for others, with whom one is trading. Even rudimentary, little-delayed forms of reciprocal exchange would begin to create selection pressures for the evolution of an increasingly longer sense of past and future (nonverbal working memory), so as to evaluate those longer term consequences of the trade. It has been suggested that in the environment of prehistoric humans, such as the grasslands of central Africa, food sources and other resources showed cyclical patterns of availability, as they do even today (Ridley, 1997). Periods of plenty were punctuated by periods of famine. Under such conditions of large swings in resource availability, sharing and its associated reciprocal exchange would have brought great advantage to individuals living in groups as a means of mediating or modulating the personal risks and costs associated with these cycles of feast and famine. Under such circumstances, it would pay those who had been lucky in hunting or scavenging to give up some of their excess bounty to others, in exchange for the same sort of reciprocation later, when those others were more fortu-

nate and the previously successful hunters were not. Like a group-insurance pool today, individuals would chip in resources they did not require at the moment to those who needed them, in exchange for the same treatment later, in their own time of need—a sort of Golden Rule would result. A group of selfish cooperators would evolve, provided that the consequences for cheating on the contracts were made sufficiently harsh by the group to make reneging on those exchanges costly (Ridley, 1997). Indeed, in some modern hunter–gatherer groups, such as Eskimos, it seems that on some occasions, successful hunters' failure to share when their turn came could cost them their lives (Dugatkin, 1999; Ridley, 1997). Under periods of extreme resource variability, reciprocal exchange is a good adaptive strategy to solve the problem, a strategy converged on by other species such as vampire bats (reciprocal blood sharing) and some birds and mammals (reciprocal grooming) in more rudimentary forms (Ridley, 1997; Williams, 1966/1996). Perhaps this is what led to the further development of the EFs.

In essence, social exchange requires a sort of mental spreadsheet that calculates temporal sequences of exchange for which the executive system seems ideally designed. Social exchanges that occur frequently between two selfish cooperators can become the foundation for building not only friendships but also social coalitions for cooperating with or acting against other individuals and coalitions. The executive functions would seem to be well-designed mental modules for mediating this adaptive strategy of social exchange and cooperative coalition formation for greater adaptive advantage. If so, it implies that one of the major detrimental effects of ADHD (and of other frontal lobe injuries) for daily adaptive functioning is the diminution of the capacity for effective social exchange and its attendant cooperative coalition formation in daily social life.

Imitation (Vicarious) Learning

Though rarely mentioned in discussions of EFs, particularly those of nonverbal working memory, the capacity to engage in imitation, particularly delayed imitation, is probably one of the most important capacities for group-living social species such as humans. Many species, as Darwin (1871/1992) noted, are capable of mimicry or even immediate imitation of particular acts. For many reasons, immediate mimicry or imitation is a good adaptive strategy, and other species have converged on it. Delayed imitation, however, especially in generalized form, is a notably human achievement (Donald, 1991, 1993). Our species has an early developing instinct, nay, nearly a compulsion, to do it (Meltzoff, 1988).

Imitation, especially delayed imitation, clearly depends on three cognitive capacities: (1) the inhibition of prepotent responses, (2) an evolved mental mechanism for carrying past sensory perceptions of others' behavior forward in time across a delay interval, and (3) a capacity to construct motor responses on the basis of those mentally reperceived actions of others. The latter two requirements are obviously the retrospective and prospective aspects of the nonverbal working memory system. Initially, it seems likely that the initial delay between the act and its imitation was undoubtedly brief, perhaps owing to the initially fleeting afterimages that occurred from primary sensory impressions. Regardless of how it originated, the capacity to inhibit prepotent responses and to carry forward in time past perceptions (retrospection) that create the template for the later imitative motor act (prospection) form the foundation of self-regulation, as noted earlier. The more highly developed the nonverbal working memory capacity, the lengthier and more hierarchically complex the sequence of actions that can be held in mind for later imitation, and the longer the delay over which it can be carried into the future. And the greater would be

the demand for response inhibition during the period when such imitative responses are being programmed and eventually executed. The more complex the sequence, the more its syntax and timing must also be held in mind. The holding of a sequence of events in mind may also form the beginnings of a subjective, or psychological, sense of time (Davies, 1995).

Imitation involves the reproduction of another person's behavior after it is observed. Vicarious learning is a more advanced form of imitation. It involves not just imitation (doing what gained reinforcement for others) but inverse imitation, not doing what another person does (avoiding actions that led to aversive, painful, or even mortal outcomes for others). Note the requirement for oppositional action involved in vicarious learning. The amount of social learning that occurs in humans through imitation and vicarious learning is substantial, to say the least. It is undoubtedly far more than the learning that could occur by operant conditioning or by trial and error alone. Imitation develops very early in childhood; in fact, rudiments of it are present in infants at 9 months of age (Meltzoff, 1988). Its development seems to parallel the development of representational memory, especially visual imagery (Kopp, 1982; Meltzoff, 1988).

No other species comes close to the human capacity for this form of learning. Evolutionary theory demands that explanations for such adaptations initially be considered from a self-interested perspective (the good of the individuals or of their genes), before giving credence to explanations at the group level (for the good of others) (Dawkins, 1976, 1997; Williams, 1966/1996). From that self-interested perspective, vicarious learning constitutes a form of *experiential theft* that is clearly in the imitator's self-interests. More precisely, it is behavioral plagiarism. Through imitation and vicarious learning, the individual profits from the experiences that others may have with real-world contingencies, without the costs, penalties, pitfalls, morbidity, and mortality associated with those contingencies. Vicarious learners gain a considerable adaptive advantage in a group-living species, because they appropriate the experience of another person for their own, with minimal costs. From that vantage point, imitation and vicarious learning are incredibly useful self-interested adaptations.

Imitation also provides for the development of tool manufacture, as well as social communication via gesture (Blackmore, 1999; Donald, 1993). The origin of imitation and later vicarious learning would have set up selection pressure for humans to evolve a covert form of behavioral rehearsal to keep others from copying (plagiarizing) their behavior while it was being rehearsed and further perfected. Though speculative, this may have initiated the need for the internalization or privatization of one's behavior-to-the-self that became the basis for the EFs. Interestingly, this resensing of one's past experiences may also be the origin of "autonoetic awareness," or the awareness of self across time (Barkley, 1997a; Kopp, 1982; Wheeler, Stuss, & Tulving, 1997).

FALSIFYING THE THEORY OF EXECUTIVE FUNCTIONING

One obvious result of redefining the EFs as being relatively covert behavior-to-the-self is that it is testable. When individuals are engaged in each of these forms of private behavior, it may be possible to detect subtle yet measurable aspects of the originally public form of that behavior. This could be done by using very sensitive instruments that can detect fine changes in muscle tension or even movement associated with the covert form of the behavior involved. Livesay and colleagues have done this to show that some changes in muscle tension and even micromovements of the oral-musculature occur during covert

verbal thought. And changes in muscle tension in the limbs have been found to occur during acts of visual imagery of imagined manipulative activity (Livesay & Samaras, 1998; Livesay et al., 1996). This prediction also could be tested by neuroimaging studies. Those studies might show that the same or similar zones of cortical activation are involved in both the public and private forms of behavior, except that in the private form, the primary sensory cortex would not be activated, and the primary motor zone associated with the public behavior would need to be suppressed to preclude the actual public execution of the response. Ryding and colleagues (1996) appear to have demonstrated this very finding in their neuroimaging studies of covert self-speech or verbal thought, and D'Esposito and colleagues (1997) have done so for visual imagery. Perhaps this explains the relatively recent discovery that the cerebellum is related in some ways to "cognition," and the planning and execution of motor actions once attributed to just the prefrontal cortex (Diamond, 2000; Houk & Wise, 1995). Not only is the cerebellum important in the execution of overt behavior but it also may be just as important in this form of covert behavior to the self that comprises nonverbal working memory.

This rendering of executive function as covert behavior-to-the-self leads to a further prediction: We should expect that the private forms of the behavior suffer from many of the same constraints, flaws, and qualities as do their public counterparts. For instance, the fact that I am largely color blind to pastel reds and greens would have little or no meaning for a cognitive psychological view of nonverbal working memory, such as that proposed by Baddeley (1986). Yet it would have substantial meaning here as a prediction that my capacity for visual imagery (nonverbal working memory) would be equally deficient in these color hues. Such a prediction has some support in research on visual imagery (Kosslyn, 1994). The same would be true of mentally simulated motor actions that would be afflicted with the same deficits, flaws, and limitations as are the publicly observable movements on which they are based. This seems to be the case for children with developmental motor coordination disorder (Maruff, Wilson, Trebilcock, & Currie, 1999). Such deficits are imminently understandable from the perspective of the present EF theory, but make little or no sense from the viewpoint of the information-processing/computer metaphor of the EFs. And so, too, would comparable deficits and constraints be predicted to occur in private speech, private emotion–motivation, and private play (reconstitution), if deficits existed in their public counterparts.

Moreover, this perspective on the executive system further argues that an individual could not engage in the public and private action simultaneously, given that many of the same brain regions are employed in both. A moment's reflection will show this to be true for speech. One cannot speak covertly to oneself and publicly to others at the same time. This should be so for the other EFs as well. By adulthood, then, humans have two means of behaving—a public one and a covert one. Behaviors proposed for execution are initially tested out in their covert form, and then one is selected for public execution (Bronowski, 1967/1977). It is the covert form that is impaired by injuries to the frontal lobes, often to the detriment of the effective use of the public form as well.

A third prediction from this model is that of a stagewise hierarchy in the development of these EFs, each requiring that the previous one emerge before it can begin to do so during maturation. So crucial may be nonverbal working memory (sensing to the self) to human development and survival that it seems to arise within the first few months of life. By ages 12–24 months, it far exceeds that of our closest living primate relative (Diamond, Cruttenden, & Niederman, 1994; Hofstader & Reznick, 1996; Kopp, 1982; Zelazo, Kearsley, & Stack, 1995). Thereafter develops the internalization of self-speech, then that of emotion–motivation, eventually leading to that of reconstitution. This se-

quence is admittedly speculative. Some type of staging in the development of EFs, however, has been suggested in cross-sectional studies of age-related differences in batteries of EF tasks (Hale, Bronik, & Fry, 1997; Levin et al., 1996; Passler, Isaac, & Hynd, 1985; Welsh, Pennington, & Grossier, 1991). None of these were longitudinal designs, however, so these studies cannot speak directly to the slope, rate, and specific staging of the developmental trajectories the EFs may take.

Noteworthy here is the additional implication that the very nature of self-control demonstrates qualitative, not just quantitative, changes throughout child development. From this model comes the prediction that young children may use just one form of self-regulation (sensing to the self, largely imagery), whereas somewhat older children have two forms (now adding self-speech), and even older children manifest three forms (with the addition of self-directed emotion). Eventually, by late childhood to early adolescence, the fourth form of self-control emerges, granting individuals four means by which to regulate their own behavior toward a more effective and successful social future.

THE IMPACT OF ADHD ON SELF-CONTROL

A central problem for persons with ADHD is the lack of capacity for behavioral inhibition (Barkley, 1999; Nigg, 2001; Quay, 1997). Given the importance of such inhibition to executive functioning as described earlier, a deficit in inhibition will result in a cascade of secondary deficits into the four EFs. As extrapolated to those with ADHD, the model predicts that deficits in behavioral inhibition lead to deficiencies in nonverbal working memory, thus resulting in (1) particular forms of forgetfulness (forgetting to do things at certain critical points in time), (2) impaired ability to organize and execute actions relative to time (e.g., time management), and (3) reduced hindsight and forethought, (4) leading to a reduction in the creation of anticipatory action toward future events. Consequently, the capacity for the cross-temporal organization of behavior in persons with ADHD is diminished, disrupting the ability to string together complex chains of actions directed, over time, to a future goal. The greater the degree to which time separates the components of the behavioral contingency (event, response, consequence), the more difficult the task will prove to be for those with ADHD who cannot bind the contingency together across time to use it to govern their behavior as well as others.

Research is beginning to demonstrate some of these deficits in persons with ADHD, such as nonverbal working memory, timing, and forethought (Barkley, 1997a; Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Barkley, Murphy, & Bush, 2001; Murphy et al., 2001). Still unstudied is the prediction from this theory that children with ADHD will be delayed in making references to time, to the past, and to the future in their verbal interactions with others relative to when normal children begin making such references in their development of sense of time, hindsight, and foresight.

For those with ADHD, the privatization of speech should be delayed, resulting in greater public speech (excessive talking), less verbal reflection before acting, less organized and rule-oriented self-speech, diminished influence of self-directed speech in controlling one's own behavior, and difficulties following the rules and instructions given by others (Barkley, 1997a). Substantial accumulated evidence supports this prediction of delayed internalization of speech (Berk & Potts, 1991; Landau, Berk, & Mangione, 1996; Winsler, 1998; Winsler et al., 2000). Given that such private self-speech is a major basis for verbal working memory (Baddeley, 1986), this domain of cognitive activity should be impaired in ADHD as well. Evidence suggests that this is so; children with ADHD have

difficulties with tasks such as digit span backwards, mental arithmetic, paced auditory serial addition, paired associated learning, and other tasks believed to reflect verbal working memory (Barkley, 1997a; Chang et al., 1999; Grodzinsky & Diamond, 1994; Kuntsi, Oosterlaan, & Stevenson, 2001).

The impairment in the internalization and self-direction of emotion arising from ADHD leads to the following predictions: Those with ADHD should display (1) greater emotional expression in their reactions to events; (2) less objectivity in the selection of a response to an event; (3) diminished social perspective taking, because the child does not delay his or her initial emotional reaction long enough to take the view of others and their needs into account; and (4) diminished ability to induce drive and motivational states in themselves in the service of goal-directed behavior. Those with ADHD remain more dependent than do others on the environmental contingencies within a situation or task to determine their motivation (Barkley, 1997a). Preliminary work has begun to demonstrate that those with ADHD do have significant problems with emotion regulation (Braaten & Rosen, 2000; Maedgen & Carlson, 2000) and that this may be particularly so in that subset having comorbid oppositional defiant disorder (Melnick & Hinshaw, 2000).

The model further predicts that ADHD will be associated with impaired reconstitution, or self-directed play, evident in a diminished use of analysis and synthesis in the formation of both verbal and nonverbal responses to events. The capacity to visualize mentally, manipulate, then generate multiple plans of action (options) in the service of goal-directed behavior and to select from among them those plans with the greatest likelihood of succeeding should, therefore, be reduced. This impairment in reconstitution will be evident in everyday verbal fluency, when the person with ADHD is required by a task or situation to assemble rapidly, accurately, and efficiently the parts of speech into messages (sentences) to accomplish the goal or requirements of the task. It will also be evident in tasks in which visual information must be held in mind and manipulated to generate diverse scenarios to help solve problems (Barkley, 1997a). Evidence for deficiency in verbal and nonverbal fluency, planning, problem solving, and strategy development more generally in children with ADHD is limited, but what does exist is consistent with the theory (Barkley, 1997a; Clark, Prior, & Kinsella, 2000; Klorman et al., 1999; Nigg et al., 2002; Oosterlaan, Scheres, & Sergeant, 2002).

In general, ADHD is predicted to disrupt the aforementioned four transitions in the source of control over behavior. The child with ADHD will be more under the control of external events than of mental representations about time and the future, under the influence of others rather than acting to control the self, pursuing immediate gratification over deferred gratification, and under the influence of the temporal now more than of the probable social futures that lie ahead. From this vantage point, ADHD is not a disorder of attention, at least not to the moment or to the external environment, but is more of a disorder of intention—that is, attention to the future and what one needs to do to prepare for its arrival. It is also a disorder of time, specifically, time management, in that individuals manifest an inability to regulate their behavior relative to time, as well as do others of their own developmental level. This creates a sort of temporal myopia in which the individual responds to or prepares only for relatively imminent events rather than ones that lie further ahead in time, for which others their age are preparing, so as to be ready for their eventual arrival (Barkley, 1997a).

By implication, this view of ADHD, combined with an evolutionary perspective on the disorder, suggests that the disorder will interfere with two of the larger social purposes for which executive functioning and self-control may have evolved—reciprocal al-

truism (social exchange) and vicarious learning. These predictions have yet to be tested directly through research on children with ADHD. But there is currently sufficient evidence available to demonstrate significant impairments in the peer relationships of children with ADHD, perhaps for these very reasons. And it is apparent that those with ADHD have a propensity for risk taking, despite having been reasonably informed of the consequences for others who do so.

CONCLUSIONS

In closing, there is obviously much promise in viewing ADHD as a disorder of self-regulation. It encourages child and developmental psychopathologists to develop more fully models of how normal self-control arises across childhood and even into adulthood, and to examine where in these models disorders such as ADHD disrupt the normal structure and processes of self-regulation to produce what is known about the disorder. Moreover, such model building also suggests new hypotheses that can not only be pursued in testing the models but also provide a greater understanding of what is disrupted by the disorder. I have also argued here that taking an evolutionary or adaptive perspective toward self-control and its associated EFs can further enlighten us on the nature of these relatively unique human abilities, and what larger domains and problems of social functioning they evolved to solve. This may also help to demonstrate what social functions may be deficient in persons with ADHD. That perspective implies that self-control may have arisen for a set of largely social functions, such as reciprocal exchange, cooperative coalitions, and vicarious learning. It provides further grounds for the development of testable hypotheses not only about self-control but also about the social deficiencies that arise in disorders of self-regulation such as ADHD.

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