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The Role of Inhibitory Control and Executive Functioning in Hyperactivity/ADHD

BY

LISA BERLIN

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ABSTRACT

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This thesis examined inhibition, executive functioning and their possible relation to childhood problems of hyperactivity and inattention, in its clinical form referred to as Attention Deficit Hyperactivity Disorder (ADHD). Concurrent as well as longitudinal relations were of interest, and both clinical and non-clinical samples were studied.

Study I demonstrated concurrent relations between executive inhibition and both hyperactivity and conduct problems in preschool. However, the relation between inhibition and conduct problems could be attributed to the large overlap between hyperactivity and conduct problems.

In Study II, linear relations were found between executive inhibition and hyperactivity, whereas inhibition to the unfamiliar was related to hyperactivity, social initiative, as well as social anxiety. Non-linear analyses showed that children with high levels of both types of inhibition were at risk for developing low social initiative and social anxiety, whereas children with low levels of inhibition were at risk for developing hyperactivity, but at the same time protected from social anxiety.

In Study III, executive inhibition was longitudinally related to ADHD symptoms in both school and at home for boys, but only in the school context for girls. Executive inhibition was also related to more general executive functioning deficits, and concurrent relations were found between executive functioning and ADHD symptoms, although in both cases only for boys. Inhibition and executive functioning made independent contributions to the understanding of ADHD symptoms for boys, and together explained about half the variance in inattention problems.

In Study IV, group differences were found between ADHD children and controls for both inhibition and various other executive function measures. These measures also discriminated well between groups. The best model, which included measures tapping inhibition, working memory and emotion regulation, classified 86% of the children correctly.

In summary, the results of the present thesis were mostly supportive of Barkley's hybrid model of ADHD, although it should be noted that the question of whether inhibition should be regarded as primary to other executive functions requires further investigation.

Key words: ADHD, hyperactivity, inhibition, executive functioning, development

Lisa Berlin, Department of Psychology, Uppsala University, Box 1225, SE-751 42 Uppsala, Sweden

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The present thesis is based on the following studies, which will be referred to in the text by their Roman numerals:

I Berlin, L. & Bohlin, G. (2002). Response inhibition, hyperactivity, and conduct problems among preschool children. *Journal of Clinical Child and Adolescent Psychology, 31*, 242-251.

II Berlin, L., Bohlin, G., & Rydell, A-M. (2002*). Two types of inhibitory control: predictive relations to social functioning*. Manuscript under revision for publication.

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ABBREVIATIONS

ADHD	Attention Deficit Hyperactivity Disorder
ADHD-C	ADHD, combined subtype
ADHD-HI	ADHD, predominantly hyperactive/impulsive subtype
ADHD-I	ADHD, predominantly inattentive subtype
ANOVA	Analysis of variance
COWAT	Controlled Word Association Test
MANOVA	Multiple analysis of variance
APA	American Psychiatric Association
BAS	Behavioral Activation System
BIS	Behavioral Inhibition System
CBQ	Child Behavior Questionnaire
CD	Conduct Disorder
CPT	Continuous Performance Test
DSM-IV	Diagnostical and Statistical Manual of Mental Disorders, 4th edition
EI	Executive inhibition
ES	Effect size
IU	Inhibition to the unfamiliar
NAS	Nonspecific Arousal System
ODD	Oppositional Defiant Disorder
PBQ	Preschool Behavioral Questionnaire
SCI	Social Competence Inventory
WISC-III	Wechsler Intelligence Scale for Children, 3rd edition

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INTRODUCTION

No matter how hard he tried, little Shelley just couldn't be still for long. Sometimes he would get out of his seat and run around the classroom. Every morning he promised his mommy, "I'll be good today." But every day something went wrong. "Why do you keep doing things I tell you not to do," asked his daddy? "By the time I think about what I am going to do, I've already done it!" Shelley said sadly.

Quote from "Shelley, the hyperactive turtle" by Deborah M. Moss (1989)

Shelley, the hyperactive turtle described in the quote above, might be one of the few turtles in the world who are hyperactive. However, current research from a number of Western countries such as Sweden, Italy and the US has shown that at least 3-5% of all school-aged children display symptoms of hyperactivity, impulsivity and inattention severe enough to meet the criteria for Attention Deficit Hyperactivity Disorder (ADHD; American Psychiatric Association [APA], 1994; Gallucci et al., 1993; Kadesjö & Gillberg, 1998). Besides this, many children experience similar kinds of problems without meeting the full criteria for ADHD, making these behavior symptoms the most common of all behavior problems in childhood (Barkley, 1998).

During the past couple of decades, a large amount of research has aimed at clarifying the underlying deficit in ADHD. When using MedLine to search for the term "hyperactivity" (and limiting the search to children), 4500 references are presented up until the year 1997, that is, the year I started conducting research within this area. During the years I have been working on this thesis, another 2000 papers have been published. Understandably, this thesis is therefore in no way an attempt to provide a general overview of the huge research field of ADHD. Being a developmental psychologist, my main interest in this area is to study factors that might be useful when trying to find early predictors of hyperactivity. During the past two decades, there has been a growing interest in executive functions, and it has been suggested that they might be related to a range of different developmental disorders. The general aim of this thesis was therefore to study executive functions, with a special focus on inhibition, and the role that these functions play in explaining the deficits associated with hyperactivity/ADHD.

Four studies provide the empirical basis of this thesis. Three of them use data from a longitudinal study of a population-based sample of normally developing children followed from preschool until grade 2. The fourth study is a clinical study, the aim of which was to determine whether tests of inhibition and executive functioning can discriminate between children diagnosed with ADHD and normal controls. However, before proceeding to the empirical studies, a background to this research area is provided, including definitions of the different concepts studied and a summary of previous research.

Defining Hyperactivity/ADHD

Diagnostic criteria

Children with Attention Deficit Hyperactivity Disorder are commonly described as having difficulties with attention and/or hyperactivity and impulsivity – ”the holy trinity” of the disorder. According to the Diagnostical and Statistical Manual of Mental Disorders – 4th Edition (DSM-IV, APA, 1994; see Table 1), some of these symptoms should be evident before age 7 years, and they should be present in two or more settings. This does not mean that the primary symptoms cannot show fluctuations across settings. On the contrary, ADHD children can often sustain their attention over long periods when engaging in leisure activities which to them are enjoyable, whereas their problems become evident during activities that they consider slow and dull, and for which immediate reinforcement is not given. Further criteria for an ADHD diagnosis is that the symptoms should have persisted for at least 6 months to a degree that is maladaptive and developmentally inappropriate for the child’s age and gender, and they should not occur exclusively during the course of other psychiatric disorders.

As can be seen in Table 1, hyperactivity is, according to the DSM-IV, characterized by symptoms such as the following: fidgeting, running around or climbing excessively in situations in which it is inappropriate, having problems playing or engaging in leisure activities quietly, and talking excessively. Impulsivity is defined as blurting out answers before the questions have been completed, having difficulty awaiting one’s turn, and interrupting or intruding on others. The third ADHD component, inattention, includes symptoms such as failing to give close attention to details or making careless mistakes, having difficulties sustaining attention, being easily distracted by extraneous stimuli and being forgetful in daily activities.

Subtypes of ADHD

Three different subtypes of ADHD are identified in the DSM-IV: the combined type (ADHD-C), the predominantly hyperactive/impulsive type (ADHD-HI) and the predominantly inattentive type (ADHD-I). This classification is based on the fact that the symptoms of hyperactivity and impulsivity have been shown to be indistinguishable from one another (Achenbach & Edelbrock, 1983; Goyette, Conners, & Ulrich, 1978), resulting in two major symptoms – hyperactivity/impulsivity and inattention. For the sake of brevity, the combination of symptoms of hyperactivity and impulsivity will henceforth be referred to as hyperactivity.

In order to be diagnosed with the combined type of ADHD, the child should display at least six out of nine symptoms of hyperactivity as well as six out of nine symptoms of inattention. As evident from their names, children diagnosed with the two other subtypes of ADHD should only meet the criteria for either hyperactivity or inattention.

Table 1.
DSM-IV criteria for ADHD [1]

A. Either (1) or (2):

(1) six (or more) of the following symptoms of inattention have persisted for at least six months to a degree that is maladaptive and inconsistent with developmental level:

Inattention

(a) often fails to give close attention to details or makes careless mistakes in schoolwork, work, or other activities
(b) often has difficulties sustaining attention in tasks or play activities
(c) often does not seem to listen when spoken to directly
(d) often does not follow through on instructions and fails to finish schoolwork, chores, or workplace duties (not due to oppositional behavior or failure to understand instructions)
(e) often has difficulty organizing tasks and activities
(f) often avoids, dislikes, or is reluctant to engage in tasks that require sustained mental effort (such as schoolwork or homework)
(g) often loses things necessary for tasks or activities (e.g., toys, school assignments, pencils)
(h) is often distracted by extraneous stimuli
(i) is often forgetful in daily activities

(2) six (or more) of the following symptoms of hyperactivity-impulsivity have persisted for at least 6 months to a degree that is maladaptive and inconsistent with developmental level:

Hyperactivity

(a) often fidgets with hands or feet or squirms in seat
(b) often leaves seat in classroom or in other situations in which remaining seated is expected
(c) often runs about or climbs excessively in situations in which it is inappropriate (in adolescents and adults, may be limited to subjective feelings of restlessness)
(d) often has difficulty playing or engaging in leisure activities quietly
(e) is often "on the go" or often acts as if "driven by a motor"
(f) often talks excessively

Impulsivity

(g) often blurts out answers before the questions have been completed
(h) often has difficulty awaiting turn
(i) often interrupts or intrudes on others (e.g., butts into conversations or games)

B. Some hyperactive-impulsive or attentive symptoms that caused impairment were present before age 7.
C. Some impairment from the symptoms is present in two or more settings (e.g., school and home).
D. There must be clear evidence of clinically significant impairment in social, academic, or occupational functioning.
E. The symptoms do not occur excessively during the course of a Pervasive Developmental Disorder, Schizophrenia, or other Psychotic Disorder and are not better accounted for by another mental disorder (e.g., Mood Disorder, Anxiety Disorder, Dissociative Disorder, or a Personality Disorder).

Note. From American Psychiatric Association (1994, pp. 83-85). Reprinted by permission.

It is, however, not clear whether the predominantly inattentive subtype is actually a subtype of ADHD, sharing a common attention deficit with the other types of the disorder (e.g., Barkley, 1998). Research examining this issue has found a number of qualitative differences between ADHD-I and the other two subtypes, indicating that it is unlikely that these subtypes have the same impairments in attention. However, these differences might go undetected as the inattention items presented in the DSM-IV are relatively global in nature and could result from a number of different disturbances (cf. Barkley, 1997a). It has been suggested that ADHD-I is associated with problems in selective attention and sluggish information processing, whereas ADHD-C is associated more with problems of persistence or effort, as well as distractibility (Barkley, 1998). Regarding the relation between ADHD-HI and ADHD-C, it has been suggested that the former is best described as an earlier developmental stage of the latter (Barkley, 1998; Hart, Lahey, Loeber, Appelgate, & Frick, 1995).

The etiology of ADHD

Much research has been conducted during the past decade to try to understand the underlying etiology of ADHD, and most psychiatrists and clinical psychologists seem to agree that although ADHD may be associated with multiple etiologies, neurological and genetic factors are the greatest contributors to the disorder (for reviews, see Barkley, 1997a, 1998). Evidence in support of this claim comes from several sources. First of all, some studies have noted similarities between symptoms of ADHD and those produced by lesions or injuries to the prefrontal cortex (e.g., Benton, 1991; Heilman, Voeller, & Nadeau, 1991). Besides this, several studies have shown a remarkable decrease in ADHD symptoms when using stimulant medication (Gillberg et al., 1997; Swanson et al., 1993), and family and adoption studies clearly show that there is a genetic component to ADHD (e.g., Biederman et al., 1992; Gillis, Gilger, Pennington et al., 1992; van den Oord, Boomsma, & Verhulst, 1994). Just recently, a study was also published suggesting that variations in a specific gene may contribute to the deficits associated with ADHD (Smalley et al., 2002).

It is, however, important to note that although biological factors might best explain the primary cause of ADHD, this does not mean that biology is destiny and that environmental factors cannot shape and mold the nature and severity of a biologically based vulnerability. Possible social factors that might contribute to how ADHD problems develop include, for example, family stress, harsh punishment, and low levels of encouragement and controlling behavior on the part of the parents (e.g., Anastopoulus, Guevremont, Shelton, & DuPaul, 1992; Fischer, 1990; Mash & Johnson, 1990; Stormshak, Bierman, McMahon, & Lengua, 2000; Woodward, Dowdney & Taylor, 1997).

Another important point is that in many instances it is difficult to talk about either biological or environmental factors, as these always interact, and many of the risk

factors mentioned above can be seen either as an effect of the disorder or as a causal factor. The fact that the level of psychosocial stress is higher in families with an ADHD child can, for example, be interpreted as contributing to the disorder, or be seen as an effect of the child's hyperactive and impulsive behavior. Another example is the finding that children with ADHD more often than other children have parents who have difficulties organizing their lives. This can be interpreted as a social risk factor, but it can also be a result of the strong heredity of the disorder, that is, the child's parent might also have the disorder or at least display higher levels of ADHD symptoms than the average adult (Farone & Biederman, 1994; Frick & Jackson, 1993).

In summary, social factors are not believed to directly cause ADHD, although they can greatly influence the severity of the disorder, as well as increase the risk of comorbid conditions such as conduct problems. It is also possible that a child with ADHD symptoms at the sub-clinical level can develop clinically relevant symptoms due to psychosocial factors.

Defining Inhibitory Control

The aim of the present study was to investigate the type of inhibition referred to as executive or response inhibition. However, as it has been argued that other types of inhibition might also play a role in the development of hyperactivity; the role of inhibition to the unfamiliar and how this type of inhibition is related to hyperactivity and to executive inhibition were also of interest.

Executive inhibition (response inhibition)

In the present study, the term executive inhibition is used to refer to inhibition as defined by Barkley (1997a). He states that inhibition is comprised of the following three interrelated processes: 1) inhibition of a prepotent or dominant response, 2) stopping of an ongoing response, and 3) interference control (distractibility). In that this type of inhibition requires inhibition of a response, it is sometimes referred to as response inhibition. It should also be noted that executive inhibition as defined above is often viewed as a type of executive function, and although I agree with this view, inhibition is here described separately, and in more detail, as it has been suggested that inhibition is primary to other executive functions (Barkley, 1997a, b).

Examining the different tasks used to assess the three types of executive inhibition might provide a better understanding of the concept. Inhibition of a prepotent response has most often been studied using the *go/no-go paradigm* (Trommer, Hoeppner, Lorber & Armstrong, 1988). This paradigm requires the participant to respond to a majority of the stimuli (e.g., pressing the space bar when a red figure is presented on a computer screen), but to withhold the response to a minority of the stimuli (e.g., a blue figure). In other words, this type of inhibition involves a conflict between responses that

have a history of being reinforced, either in the past or during the task itself, and those responses specified in the experimental instructions.

The *stop-signal paradigm* is believed to be a laboratory analogue of common, everyday situations requiring rapid and accurate execution of a thought or action, and on occasion, stopping of this action (Schachar, Tannock, & Logan, 1993). The participant is presented with a computer-administered primary task (usually a forced-choice reaction-time task) and asked to respond every time a stimulus appears on the screen, except in cases when a stop-signal is presented. Thus, no response habit is necessary in this situation, and instead the task requires stopping of an ongoing response, the second type of inhibition according to Barkley. The difficulty of the task is dependent on the interval between the presentation of the primary task stimulus and presentation of the stop signal, but also on the participant's primary reaction time, in that more responses will be inhibited if the reaction time is slow. Therefore, the stop signal paradigm traces each participant's mean reaction time to trials on which no stop signal is presented and presents stop signals at various intervals before the participant's mean primary reaction time. When analyzing the results, the probability of inhibiting a response at each stop signal interval is plotted as a function, with steeper inhibition functions indicating better inhibitory control.

Regarding the last type of executive inhibition, referred to as interference control or distractibility, it has most often been measured with the *Stroop task* (Stroop, 1935), where the interference is embedded in the task. In the original version of this task, the participants are required to inhibit an overlearned response (e.g. reading the word *blue*), and instead name the color of the written word (e.g. *red*). As this requires that the participants have good reading skills in order for the task to produce an interference, a modified version of the Stroop task using pictures has been used for younger children (Gerstadt, Hong, & Diamond, 1994).

Inhibition to the unfamiliar

Within child temperamental research, the concept of inhibition has been dominated by the works of Kagan and colleagues who introduced the term *behavioral inhibition toward the unfamiliar,* that is, the general tendency to withdraw when faced with novel situations (Kagan, Reznick, Clarke, Snidman, & Garcia-Coll, 1984). This includes withdrawal in social, as well as non-social, encounters and has been used to describe two different groups of children who are either inhibited or uninhibited. Inhibited children are characterized by showing great distress when confronted with situations that are unfamiliar to them, and this behavior has been linked to physiological responses such as higher heart rates and greater sympathetic cardiac reactivity compared to children who are not inhibited (Snidman, Kagan, Riordan, & Shannon, 1995).

Uninhibited children, on the other hand, do not show this type of uncertainty in novel situations. Physiological measures have shown that these children are characterized by low sympathetic tone and low levels of cortisol (Kagan, 1994). Studying development over time, this type of inhibition has been shown to be relatively stable during early and middle childhood (Bengtsgård & Bohlin, 2001; Kagan, Reznick & Snidman, 1987; Kerr, Lambert, Sattin, & Klackenberg-Larsson, 1994; Sanson, Redlow, Cann, Prior & Oberklaid, 1996), as well as from childhood to early adulthood (Gest, 1997).

Kagan and co-workers (e.g., Kagan & Snidman, 1991) have argued that "inhibited" and "uninhibited" children constitute two distinct temperamental types as described above. However, other researchers have claimed that inhibition to the unfamiliar might just as well be seen as a varying along a continuous dimension, and the finding that the relative stability is not higher for extreme cases has been taken as support for this notion (e.g., Asendorpf, 1990; Broberg, Lamb, & Hwang, 1990; Sanson et al., 1996).

Defining Executive Functioning

Executive functioning is a relatively vague concept and there has been a great deal of debate regarding how it should be defined. Welsh and Pennington (1988) defined executive functioning as a broad range of abilities, serving the purpose of maintaining an appropriate problem-solving set for attainment of a future goal. The term has also been used as an umbrella term for the functions of the prefrontal cortex (Pennington, Bennetto, McAleer, & Roberts, 1996). This area of the brain is relatively immature during childhood, with development thought to be a protracted process that continues at least until early adolescence (for a review, see Anderson, 1998).

Despite the confusion regarding an exact definition of executive functioning, most researchers agree that this term includes functions such as planning, persistence, mental flexibility, working memory and inhibition (e.g., Barkley, 1997a; Lezak, 1993; Welsh, 2002). All these functions fit well with the definitions of executive functioning presented above, but this does not mean that they all form a single dimension. Using factor analysis of different executive functions, several studies have found a factor for inhibition and a separate factor for working memory. Other factors that have been found in some, but not all studies, include vigilance or sustained attention, and sometimes a separate factor referred to as selective attention or motor speed has also been found (for a review, see Barkley, 1997a).

As is always the case when conducting factor analysis, the number and type of factors derived is largely dependent on how many and what measures the researcher chooses to include in the analysis. The point that I am trying to make here is simply that different executive functions appear to form separate factors and although describing executive functioning using these factors might be an oversimplification, it might serve a valuable purpose when developing theoretical models of the deficits associated with

different psychopathologies. An example of such a model within the ADHD area is the hybrid model of executive functions presented by American psychiatrist Russell Barkley, and a more detailed description of his model is provided below when describing the most influential theories of ADHD.

Theories of ADHD

During the past decades, several theoretical formulations have been presented in order to account for the different deficits associated with ADHD. In this section, I wish to present four different theoretical formulations, which have been of most importance when designing the studies included in this thesis. Barkley's theory has provided the basis for all of the studies included in this thesis, and his theory will therefore be described in detail. The presentations of the other theories will be brief, although hopefully enough information will be provided so as to allow a comparison between these models and Barkley's model.

Barkley's hybrid model of ADHD

To date, one of the most influential, and certainly the most comprehensive model of ADHD is the hybrid model of ADHD presented by Russell Barkley. As the model is rather complex, at least in comparison with other models within this area of research, the whole model is presented in Figure 1. According to the hybrid model, ADHD is seen as primarily a deficit in executive inhibition as defined above. Further, Barkley (1997a, b) views inhibition as primary to other executive functions in that the first action must always be to inhibit a response and thereby produce a delay during which other executive functions can occur. This does not mean that inhibition directly causes the other executive functions, but it "sets the occasion for their performance" and protects that performance from interference (Barkley, 1997b, p. 68).

Based on the view that inhibition is primary to other executive functions, Barkley also proposes that children with ADHD have secondary problems with regard to four other executive functions, which he refers to as (1) non-verbal working memory, (2) internalization of speech (verbal working memory), (3) self-regulation of arousal, motivation, and arousal, and (4) reconstitution. Thus, Barkley's model has a hierarchical organization with inhibition at the top of the hierarchy and the other four executive functions at the lower level. Together these functions should be able to account for the deficits associated with ADHD as presented in what Barkley in his hybrid model refers to as the Motor Control/Fluency/Syntax (see Figure 1). Below follows a more detailed description of each of the four executive functions included in the model.

Non-verbal working memory

Working memory has been defined as the ability to hold an event in mind so as to use it to control a response (Goldman-Rakic, 1995), and it includes both a verbal and a

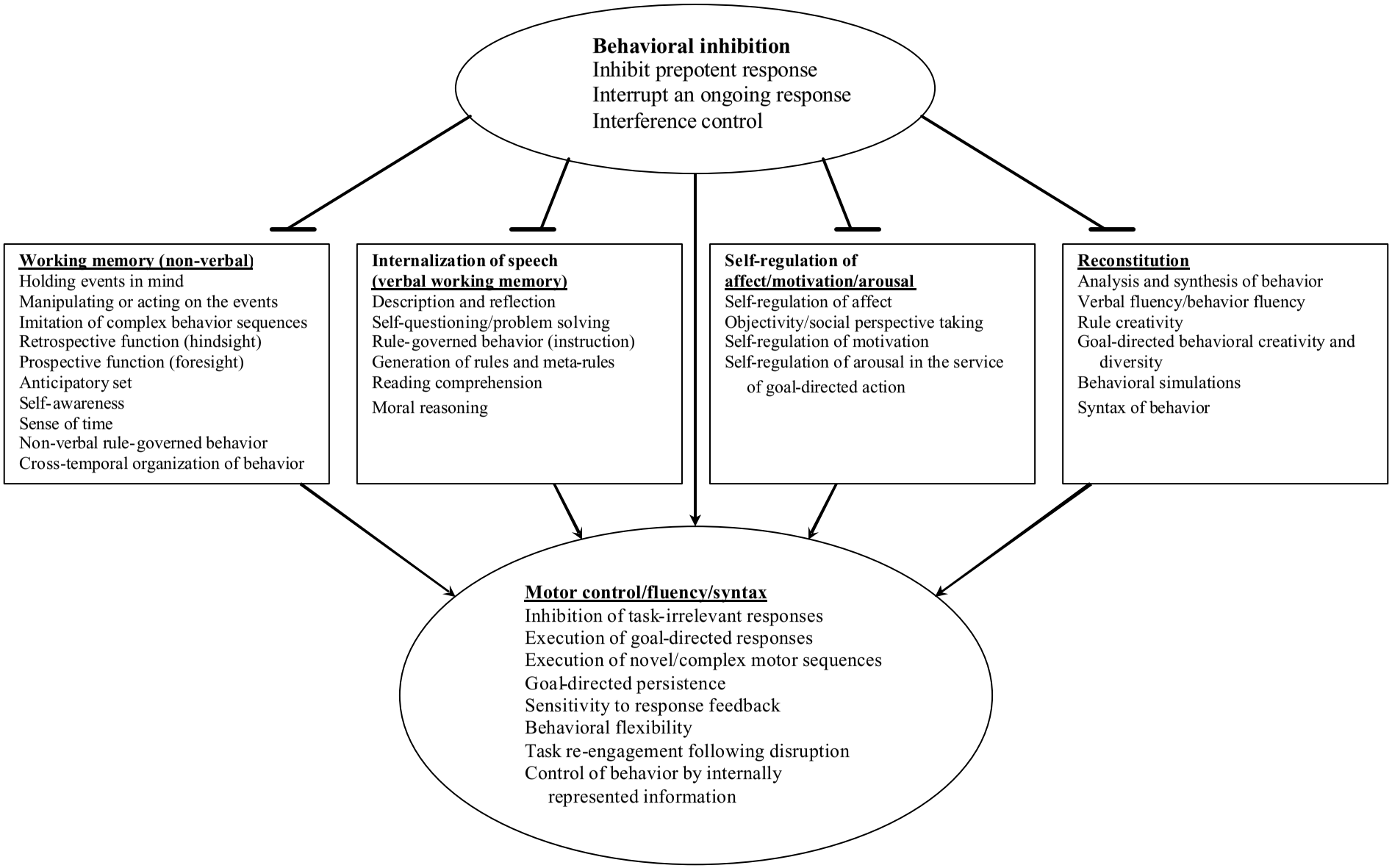


Figure 1. Barkley's (1997a) complete hybrid model of executive functions (boxes) and the relation of these four functions to the behavioral inhibition and motor control systems. Reproduced by permission from Guilford Publications

non-verbal part. Regarding the non-verbal component, Barkley (1997a) includes a number of sub-functions in that disruption of the working memory system is believed to affect functions such as imitation of behavior sequences, which is a powerful tool by which humans learn new behaviors. Besides this, Barkley (1997a) claims that if one cannot hold an event in mind, this will also affect the human sense of time in that keeping events in working memory leads to a sense of temporal continuity.

Internalization of speech (Verbal working memory)

Although Barkley refers to this part of the model as internalization of speech, he regards this as comprising what most researchers refer to as verbal working memory, or the articulatory loop of the working memory system (e.g., Baddley & Hitch, 1994). Often, this component of the model has been studied using traditional verbal working memory tasks such as digit spans, where the participant has to repeat increasingly longer sequences of digits, either exactly as presented by the experimenter, or in a backward order. Regarding internalization of speech, this refers to the development over which speech becomes increasingly covert and then later internalized (Berk, 1992; Vygotsky, 1987). Normally, overt private speech emerges around age 3 to 5 and serves a problem-solving function, it becomes increasingly covert during the early school years and is predominantly internalized by ages 9-12 (Berk, 1992). For some children, this development is delayed, and according to Barkley, this should result in difficulties following instructions, especially if an immediate reward is available.

Self-regulation of affect/motivation/arousal

The development of self-regulation of affect/motivation/arousal, the third type of executive function in Barkley's model, develops in a similar manner as internalization of speech, that is, from being expressed purely in its public form, to becoming more and more regulated and covert (Barkley, 1997a). Because children with ADHD are believed to have poor inhibitory control, they cannot delay their behavior enough to modify their emotional reaction in a way that is appropriate for a certain situation. Regulation of emotions is also believed to have a motivational significance and it may also affect how well a person can regulate energy resources (Frijda, 1994). Due to the apparent link between emotion, motivation and arousal, Barkley believes that all these three components of self-regulation are related to ADHD.

Reconstitution

Reconstitution, the last type of executive functioning in the model, includes analysis and synthesis, that is, decomposition of sequences of events or messages into their parts, and manipulation of these parts in order to reconstitute (i.e., reconstruct) new events or messages (Barkley, 1997a). Reconstitution is linked to inhibition in that a delay in responding is required in order to mentally organize information, and such a delay is provided by inhibition. It is also clearly linked to working memory in that information has to be retained in memory before any type of manipulation of the information can take place. In fact, although Barkley refers to reconstitution as a separate

part of his model, he recognizes that this might just represent a developmentally more advanced function of the working memory system. Empirical studies in support of this function have often used verbal fluency tasks, where the participants are required to generate as many words as possible from a certain category (e.g., animals), but reconstitution also includes behavior flexibility and creativity, as well as the ability to assemble information into meaningful sequences.

The Gray/Quay theory of BIS and BAS

Gray (1982) has advanced a neuropsychological model that consists of three interacting systems: the Behavioral Activation System (BAS) the Behavioral Inhibition System (BIS), and the Nonspecific Arousal System (NAS). The NAS is seen as a flight/fight system that responds to unconditional pain and punishment, whereas the BAS responds to conditioned stimuli for either reward or relief from punishment. The third system, the BIS, responds to conditioned stimuli for punishment and nonreward as well as novelty and innate fear stimuli. In his original work, Gray (1982) used his theory to describe anxiety problems, which he believed to be a result of an overactive BIS. Besides this, Quay (1997) has used Gray's theory as a basis for explaining the deficits associated with ADHD, which he believes are related to an underactive BIS.

The fact that ADHD and anxiety problems are both believed to be related to BIS, although in opposite directions, is problematic in that this implies that the two disorders cannot co-occur in a child. However, in reality about a quarter of children with ADHD will meet the criteria for an anxiety disorder (Cohen et al., 1993). In explaining this finding, it is important to note that the BIS, at least as originally described by Gray, is a system that is primarily linked to punishment and reward, whereas this is not the case for inhibition as defined by Barkley.

Making this distinction is important in that this implies that it is only when using executive tasks with motivational conditions, that is, containing reward or punishment, that they should be seen as measures of BIS functioning (cf. Nigg, 2000). Thus, Quay's (1997) use of deficiencies in inhibition, as measured by the stop-signal paradigm and commission errors on go/no-go tasks, as support for an underactive BIS is questionable. In Nigg's (2000) working inhibition taxonomy, Gray's BIS is referred to as a type of motivational inhibition, whereas the concepts included in Barkley's definition of inhibition are considered as examples of executive inhibition.

When making such as distinction between different types of inhibition as described above, the evidence of an underactive BIS in ADHD is fairly limited (Nigg, 2001). It should, however, be noted that it has been suggested that different types of inhibition interact to shape behavior. Rothbart and co-workers (e.g., Rothbart & Bates, 1998) have, for example, suggested that because motivational inhibition systems emerge earlier in development than executive inhibition, early deficits of the former could dis-

rupt normal development of the latter. A further description of Rothbart's theory is provided in the next section.

Rothbart's theory of effortful control

Rothbart's theory of effortful control is not a very well known theory within ADHD research. However, it is of major importance when trying to explain how executive inhibition and inhibition to the unfamiliar might interact, and as this was one of the aims of the thesis, a presentation of Rothbart's theory is necessary.

Rothbart and coworkers (e.g., Derryberry & Rothbart, 1997; Rothbart & Bates, 1998) point to the role of two control systems, a fear/behavioral inhibition system and a system of effortful control. The fear/behavioral inhibition system is seen as a motivational reactive system, which has modulatory effects through its connections to other systems; approach and reward-oriented behaviors may for example be suppressed by high behavioral inhibition. The second system, the system of effortful control, reflects the functioning of the anterior attentional system and is an active control system with a self-regulatory function. It provides the ability to inhibit a dominant response in order to perform a subdominant response, and it is believed to have regulatory functions in relation to the more basic motivational temperamental systems such as the fear/behavioral inhibition system and the approach system. It is my belief that these two control systems should be reflected in the two forms of inhibition of interest in the present thesis – inhibition to the unfamiliar to the fear/behavioral inhibition system, and executive inhibition to the system of effortful control.

With regard to psychopathology, Rothbart and colleagues (e.g., Derryberry & Rothbart, 1997; Rothbart & Bates, 1998) have stressed the importance of investigating the role of both control systems in order to understand the basis of behavior problems. In the case of ADHD, weak fear regulation may result in impulsive behavior, especially if the child is unable to voluntarily constrain his/her behavior through the regulatory system of effortful control (i.e., when the child has both low inhibition to the unfamiliar and low executive inhibition). It has further been suggested that whereas ADHD might be described as a problem of under-regulation of both control systems, social anxiety might arise from over-regulation (Derryberry & Rothbart, 1997).

The cognitive energetic model

In line with Barkley' theory, Sergeant, Oosterlaan, and van der Meere (1999) agree that deficits in executive inhibition are common among children with ADHD. However, they do not believe this deficit to be primary to the disorder, but rather a result of poor allocation of three energetic resources, or energetic pools. The first pool, effort, refers to the necessary energy to meet the demands of the task, and effort is believed to both excite and inhibit the two other energetic pools, referred to as arousal and activa-

tion. Arousal, which is influenced by signal intensity and novelty, is defined as phasic responding, and it is believed to be influenced mainly by signal intensity and novelty. Tonic changes of physiological activity are thought to represent the operation of the third energetic pool, referred to as activation. The effort and activation pools are closely connected and have considerable effect on motor output, therefore these two pools are believed to be the most important ones when explaining the deficits associated with ADHD (Sergeant et al., 1999). These theoretical formulations are also in line with Douglas' (1999) view of ADHD, although she claims that the disorder involves a more general regulatory deficit.

An overview of previous research

Executive functioning and hyperactivity/ADHD

Previous studies of executive inhibition among children with ADHD, have often found them to differ from comparison controls both on tasks measuring response inhibition using either the go/no-go paradigm (e.g., Iaboni, Douglas, & Baker, 1995; Shue & Douglas, 1992) or different types of stop-signal tasks (e.g., Oosterlaan & Sergeant, 1996; Schachar & Logan, 1990; Schachar, Tannock, Marriott, & Logan, 1995). There are also a few studies showing poor executive inhibition to be related to hyperactivity in non-clinical samples (Hughes, Dunn, & White, 1998; Hughes, White, Sharpen, & Dunn, 2000). Far fewer studies have examined interference control, but generally previous studies have found that distractions outside the immediate task are not likely to differentiate between children with ADHD and normal controls (Douglas, 1983; van der Meere & Sergeant, 1988). However, when the distractions are embedded in the tasks, such as the Stroop task (Stroop, 1935), significant group differences have most often been found (Barkley, Grodzinsky, & DuPaul, 1992; Grodzinsky & Diamond, 1992; Leung & Connolly, 1996).

Looking specifically at different types of executive functions included in Barkley's model, non-verbal working memory deficits among ADHD children have mainly been observed for tasks of memory for spatial location (Mariani & Barkley, 1997) and repetition of hand movements (Barkley et al., 1992; Breen, 1989; Mariani & Barkley, 1997). Regarding verbal working memory, deficits in this area have been demonstrated among ADHD, primarily using repetition of digit spans (e.g., Barkley, Murphy, & Kwasnik, 1996; Mariani & Barkley, 1997). Besides this, the development of internalization of speech has consistently been shown to be delayed among children high in ADHD symptoms (Berk & Landau, 1992; Berk & Potts, 1991; Winsler, Diaz, McCarty, Atencio, & Chabay, 1999).

Further support for deficits in the executive functions included in Barkley's model comes from studies showing significant differences between ADHD children and controls with regard to measures of self-regulation of affect/motivation/arousal

(Douglas, 1983, 1988), and verbal fluency (Fischer, Barkley, Edelbrock & Smallish, 1990; Loge, Staten, & Beatty, 1990; Reader, Harris, Schuerholz, & Denckla, 1995). Empirical data regarding reconstitution of story narratives among hyperactive children are scarce, but available studies suggest that these children produce less information and make more errors compared to controls (Tannock, Purvis, & Schachar, 1993).

There are, however, also a number of studies that have failed to find significant group differences for executive functions such as working memory (e.g., Kerns, McInerney, & Wilde, 2001), verbal fluency (e.g., Fisher et al., 1990; Weyandt & Willis, 1994) and self-regulation of motivation (e.g., Stevens, Quittner, Zuckerman, & Moore, 2002). Of special importance when evaluating Barkley's theory are recent failures to find significant group differences even for measures of inhibition, most often using the stop-signal paradigm (e.g., Barkley, Edwards, Laneri, Fletcher, & Metevia, 2001; Kuntsi, Oosterlaan, & Stevenson, 2001; Oosterlaan, Logan & Sergeant, 1998). Instead of making more inhibitory errors, the performance of children with ADHD has been characterized by many omission errors and/or long and variable reaction times, a finding that has been taken as support for the cognitive energetic model, in which ADHD children are primarily seen as having problems regulating effort and activation (Sergeant et al., 1999). The finding that inefficient task behavior has primarily been demonstrated when using tasks with fast or slow, but not medium, event rate might also be taken as evidence for ADHD children's inability to adjust their state.

Inhibition to the unfamiliar and hyperactivity/ADHD

Regarding inhibition to the unfamiliar, it is inhibited children's risk of developing internalizing problems that has most often been in focus (e.g., Biederman, Rosenbaum, Chaloff, & Kagan, 1995; Kagan, 1997; Lonigan & Phillips, 2001). The few times that uninhibited children have been studied, they have often been described as friendly, sociable and spontaneous (Kagan, 1998), although the results from some recent studies suggest that uninhibited behavior might not be entirely unproblematic.

The Kagan group (Schwartz, Snidman, & Kagan, 1996), for example, reported a higher incidence of externalizing problems among uninhibited children in one study, and Sanson and colleagues (1996) found that higher levels of approach were associated with higher levels of aggression and hyperactivity. However, as these two studies did not compare uninhibited children with normal controls, it is unclear whether these children are more likely to show externalizing problems, or whether inhibited children are especially unlikely to do so. Previous studies have also found empirical support for a protective effect of high inhibition to the unfamiliar, suggesting that this type of inhibition could lower the risk of conduct problems and delinquency (Kagan, 1994; Kerr, Trembley, Pagani, & Vitaro, 1997; Wångby, Bergman, & Magnusson, 1999). Together, these studies suggest that inhibition to the unfamiliar, and not only executive inhibition, might be important when studying predictors of ADHD symptoms.

Critical issues in ADHD research

Comorbidity

The issue of comorbidity relates to the co-occurrence of several different disorders in one individual. Related to the concept of comorbidity is the issue of specificity, that is, to what extent predictors are unique to a particular disorder. If the deficit in, for example, executive inhibition is not specific to ADHD, it cannot be a necessary and sufficient cause of the disorder.

Conduct Disorder and Oppositional Defiant Disorder

Together with ADHD, conduct disorder (CD) and oppositional defiant disorder (ODD) are among the most common psychiatric disorders of childhood (APA, 1994). Included in the diagnostic criteria for CD are problems of aggression (e.g., bullying, threatening and intimidating others, being physically cruel), destruction of property, deceitfulness, thefts, and serious violation of rules (APA, 1994). ODD includes some of the features observed in CD (e.g., disobedience and aggression), although not in their persistent and more serious forms. In fact, ODD is often seen as a developmental precursor of CD, and when a child meets the criteria for both disorders, the diagnosis of CD takes precedence and ODD is not diagnosed. In a review of the comorbid conditions of ADHD, Pliszka (1998) concludes that about half of the children with ADHD also meet the criteria for either CD or ODD.

Children with CD or ODD more often come from families with social problems compared to children with ADHD, and they more often have learning disabilities (Pliszka, 1998). Regarding performance measures, deficits in executive inhibition have been found also among children with CD (e.g., Hurt & Naglieri, 1992; Oosterlaan et al., 1998), indicating that this deficit might not be specific to ADHD. However, as most previous studies have failed to control for the large overlap between CD and ADHD, the apparent relation between executive inhibition and CD could be a result of high levels of ADHD symptoms among children with CD. Even though children diagnosed with CD do not meet the criteria for comorbid ADHD, they may still have considerably higher levels of ADHD symptoms compared to normal controls. It has therefore been argued that it is important to treat data dimensionally, instead of just categorically, and in that way control for comorbid symptoms at a sub-clinical level (Nigg, Hinshaw, Carte, & Treuting, 1998).

Social Anxiety

Social anxiety refers to behaviors such as worrying about not doing the right thing or showing things that the child has made him- or herself. In that Gray's theory of BIS and BAS (see above) has linked an underactive BIS to ADHD, whereas an overactive BIS would result in anxiety problems (Daugherty, Quay, & Ramos, 1993), there has

been an increased interest in both executive inhibition and inhibition to the unfamiliar and their possible relations to ADHD and anxiety problems.

In a review of studies using the stop-signal task, Oosterlaan (2001) concludes that although some empirical support has been found for higher inhibitory control among children high in anxiety, there are also several studies that have failed to find significant group differences. As already mentioned above when presenting Gray's theory, it may, however, be premature to interpret these findings as evidence against Gray's theory in that one has to use tasks containing reward or punishment in order to tap BIS functioning. However, even among the studies that have included reward and punishment, many have failed to find significant group differences between children high in anxiety and normal controls (e.g., Oosterlaan & Sergeant, 1998). Rather consistent relations have, however, been found between inhibition to the unfamiliar and social anxiety (e.g., Buss, 1986; Crozier, 1999; Lonigan & Philips, 2001).

Should ADHD be regarded as a category or as a dimension?

One debate in the scientific literature concerns the question of whether ADHD should be seen as representing a category or a dimension of behavior. Regarding it as a category, a child either has the disorder or does not. The DSM system uses this categorical approach by requiring that certain thresholds be met before a diagnosis can be made. The view of regarding psychopathologies as representing dimensions of behavior claims that ADHD constitutes the extreme end of a dimension, or dimensions, of behavior that falls along a continuum including normal children. This approach does not necessarily see ADHD as a disease, but views these children as being high in symptoms of hyperactivity or inattention.

Recent genetic studies support the notion that ADHD represents a dimensional trait rather than a pathological category in that heritability estimates are about as high regardless of whether a continuum or categorical approach is used to characterize ADHD (e.g., Levy, Hay, McStephen, Wood, & Waldman, 1997; Sherman, McGee, & Iacono, 1997). Another way of studying this question involves exploring changes in the degree of association between symptom severity and some variable characteristic of the disorder. A linear relation, where the degree of association is similar across severity levels, is taken as support for a dimensional approach, whereas deviations from linearity support a categorical approach. Few studies have included large enough samples to examine this issue, although Sonuga-Barke and co-workers did conduct such an analysis and their results are in line with genetic studies in finding support for the dimensional approach (Sonuga-Barke, Dalen, Daley, & Remington, 2002).

Also Barkley (1997a) supports a dimensional approach in that he views deficits in inhibition and executive functioning as actually being delays, meaning that there is a quantitative rather than a qualitative difference between ADHD children and normal

controls with regard to the development of these functions. This also implies that the processes underlying normal and abnormal development are essentially the same and studies of non-clinical samples can improve our understanding of the deficits associated with clinical conditions. Barkley (1998) further states that until it can be shown that individuals who achieve the diagnostic threshold and those who are sub-threshold show qualitative differences, the dimensional approach is the most empirically valid, whereas the categorical approach remains one of convenience and tradition.

The possibility of preschool prediction

It has been estimated that about half of children who receive a diagnosis of ADHD manifest behavior problems by the time they are 3 years old (Barkley, 1989). However, finding preschool predictors of ADHD is despite this a tricky business, mostly due to the normative nature of hyperactive behavior in preschool. By this I mean that a relatively large number of children display hyperactive behavior in preschool, making it difficult to distinguish between early signs of more serious behavior problems, and age-appropriate behavior (cf. Olson, 1996). Looking at other predictors besides activity level, most previous studies have not studied ADHD specifically, but rather general disruptive behaviors (i.e., hyperactivity as well as conduct problems). In a series of studies, Campbell and co-workers have examined factors such as low SES, conflictual mother-child interactions, family stress and difficult temperament, and found that these predictors were all related to later disruptive behavior (e.g., Campbell, 1994; Campbell, Breaux, Ewing, & Szumowski, 1986; Campbell & Ewing, 1990).

To my knowledge, the effects of early executive inhibition on later hyperactivity have not been studied previously, and the question of preschool prediction therefore remains to be answered. In discussing developmental implications of his theory, Barkley (1997a) claims that because executive inhibition is seen as the primary deficit in ADHD, longitudinal relations between preschool inhibition and later hyperactivity should be expected. Regarding the other executive functions included in the model, it is important to note that the various executive functions are likely to emerge at different points in development. Thus, the primary characteristic of preschool children with ADHD is likely to be poor response inhibition, whereas these children might not differ from controls on measures of the other executive functions, as these have yet to mature even among normally developing children. Consequently, school-aged children with ADHD are likely to manifest a far more complicated picture of deficits with regard to executive functioning compared to preschool children with the same disorder.

These theoretical formulations have serious consequences with respect to choosing what tasks to include when studying the deficits associated with ADHD, and they also have implications when interpreting whether the results are supportive of Barkley's theory. First of all, it is important to choose tasks that are difficult enough so that the ADHD children cannot perform them well, but easy enough so that most normal

children have learned to master them or at least are in the process of doing so. If a task is chosen that taps a function that not even normal children have developed, group differences can of course not be expected and the results should not necessarily be seen as contradictory to Barkley's theory.

Sex differences

Since the sample sizes in clinical ADHD studies often are small, and the boy-girl ratio in clinical samples often ranges between 4:1 to 9:1 (APA, 1994), girls have either been excluded from previous studies, or the number of girls has been too small to conduct separate analyses for each sex. Previous studies can therefore not tell us much about ADHD in girls. Theoretically, it has been claimed that if a developmental disorder is more prevalent among one sex, the underrepresented sex is generally more severely affected, probably due to the fact that the underrepresented sex has a higher threshold to insult (e.g., James & Taylor, 1990). This would explain the lower number of ADHD diagnoses among girls, and suggest that those who do receive a diagnosis must be more severely affected in order to cross the threshold.

The few studies investigating both boys and girls have mainly focused on gender differences in prevalence, severity of problems, and familial psychopathology (for a review, see Gaub & Carlson, 1997; Henker & Whalen, 1999). In their meta-analysis, Gaub and Carlson (1997) concluded that, compared to ADHD boys, girls with the disorder showed lower levels of hyperactive behavior, but were more intellectually impaired. The few studies examining sex differences in executive functioning have generally not found any significant group differences (e.g., Arcia & Conners, 1998; Houghton, et al., 1999; Nydén, Hjelmquist, & Gillberg, 2000).

When discussing sex differences in ADHD, it is important to note that girls with ADHD are less likely to be referred to clinics compared to boys, and this implies that ADHD girls in clinic-referred samples might not be representative of the disordered population in general (Carlson, Tamm, & Gaub, 1997). It has therefore been argued that the use of population-based samples to study sex differences in ADHD symptoms is particularly appropriate (Carlson et al., 1997). Besides this, one should not assume that the predictors of ADHD symptoms are the same for both sexes, and longitudinal studies using samples large enough to study possible differential pathways of boys' and girls' problem behaviors are needed in order to examine this issue.

Relations between ADHD, executive functioning and intelligence

One important question that has been raised in the ADHD literature concerns the issue of whether executive functions are really discernable from general cognitive ability (i.e., intelligence or IQ). A number of different lines of evidence have, however, been presented, supporting a distinction between these concepts. This literature is unfor-

tunately very complex, and it is sufficient here to say that (a) factor analyses have identified separate dimensions of executive functions and that of intelligence (e.g., Cardon, Fulker, DeFries, & Plomin, 1992; Pedersen, Plomin, & McClearn, 1994), and (b) patients suffering injuries to the frontal lobes often show little or no alteration in IQ scores, although their executive functions are usually seriously affected (Stuss & Benson, 1986). It should, however, be noted that these results apply primarily to crystallized intelligence, whereas measures of fluid intelligence are more similar to executive functioning as defined above.

Notwithstanding the fact that executive functioning might be discernable from intelligence, this does not mean that the former has no relation or effect upon the latter. In fact, several studies have found that measures of various executive functions as well as ratings of hyperactivity are related to intelligence (e.g., McGee, Williams, & Silva, 1984; Sonuga-Barke, Lamparelli, Stevenson, Thompson, & Henry, 1994; Welsh & Pennington, 1988). This raises the question of whether it is advisable to statistically control for intelligence when examining executive functioning deficits among children with ADHD. Based on the findings presented above, it has been argued that controlling for IQ will probably eliminate some of the differences between ADHD children and controls that are a result of the variable of interest, ADHD (Barkley, 1997a). Consequently, researchers might be best off reporting their data both with and without controlling for intelligence, letting the reading make his or her own interpretation of the results.

The discriminant ability of tests of executive functioning

Although significant group differences between ADHD children and controls have been observed for various measures of executive inhibition as well as for measures of other executive functions, it is important to note that group differences alone are insufficient indices of the discriminant ability of those measures (cf. Doyle, Biederman, Seidman, Weber, & Farone, 2000). Researchers comparing ADHD children with controls are comparing the means between groups. This is, however, not what clinicians are doing when setting a diagnosis – they are classifying individuals. Instead of group differences, discriminant ability is best examined using measures of sensitivity and specificity. Sensitivity refers to the probability of an abnormal test score given that a person has the diagnosis in question, whereas specificity is defined as the probability of a normal test score given that the person does not have the diagnosis.

The relatively few previous studies that have complemented their analysis with analysis directed towards examining the discriminant ability of tests of executive functioning have generally found that these tests are better at excluding normal children from the ADHD category than at confirming ADHD in children diagnosed with the disorder (e.g., Barkley & Grodzinsky, 1994; Doyle et al., 2000; El-Sayed, van't Hooft, Larsson, Malmberg & Rydelius, 1999; Perugini, Harvey, Lovejoy, Sandstrom

& Webb, 2000). In terms of conditional probabilities, the specificity has been relativity high in these studies, whereas the sensitivity has been low. From the perspective of understanding the deficits of ADHD, these results are disappointing in that they indicate that there is a relatively large number of diagnosed children who do not have executive function impairments. None of these studies, however, used measures from Barkley's full model and might therefore have missed children for whom the deficit primarily pertained to a specific function.

Interestingly, previous studies have shown that it is often tests measuring executive inhibition or working memory that have been best at discriminating between groups. These findings are clearly in line with Barkley's (1997a) notion of inhibition as the primary deficit in ADHD, but also with theoretical formulations by Roberts and Pennington (1996). They argue that inhibition and working memory are sufficient to characterize the entire domain of executive functioning, implying that measures of these two functions should discriminate well between ADHD children and controls if ADHD is believed to be associated with deficient executive functioning.

Before drawing any certain conclusions, however, more research is needed, as the number of previous studies examining this issue is very small, and the studies are also limited in certain ways. For example, the study by Barkley and Grodzinsky (1994) included only 12 participants in each group. Doyle and co-workers (2000) used a very large sample, but as this was a 4-year follow-up it is unclear whether all the subjects met the criteria for ADHD at the time of the testing.

Aims of the thesis

The general aim of the empirical studies included in this thesis was to examine the role of inhibition and executive functioning as possible correlates and predictors of ADHD symptoms. In order to do so, I have followed a sample of children from the age of 5 to 8½, and the three first studies contain some of the data that have been collected as part of this longitudinal investigation. However, as the children included in the longitudinal study more or less represented a cross-section of the normal distribution of behavior problems, I have also studied a group of children with clinically significant ADHD problems. By including these two different samples in my thesis, I hope to provide a more comprehensive view of the role of inhibition and executive functioning in the development of problems of hyperactivity and inattention among children. More specifically, the major aims of this thesis were:

- To investigate whether executive inhibition measured as early as preschool is related to hyperactivity in a non-clinical sample. This question was addressed using concurrent (Study I) as well as longitudinal data (Study II and III). If such a relation can be found as early as the preschool years in non-clinical samples, it might

be possible to improve the prediction of disruptive behavior problems by adding measures of executive inhibition to information about other factors.

- To address the issue of specificity of deficits in executive inhibition. Because previous studies have shown that hyperactivity and conduct problems often co-occur, we wished to control for conduct problems when studying the effects of inhibitory control on hyperactivity, and to control for hyperactivity when studying the effects of inhibitory control on conduct problems (Study I).

- To study sex differences in inhibition and executive functioning and also in the relations between these cognitive measures and ADHD symptoms. This seemed to be an important issue, as one should not assume that the predictors for ADHD symptoms are the same, or at least as strong, for boys and girls (Study I and III)

- To study the empirical overlap between two different types of inhibition - executive inhibition and inhibition to the unfamiliar - and to see how they are longitudinally related to ADHD symptoms. Both main effects of each one of these types of inhibition and interactive effects were of interest, in that it has been suggested that the combination of these two concepts should be important to the understanding of both externalizing and internalizing problem behaviors in children (Study II)

- To test the hypothesis that preschool executive inhibition can be seen as a precursor to more general problems of executive functioning, believed to characterize the school-aged child with high levels of ADHD symptoms. Besides examining direct effects, we also wanted to examine whether general executive functioning can be seen as a mediator in the relation between preschool executive inhibition and ADHD symptoms at school-age (Study III).

- To examine whether children with clinically relevant ADHD symptoms have deficits in executive inhibition and each of the four other types of executive functions included in Barkley's model of ADHD. Besides studying group differences, we also wanted to address the question of whether measures pertaining to each of the different functions included in Barkley's model could discriminate between ADHD children and controls (Study IV).

THE EMPIRICAL STUDIES

METHOD

Participants and procedure

Longitudinal study (Study I, II, and III)
The present study included 151 children (75 boys) who were part of a larger longitudinal study conducted at Uppsala University, Sweden (see Figure 2 for an overview of the design of this study). A national population-based register, which includes all Swedish residents, was used for recruiting a random sample of 1000 5-year-old children living in the city of Uppsala, a university city and the country's fourth largest city. From this sample, 705 filled out and returned a questionnaire and a sub-sample of 151 children was recruited for the longitudinal study.

One of the main aspects in focus in our longitudinal study (of which this thesis is a part) was to examine inhibition to the unfamiliar as a predictor of problem behavior. The longitudinal sample was therefore selected so as to obtain large variation with regard to this variable, which meant that we had to over-sample in the inhibited end as the distribution of inhibition to the unfamiliar was positively skewed in our large sample of 705 children. In that we also wished to obtain large variation with regard to hyperactivity, we made sure that the sub-sample closely represented the larger random sample with regard to this variable. Thus, the recruited longitudinal sample was normally distributed for inhibition to the unfamiliar as well as for hyperactivity.

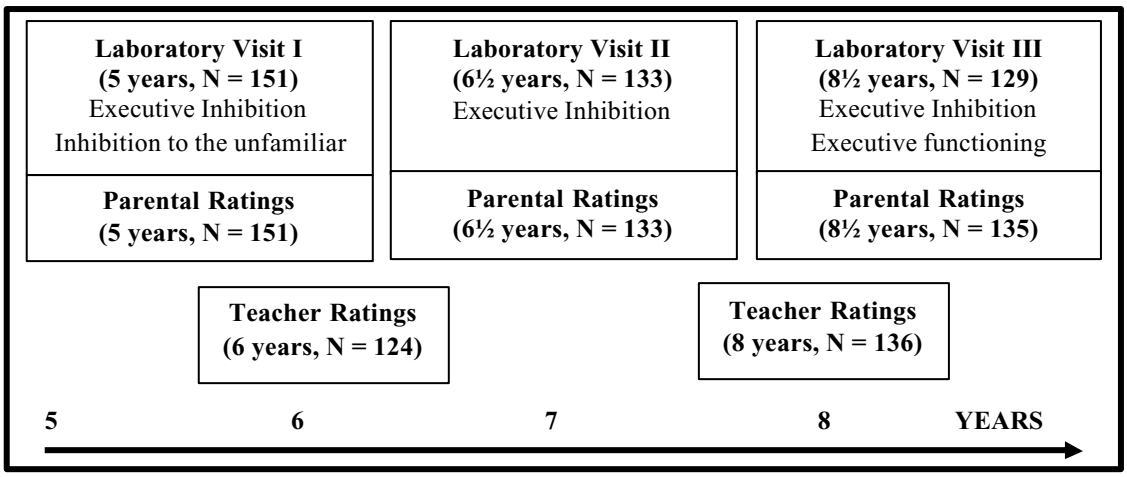


Figure 2
Design of the longitudinal study

At 5 years of age (M = 5.2 years, SD = 1.12), the sub-sample of 151 children were seen in the department laboratory for the first time. The visit included the tests of executive inhibition as well as the measures of inhibition to the unfamiliar. Besides this, parental ratings of behavior problems were collected at the time of the visit.

About 9 months after the visit to the department laboratory (*M* = 6.0 years, *SD* = 2.6), the children's nursery school teachers or day-care providers in the home, completed questionnaires regarding behavior problems in the out-of-home setting for 124 of the children. Reasons for attrition regarding the teacher ratings were that the child did not have out of home care (4 children), the parents did not consent to contact with the child's nursery school (13 children), or the questionnaires were not returned despite two reminders (10 children).

When the children were about 6 ½ years of age (*M* = 6.6 years, *SD* = 1.3), 133 children visited the department laboratory once again. Reasons for not participating in the second visit were mainly lack of time (12 children) or the fact that the family had moved out of the area (6 children). This visit lasted about 90 minutes and included measures of executive inhibition, as well as some other measures that will be reported elsewhere. Parental ratings of problem behaviors were also collected.

When the children were 8 years old (*M* = 8 years, 0 months, *SD* = 2 months), the children's elementary teachers were contacted by mail and asked to fill out a questionnaire, containing the problem behavior and social competence instruments included in this thesis. Data from the child's schoolteacher were collected for 135 of the children (89% of the children seen in the laboratory at age 5). Reasons for attrition were that the child's parents did not give consent to contact the child's teacher (10 children), the teacher did not return the questionnaire despite two reminders (5 children), or the child could not be reached (1 child).

When the children were about 8 ½ years of age (*M* = 8 years, 8 months, *SD* = 1.6 months), 129 children were seen in the department laboratory where they were asked to perform the executive function tasks included in the present study. Reasons for attrition were that the child had moved out of the area (11 children), or lack of time (11 children). Once again, ratings of problem behaviors were also collected from the accompanying parent. Ratings were also sent by mail to those families that did not participate in the laboratory visit, which resulted in parental ratings for a total of 136 children.

Clinical study (Study IV)

The clinical study included 63 boys, who ranged in age between 7 and 10 years. The clinical group consisted of 21 boys who had been diagnosed with ADHD (either the combined or the predominantly hyperactive/impulsive subtype), according to the diagnostic criteria in DSM-IV (APA, 1994). All of the children had been referred to a specialized, neuropsychiatric clinic for examination due to severe behavior problems. The boys were examined according to standardized procedures at the clinic (which besides parental and teacher interviews and rating scales also included medical history, neuropsychiatric and medical evaluations, fine- and gross-motor testing), and diagnosed by an experienced child psychiatrist. All ADHD children had a score of 15

or above on the Conners Rating Scale, hyperactivity index (Conners, 1990) for both parent and teacher ratings, as well as an IQ above 70 measured by the Wechsler Intelligence Scale for Children (WISC-III, Wechsler, 1991). Children showing evidence of progressive neurological disease or autistic disorder were excluded from the study. None of the children were taking stimulant medication.

The control group consisted of 42 boys matched to the ADHD boys with regard to age (ADHD, *M* = 8.3 years; Controls, *M* = 8.4) and ethnic background. The control children were recruited from two local elementary schools. Parents with boys in grade 1 through 4 were contacted by mail and asked to participate in the study, and among those children for whom consent was given, the boys who best matched the children in the clinical group were selected for the study.

Measures

Executive inhibition

Go/no-go tasks

The go/no-go paradigm was originally introduced into the field of ADHD research by Trommer and colleagues (Trommer et al., 1988). It requires that the participant produce a simple motor response ("go") to a majority of the stimuli, while inhibiting this response ("no-go") in the presence of a minority stimulus. Two different versions of this task were used. The first version of the task, used in the longitudinal study at age 5 and age 8½, included four different stimuli: a blue square, a blue triangle, a red square, and a red triangle. In the first part of the task, the children were instructed to "go" (i.e. to press the space bar) when a blue figure appeared on the screen, but to make no response ("no-go") when a red figure appeared. The same stimuli were used for the last part of the task, but the children were instructed to "go" every time they saw a square, and to inhibit their response every time they saw a triangle, irrespective of color. Altogether the task included 60 stimuli with a "go-rate" of 77%. Scores derived from the task were commission errors (pressing the key when a "no-go" target was presented) and omission errors (failing to press the key when a "go" stimulus was presented). Commission errors were used as a measure of executive inhibition.

In the longitudinal study at age 6½ and in the clinical study, the design of the task was the same but the stimuli were more complex (e.g., a square with a vertical or diagonal line in the middle). The children were presented with four different figures and they were instructed to press a key as fast as possible every time they saw one of three figures ("go"), but to inhibit their response when they saw the fourth figure ("no-go").

Stroop-like task

In the original Stroop test (Stroop, 1935) a conflict is produced when the participant has to inhibit an over-learned response (e.g. reading the word *blue*), and instead name

the color of the written word (e.g. red). Thus, it is a measure of interference control. However, because hyperactivity and reading disorder have been shown to co-occur (Frick, et al., 1991), and the participants must be able to read proficiently in order for the test to produce an interference, a new version of the Stroop test was constructed. This task was based on the Day-Night Stroop Task by Gerstadt and co-workers (1994), but because children have been shown to perform at ceiling already by age 6 using this task (Passler, Isaac, & Hynd, 1985), our version included four pairs of pictures instead of just one (see Figure 3). The child was instructed to say the opposite as fast as possible every time a picture was presented on the computer screen (e.g., to say boy every time he/she saw a girl). Several types of errors were registered. However, because "not corrected errors (i.e., just saying the wrong word) and "no answer" could result from the fact that the child did not fully understand the task, corrected errors (i.e., first saying, or starting to say, the wrong word and then correcting oneself) were used as a measure of interference control.

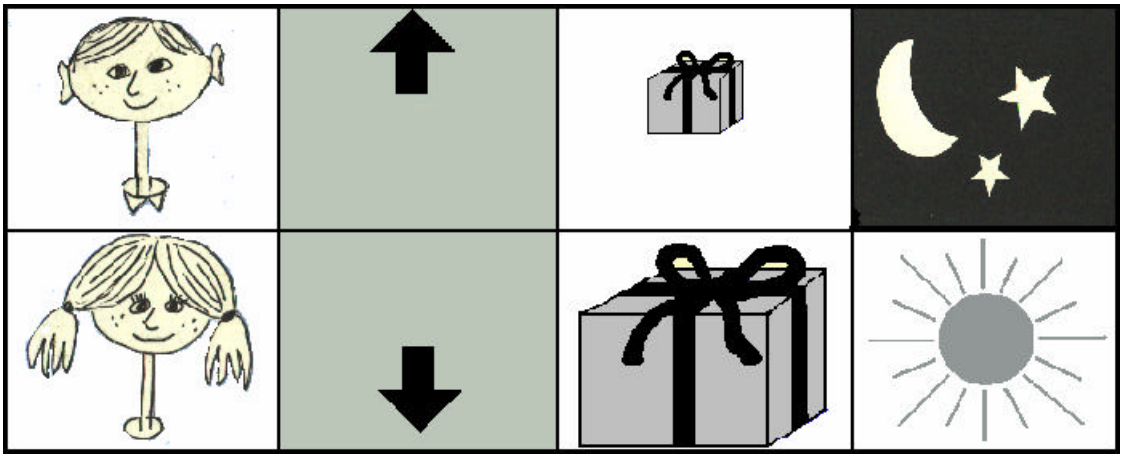


Figure 3
Stimulus-pairs presented in the Stroop-like task (girl-boy, up-down, big-small, night-day)

Inhibition to the unfamiliar

Observational measures

As inhibition to the unfamiliar includes both social and non-social inhibition, two different observational methods were used, which were later standardized and aggregated into one measure of overall inhibition to the unfamiliar. In the *Riskroom Procedure* (Kagan, Reznick & Gibons, 1989), which measures non-social inhibition to the unfamiliar, the child was asked to play freely for 7 minutes in a room containing toys suggesting risk (e.g., a tunnel through which the child could crawl, a "magic box" with a round hole through which the child could stick his/her hand, a set of fragile windchimes). The session was videotaped and the child's level of inhibition was assessed using a scale ranging from 1 (short latency to touch the first toy, plays freely with the toys during the whole session) to 7 (does not play with toys or very long latency to

touch of first toy). Intercoder reliability was obtained using the ratings of 22 children and amounted to $r = .97$.

In the *Stranger Encounter Situation* (Klein, Plunkett, & Meisel, 1988; Plunkett, Klein, & Meisels, 1988), which measures social inhibition to the unfamiliar, the child and parent were first left alone in a room. After a few minutes, a stranger entered the room and tried to make contact with the child in 5 consecutive episodes, each lasting 30 or 60 sec. In the first episode, the stranger entered the room ignoring the child and his/her parent. Over the episodes, the stranger became more active in trying to relate to the child, ending up being intrusive before retreating and leaving the room. Inhibition was coded for each episode on a scale ranging from 1 (child is not at all uncomfortable with the stranger or with the situation) to 5 (child actively avoids all contacts with stranger – e.g., turns away when spoken to, turns to mother). The score used in the present study is a global rating of all 5 episodes. Interobserver agreement was .92 using the ratings from 27 observations made by two independent observers.

Parental ratings

The child's inhibition toward the unfamiliar was also rated by a parent using the mean of an 11-item scale ($\alpha = .86$) from the screening questionnaire that had been collected a few months before the laboratory visit. Seven of these items reflected social inhibition, and consisted of four items from the EAS inventory (Buss & Plomin, 1984) and three items constructed in the research group (e.g., "my child becomes reserved upon entering a room full of strangers"; see Bohlin, Bengtsgård & Andersson, 2000). The last 4 items reflected non-social inhibition (e.g., "hesitant to explore new places and contexts on his/her own") and were also taken from the EAS inventory.

Executive functioning

Non-verbal working memory

Non-verbal working memory was assessed using three different tasks. In Study III, we used a spatial working memory task originally developed by Park, Holzman and Goldman-Rakic (1995) for use with monkeys and later adapted for use with humans by Öhman and colleagues (personal communication, May 2001). The children were told that the light blue color on the computer screen in front of them was the sky and that they would soon see an airplane that would appear somewhere on the sky and then disappear. They were instructed to try to remember the location of the airplane and when clouds were later presented on the screen, they were told to indicate which one of the clouds was in the same location as the airplane had been earlier. During the delay period between the airplane and the clouds, a distraction task was presented where a response was required every time a lion was presented (25% of the trials), but refraining from responding when a frog was presented (75%). The score used was number of correct answers on the primary task.

In Study IV, the spatial working memory task described above was not used. Instead, the children were presented with a sequence of hand movements and then asked to repeat the sequence (Kaufman Hand Movements Test; Kaufman & Kaufman, 1983). Altogether the child was presented with 17 different hand movements using three simple movements (fist, palm and side), and the result was registered as number of errors, that is, how many times the child was unable to reproduce the sequence of hand movements correctly.

Study IV, also included a time reproduction task, where the experimenter presented the child with six different time intervals (two intervals each of 12, 24 or 36 sec) using a flashlight and the child was asked to repeat the time interval as closely as possible. In line with the study by Barkley and colleagues (Barkley et al., 2001), an absolute discrepancy score was calculated across the six intervals by subtracting the sample duration from that produced by the participant and eliminating its sign (+ or -).

Internalization of speech (verbal working memory).
This function was tested in both Study III and Study IV, but different tasks were used in the two studies. In Study III, this function was tested using the *Digit Span* subtest from WISC-III-R (Wechsler, 1991). This test involves repetition of a series of increasingly longer strings of digits presented by the experimenter at a rate of one per second. The total number of correct trials on both the forward and the backward condition was registered as a measure of verbal working memory.

As internalization of speech according to Barkley's model includes several subfunctions, this part of the model was in Study IV also investigated using a Puzzle Cheating Task, which aimed to measure *rule-governed behavior*. A puzzle was placed underneath a box with an opening for the hand and a cloth covering the front. The cloth could easily be lifted up so that the child could look at the puzzle. The children were instructed that they should try to get as many pieces in the right place without lifting the cloth to look at the puzzle. The experimenter then made an excuse to leave the room and rule-governed behavior was later assessed from the videotape using a scale from 1 (very low rule-governed behavior, that is, many instances of cheating and/or flagrant cheating) to 5 (behavior fully rule-governed, no instances of cheating).

Self-regulation of affect/motivation/arousal.
Three different measures were used to study this part of Barkley's model. In Study III, regulation of arousal was measured with the mean reaction time for correct responses and variability in reaction time on the go/no-go task (the version used at age 8½, see description above). These two measures were standardized and a mean value was calculated. In line with, for example, Kuntsi and co-workers (2001), a high value indicated long reaction times and high variability, and this was seen as an indication of poor regulation of arousal, whereas short reaction times and low variability indicated good regulation.

In Study IV, the child's level of arousal was measured by registering the number of omission errors on a continuous performance task (CPT). This task used the same stimuli as the go/no-go task used in the clinical study (see presentation above), but in this task the child was instructed to respond only to a minority of the stimuli, and no prepotency for responding was therefore created. Altogether, the child was presented with 100 stimuli and as a response was only required 24 times. Due to the monotonous nature of this task, it is considered to challenge the child's ability to adjust arousal to an optimal level for performing the task at hand (Corkum & Siegel, 1993). Omission errors on this task were therefore used as a measure of regulation of arousal.

Study IV also included a measure of emotion regulation, a behavioral rating by one of the child's parents using a scale developed by Rydell, Bohlin and Berlin (in press). As negative emotions are those in most need of regulation (Kopp, 1989), only this scale (9 items, a = .94) was used in the present study (e.g., "When my child becomes angry, he has difficulties calming down on his own"). For clarity, we thought it would be best if all measures of executive functioning included in Study IV had the same directionality (i.e., high values = poor executive functioning), and the ratings were therefore reversed, resulting in a measure of emotion regulation problems ranging from 1 (very well regulated) to 5 (very poorly regulated).

Reconstitution.

As described above, reconstitution refers to two interrelated processes: analysis and synthesis of behavior (Barkley, 1997b). Two different tasks were used to assess this function. In Study III, a measure of verbal fluency, the Controlled Oral Word Association Test (COWAT; Gaddes & Crockett, 1975) was used. The participants were given two phonological categories (the letters F and A) and two different semantic categories (animals and things to eat) and were asked to name as many different words as possible for each category. A time limit of one minute was provided for each trial. An aggregated measure of generated words for all four categories (semantic and phonological) was used as a measure of reconstitution.

In Study IV, the child was presented with a story and then asked to reconstitute that story after a certain delay. The whole procedure was video-filmed and reconstitution of the story was later coded from the tape in accordance with the procedure described by Tannock and co-workers (1993). However, as we wanted high values to indicate poor performance, the scale was reversed. Thus, we started with 50 points (i.e., the maximum number of information units) and deducted a point for every piece of information that the child could recall. This resulted in a total score ranging from 0 ("perfect reconstitution") to 50 ("cannot reconstitute anything of the story"). Interrater reliability was .98, using the ratings of 14 children.

Intelligence

The children's intelligence was assessed in both the longitudinal and the clinical sample. Study I included the *Peabody Picture Vocabulary Test – Revised* (Dunn & Dunn, 1981), which is a measure of verbal intelligence. In Study III and IV, the Block design subtest from WISC-III (Wechsler, 1991) was used to assess intelligence. Besides this, all children in the clinical sample were tested with all subtest of the WISC-III and children with an IQ of 70 or less were excluded from the study.

Problem behaviors

ADHD-symptoms
In Study I and II, the Conners Rating Scale, 10-item hyperactivity index (Conners, 1990) was used to study ADHD symptoms. Factor analysis (Parker, Sitarenios, & Conners, 1999) has shown that the first 6 items of the scale (e.g., restless, impulsive, constantly moving around) taps hyperactivity, whereas the last four questions reflect behavior associated with ADHD (e.g., emotional lability). As we strove to keep all measures as pure as possible, the last four items were excluded from the scale. Ratings were made on a four-point scale ranging from 0 (does not apply at all) to 3 (applies very well). The hyperactivity score was calculated as a mean of all 6 items (a = .89). In Study III, we wished to study hyperactivity and inattention separately, and we therefore chose to use a different measure of ADHD symptoms, ADHD Rating Scale IV (DuPaul, Power, Anastopoulos, & Reid, 1998), which contains the items for ADHD as presented in DSM-IV (APA, 1994; see also Table 1). The scores presented in Study III are total scores for the nine items of hyperactivity and the total score for the nine items of inattention. Cronbach's alpha ranged between .82 and .91.

Conduct problems
The Preschool Behavior Questionnaire (PBQ; Behar & Stringfield, 1974; Hagekull & Bohlin, 1992) was used to measure conduct problem behavior in Study I. The PBQ is a preschool version of the Children's Behavior Questionnaire by Rutter, Tizard and Whitmore (1970), and includes items such as the following: fights or teases, lies, bites or kicks when angry, disobedient, destructive, often gets into fights, fails to show consideration for others, and blames others when things go wrong. Thus, this scale corresponds quite well with the items of oppositional defiant disorder in the DSM-IV (APA, 1994). Internal consistency, expressed as Cronbach's alpha, was .89.

Social anxiety
Social anxiety was measured by six newly constructed items (e.g. "prefers not to show things that he/she has made, e.g., show a drawing for the class," "worries about not doing the right thing") in accordance with the description of social anxiety in children by Beidel and Turner (1998). Cronbach's alpha was .80.

Social competence

Children's social competence was assessed by the Social Competence Inventory (SCI; Rydell, Hagekull & Bohlin, 1997), containing two scales that have been derived through factor analysis and validated against observations in a Swedish sample (Rydell et al., 1997). The *Prosocial Scale* includes 17 items (α = .93) capturing the child's ability to engage in positive peer interactions (e.g., "good at preventing conflicts" and "has the capacity for generosity"). The *Social Initiative Scale* includes 7 items (α = .90), capturing the child's ability to initiate and take part in social interactions (e.g., "suggests activities to peers" and "easily makes contact with other children").

Summary of all measures included in each of the studies

STUDY I *Laboratory measures:* Executive inhibition - Go/no-go task (5 and 6½ years) - Stroop-like task (6½ years) Intelligence (6½ years) - Peabody Picture Vocabulary Test-Revised *Behavioral ratings* Hyperactivity - Conners rating scale (teacher, 6 years) Conduct problems - PBQ (teacher, 6 years)	**STUDY II** *Laboratory measures:* Executive inhibition - Go/no-go task (5 years) Inhibition to the unfamiliar - Risk room procedure (5 years) - Stranger Encounter Situation (5 years) *Behavioral ratings:* - Hyperactivity (teacher, 8 years) - Social anxiety (teacher, 8 years) - Prosocial orientation (teacher, 8 years) - Social initiative (teacher, 8 years)
STUDY III *Laboratory measures:* Executive inhibition - Go/no-go task (5 years) Executive functioning (8½ years) - Spatial working memory task - Digit span - Reaction time (RT) and variability in RT - Verbal fluency Intelligence (8½ years) - Block design subtest from WISC-III *Behavioral ratings:* - Hyperactivity (teacher 8 y, parent, 8½ y) - Inattention (teacher 8 y, parent, 8½ y) - Emotion regulation (parent, 8½ y)	**STUDY IV** *Laboratory measures:* Executive inhibition - Go/no go task - Stroop-like task Executive functioning - Hand movements - Time reproduction - Puzzle cheating task - Continuous performance task - Story reconstitution Intelligence - Block design subtest from WISC-III *Behavioral ratings:* - Hyperactivity (teacher and parent) - Emotion regulation (parent)

Figure 4
Overview of laboratory measures and behavioral ratings used in each of the four studies

STUDY I:

Response Inhibition, Hyperactivity and Conduct Problems Among Preschool Children

Background and aims

In spite of the growing acknowledgement of the possibility that ADHD should be seen as the extreme end of a continuum of inhibitory functioning and associated behaviors, instead of representing a separate category (e.g., Barkley, 1998), practically all previous studies of inhibitory functions have examined children already diagnosed with ADHD. Further, since ADHD children usually are not diagnosed until they reach school, few previous studies have used samples of preschool children. If preschool children with high levels of hyperactive behavior are shown to perform poorly on tests of response inhibition, these tests might be able to improve the possibilities of identifying children who are at high risk of developing ADHD later in life.

The aim of Study I was therefore to investigate whether differences in response inhibition are related to hyperactivity in a non-clinical sample of preschool children. Both boys and girls were included, so that it would be possible to examine the effect of response inhibition on problem behaviors separately for each sex. In contrast to previous non-clinical studies, Study I examined hyperactivity specifically, instead of relating inhibition to externalizing problems in general. Finally, since previous studies have shown that hyperactivity and conduct problems often co-occur, we included a measure of conduct problems. This way, we were able to control for conduct problems when studying the effects of inhibitory control on hyperactivity, and to control for hyperactivity when studying the effects of inhibitory control on conduct problems.

Given that response inhibition has been proposed to be the primary deficit in ADHD, it was hypothesized that (1) only the measures of response inhibition would be related to hyperactivity, and (2) a possible relation between conduct problems and inhibition would disappear when controlling for hyperactivity.

Results

Regarding inhibition of a prepotent response, the results showed a significant relation between commission errors and problem behaviors (see Table 2). Children who were rated as high in hyperactivity and conduct problems were more likely to fail to inhibit a response when a target was presented. This effect was found for the go/no-go task administered at 5 years, as well as for the similar task administered at 6 ½ years of age. However, there were no significant relations between omission errors and any of the problem behaviors.

Regarding interference control, there was a significant relation between corrected errors and both hyperactivity and conduct problems, but not between problem behavior and any other type of error on the Stroop-like task. Based on their similar relations to problem behavior, the three measures of executive inhibition were standardized and aggregated into an overall measure of inhibition. As can be seen in Table 3, this measure was shown to explain about 19% of the variance in hyperactivity and about 13% of the variance in conduct problems.

Table 2
Pearson's product moment correlations between the three laboratory tasks and teacher ratings of hyperactivity and conduct problems

	Hyperactivity	Conduct Problems
Go/no-go task (5 years)		
- Commission errors	.39***	.34***
- Omission errors	.08	.11
Go/no-go task (6½ years)		
- Commission errors	.25**	.25**
- Omission errors	.02	.02
Stroop-like task		
- Corrected errors	.30**	.19*
- Not corrected errors	.03	.03
- No answer	.11	.06

* $p < .05$, ** $p < .01$, *** $p < .001$

Regarding sex differences, boys were rated as having significantly higher levels of conduct problems compared to girls, and they were also shown to make a larger number of errors that could be attributed to poor executive inhibition. Regarding sex differences in the relations between inhibition and problem behavior, there was a significant relationship between inhibition and both hyperactivity and conduct problems for boys as well as girls (see Table 3) Although the relation between inhibition and hyperactivity was somewhat stronger for boys compared to girls, this difference was not statistically significant ($z = .89$, *ns*).

Table 3
Pearson's product moment correlations between the aggregated measure of executive inhibition and the teacher ratings of hyperactivity and conduct problems

	Errors of response inhibition		
	Total sample	Boys	Girls
Hyperactivity	.43***	.47***	.33**
Conduct problems	.36***	.28*	.32*

* $p < .05$, ** $p < .01$, *** $p < .001$

In order to study whether response inhibition is uniquely related to hyperactivity, the effect of *hyperactivity* was controlled for when computing correlations between response inhibition and conduct problems, and the effect of *conduct problems* was controlled for when studying the association between inhibition and hyperactivity. When studying the sample as a whole, the results showed that the correlation between inhibition and hyperactivity was significant when controlling for conduct problems ($r = .26$, $p < .01$), whereas the association between inhibition and conduct problems did not remain significant when controlling for hyperactivity ($r = .07$, *ns*).

In the analyses of each sex separately, it was found that for boys, the results were consistent with the results for the whole sample ($r = .39$, $p < .01$ for hyperactivity and $r = -.09$, *ns*, for conduct problems). However, when conducting the same analyses for girls, the results showed that neither the correlation between inhibition and hyperactivity ($r = .15$, *ns*), nor that between inhibition and conduct problems ($r = .13$, *ns*) was significant when controlling for comorbid conduct problems or hyperactivity.

Conclusions

Although several previous studies have shown a relation between inhibition and ADHD symptoms, mostly using clinical samples of school-aged children (e.g., Barkley, 1997a, b; Pennington & Ozonoff, 1996), this study is one of the first to show that this relation also exists in non-clinical samples of preschool children. Further, by using a dimensional rather than a categorical approach, we were able to control for symptoms of hyperactivity and conduct problems at the sub-clinical level. The result showed that the relation between inhibition and hyperactivity did not disappear when controlling for conduct problems, whereas the relations between inhibition and conduct problems was no longer significant when controlling for hyperactivity.

These findings indicate that the association between inhibition and conduct problems was caused by the large overlap between conduct problems and hyperactivity, and it provides further support for the notion that response inhibition is specifically related to hyperactivity. It should, however, be noted that inhibition was only shown to explain about a fifth of the variance in hyperactivity, which could be regarded as rather modest for a variable taken to represent the core deficit in ADHD (Barkley, 1997a).

Regarding sex differences, the results of the present study showed that the association between response inhibition and hyperactivity did not remain significant for girls when conduct problems were controlled for in the analysis. Thus, for girls, the overlapbetween hyperactivity and conduct problems largely also overlapped with inhibition. This finding is interesting, and even though the correlations for boys and girls did not differ significantly from each other, these results could be taken as an indication that it might be premature to conclude that inhibition, hyperactivity and conduct problems are similarly associated across gender.

Study II:

Two Types of Inhibitory Control:
Predictive Relations to Social Functioning

Background and aims

Study II is an empirical attempt at elucidating the relations and interplay between two types of inhibitory control - inhibition to the unfamiliar and executive inhibition. Physiologically, these types of inhibition are believed to be linked to areas of the brain that are partially overlapping and reciprocal in influence. Theoretically, the study is in line with formulations by Rothbart and coworkers (e.g., Derryberry & Rothbart, 1997; Rothbart & Bates, 1998), who have stressed the importance of examining the integrative effects of basic reactive and executive self-regulatory systems in order to understand the development of both adaptive and maladaptive behavior. However, despite physiological as well as theoretical links between these two concepts, relatively little empirical data exist, especially of the longitudinal kind.

The first aim of Study II was to investigate the potential overlap between inhibition to the unfamiliar and executive inhibition. Second, executive inhibition and inhibition to the unfamiliar measured at age 5 were studied in relation to teacher ratings of hyperactivity, social anxiety, as well as to social competence, three years later. We wished to examine the independent contributions of the two types of inhibition to behavioral outcome as well as to study interactive effects. Methodologically, the present study aimed at using variable-oriented analyses to cover linear effects, and additionally, study combinations of high and low levels of the two types of inhibition using pattern-oriented analyses. It has been argued by, for instance, Bergman and Magnusson (Bergman, 1998; Bergman & Magnusson, 1997; Magnusson, 1995) that this type of analysis is an important complement to variable-oriented analyses when studying individual development.

Statistical analysis

The SLEIPNER statistical software program was used for performing EXACON-analyses, that is, pattern-oriented analyses of single cells in a contingency table (Bergman & El-Khouri, 1998). The basis of this analysis is to use chi-square tests for each cell in the table, testing whether the observed value differs significantly from the value expected by chance. To study different configurations of executive inhibition and inhibition of the unfamiliar, the sample was divided into participants with low, medium and high values on these two types of inhibition. The 30% most and least inhibited children formed the extreme groups, and the remaining 40% of the children were classified as medium inhibited. This resulted in 9 different profiles (e.g., “high executive inhibition in combination with medium inhibition to the unfamiliar”, see Figure 5). A cut-off of 30% was used to define problem behavior groups.

In the first EXACON analysis, only the measures of hyperactivity and social anxiety were included, resulting in four different problem behavior outcomes (only hyperactivity, only social anxiety, both hyperactivity and social anxiety, and no behavior problems). In a second analysis, the two social competence aspects were studied, using the nine different profiles described above and four different outcomes (only low social initiative, only low prosocial orientation, both low social initiative and low prosocial orientation, and high levels of both aspects of social competence). A significance level of .05 was used for identifying significant predictor *types* (i.e., predictor-outcome combinations for which there were more subjects than could be expected by chance) and significant predictor *antitypes* (i.e., fewer subjects than could be expected by chance). Bonferroni corrections were used for all analyses, except for those where specific hypotheses were posed (see hypotheses below).

Hypotheses

Based on theory and previous studies (see general introduction to the thesis) it was hypothesized that the two types of inhibition would be modestly correlated and that executive inhibition would be positively related to hyperactivity, conduct problems and negatively related to prosocial orientation. It was also hypothesized that inhibition to the unfamiliar would be positively related to social anxiety and negatively related to social initiative.

Regarding the pattern-oriented analyses, the hypotheses regarding linear relations imply that children with low levels of executive inhibition would have a higher risk than expected by chance of showing hyperactive behavior, irrespective of their level of inhibition to the unfamiliar. However, we also wished to test the alternative hypothesis that the increased risk pertains only to children with low executive inhibition in combination with low or medium levels of inhibition to the unfamiliar, that is, a high level of inhibition to the unfamiliar was assumed to serve a protective function. It was further hypothesized that children showing high levels of both types of inhibition would constitute an antitype of hyperactivity, that is, children with this profile would be less likely than expected by chance to show hyperactivity.

Regarding social anxiety, a hypothesis in line with linear assumptions would be that children with high levels of inhibition to the unfamiliar would be more likely to develop problems in this domain. In line with the thinking that problems arise from either over- or underregulation (Derryberry and Rothbart, 1997), an alternative prediction would be that children with high inhibition to the unfamiliar in combination with high executive inhibition would be most at risk for developing social anxiety. This thinking would also imply that children showing low levels of both types of inhibition would be less likely than expected by chance to show social anxiety, and children with medium values would be more likely than chance to have no problem behaviors, and less likely to have any type of behavior problem.

Because previous studies have shown that high social anxiety is related to low social initiative (e.g., Rubin, 1993), the same hypotheses were posed for these two outcomes. Further, low prosocial orientation was hypothesized to be linked to the same profiles as hyperactivity, as these problem behaviors have been shown to co-occur (e.g., Milich & Dodge, 1984).

Results

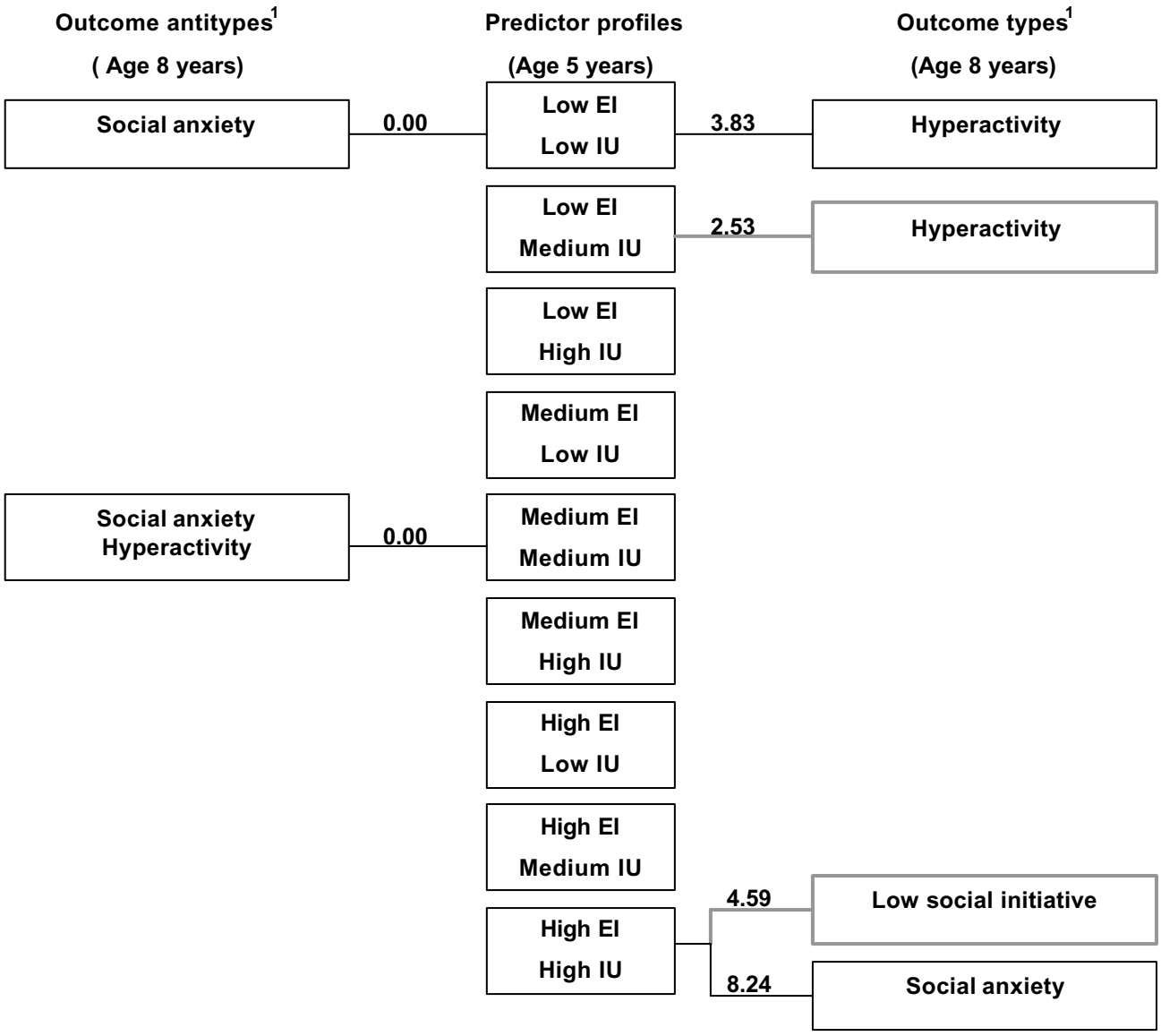
With regard to the relation between inhibition to the unfamiliar and executive inhibition, the results showed that performance on the task measuring executive inhibition was positively related to both parental ratings ($r = .22$, $p < .01$), and the laboratory observations ($r = .18$, $p < .05$) of inhibition to the unfamiliar. When aggregating the three measures of inhibition to the unfamiliar, this measure was shown to be significantly correlated with executive inhibition, $r = .21$, $p < .01$.

Regarding linear relations to problem behavior, executive inhibition was shown to be negatively related to hyperactivity, and inhibition to the unfamiliar was negatively related to hyperactivity and positively related to social anxiety, although the latter effect was only marginally significant. Regarding social competence, inhibition to the unfamiliar was negatively related to social initiative but not to prosocial orientation, whereas executive inhibition was not shown to be significantly related to either of the two aspects of social competence.

As both types of inhibition were shown to be related to hyperactivity, we wished to examine whether these effects were independent. The result of the regression analysis showed significant effects for both executive inhibition, $\beta = -.29$, $p < .001$, and inhibition to the unfamiliar, $\beta = -.17$, $p < .05$. As the other outcomes were only related to one type of inhibition, only interaction effects were studied in these regression analyses. However, no such interactive effects were found for any of the problem behaviors, or for the two aspects of social competence, βs from .01 to .13, *ns*.

The results of the non-linear analyses (EXACON) are presented in Figure 5. In line with the hypotheses, significant types for hyperactivity were found for children with low executive inhibition and low levels of inhibition to the unfamiliar, $\chi^2 = 4.06$, $p < .05$. There was also a relation at the level of tendency between hyperactivity and the profile of low executive inhibition and medium inhibition to the unfamiliar, $\chi^2 = 2.17$, $p < .10$, but low executive inhibition and high inhibition to the unfamiliar were not associated with hyperactivity, $\chi^2 = 1.35$, *ns*.

Contrary to the hypotheses, the results did not show that children high in both types of inhibition were less likely than expected by chance to have high ratings of hyperactivity, $\chi^2 = 1.58$, *ns*. None of the children with medium levels of both types of inhibition did, however, show the combination of hyperactivity and social anxiety, and



[1] Black lines indicate significant types/antitypes, p < .05, whereas grey lines indicate types/antitypes at the level of tendency, p < .10

Figure 5

Results of the EXACON analyses, showing likely (types) and unlikely (antitypes) combinations of inhibition to the unfamiliar (IU) and executive inhibition (EI) as well as odds ratios relative to chance.

this was shown to be a significant antitype just as hypothesized, $\chi^2 = 2.65$, $p < .05$. Studying odds ratios (see Figure 5), the results showed that among children with low executive inhibition, those with low levels of inhibition to the unfamiliar were almost 4 times more likely, and those with medium levels 2.5 times more likely, to have high levels of hyperactivity compared to children with other behavior profiles.

The results regarding social anxiety and social competence showed that children with high levels of both types of inhibition were more than 5 times more likely to have high ratings of social anxiety, $\chi^2 = 6.22$, $p < .01$. Besides social anxiety, children with high levels of both types of inhibition were also almost 3 times more likely to show low social initiative, although this effect was only marginally significant, $\chi^2 = 2.55$, $p < .10$. The results further showed that none of the children with low levels of both types of inhibition had high ratings of social anxiety, and in line with our hypotheses, this was a significant antitype, $\chi^2 > 2.80$, $p < .05$. Contrary to the hypotheses, no significant types were found for low prosocial orientation, all $\chi^2 < 1.86$, *ns*.

Conclusions

Study II adds to previous knowledge regarding concurrent clinical and non-clinical relations between executive inhibition and hyperactivity (e.g. Barkley, 1997b; Hughes et al., 1998; Pennington & Ozonoff, 1996) by contributing evidence for a predictive relation as well. Our finding that inhibition to the unfamiliar is related to social anxiety and low social initiative is also consistent with previous studies, especially studies by Rubin (1993), in which it is suggested that children with high inhibition to the unfamiliar place themselves at risk for not developing important social skills. When these children become old enough to recognize their difficulties, they may begin to develop internalizing behavior problems such as social anxiety.

Although no interactive effects of the two types of inhibition were found in the linear analyses, the results showed that when studying behavior patterns low executive inhibition was related to hyperactivity, except when in combination with high inhibition to the unfamiliar. These results indicate that executive inhibition is associated with an increased risk for developing hyperactivity, but that high levels of inhibition to the unfamiliar can function as a protective factor for these children. The non-linear analyses further showed that executive inhibition potentiated the effect of inhibition to the unfamiliar, in that only children with high levels of both types of inhibition were at risk for developing social anxiety and low social initiative.

Altogether, the results of the present study provide an overall picture of one group of children with high levels of both types of inhibition at age 5, who are at risk for developing social withdrawal and social anxiety, and another group of children with low levels of both types of inhibition, who are at risk for developing hyperactive behavior, but who at the same time are somewhat protected from developing social anxiety.

Study III:

Relations between inhibition, executive functioning and ADHD symptoms: A longitudinal study from age 5 to 8½ years

Background and aims

Barkley (1997a) has made a number of statements regarding his model. Two of them are of special importance to Study III. First of all, Barkley claims that inhibition starts to develop earlier than the executive functions and that these functions later develop in parallel with each other so that a progressive increase in inhibitory control is associated with an increase in executive functioning. Second, he views these deficits as actually being delays, meaning that there is a quantitative rather than a qualitative difference between ADHD children and normal controls with regard to development of these functions. This also implies that the processes underlying normal and abnormal development are essentially the same, and that studies of non-clinical samples can improve our understanding of the deficits associated with clinical conditions.

With the above statements as the basis of the investigation, the present study set out to study executive inhibition, each of the four executive functions included in Barkley's model, and ADHD symptoms in a non-clinical sample. Previous studies have rarely examined the effects of early inhibitory control on later adjustment. Nigg, Quamma, Greenberg, and Kusche (1999) did, however, find a significant, independent effect of executive inhibition in grade 1 on disruptive problems measured two years later, although the other measures of executive functioning did not contribute independently in the regression model. The possibilities of preschool prediction, differential pathways for boys and girls, and specific relations to ADHD-related behaviors are, however, still uninvestigated, as Nigg and co-workers did not address these issues.

The aim of Study III was to examine whether preschool executive inhibition is able to predict later executive functioning and ADHD symptoms among boys and girls. The concurrent relation between executive functioning and ADHD symptoms was also of interest, as well as the independent contributions of inhibition and executive functioning on ADHD symptoms. Based on Barkley's (1997a) theory, it was hypothesized that preschool inhibition would be longitudinally related to measures of both other executive functioning and ADHD symptoms. Concurrent relations between executive functioning and ADHD symptoms were also expected. Regarding the issue of independent effects, this has not been tested empirically before, and therefore no specific hypothesis could be made.

Results

Descriptive statistics for boys and girls as well as *t*-tests examining sex differences in all variables showed that there were rather large sex differences with regard to errors

of inhibition in preschool and inattention and hyperactivity in school. With regard to executive functioning, the only significant sex difference was found for verbal working memory, where boys performed at a lower level compared to girls. There was a also tendency for boys to do less well compared to girls with regard to reconstitution.

When studying the predictive relation between inhibition and ADHD symptoms, all relations in both school and at home were found to be significant when studying the whole sample, although for girls they were only significant in the school setting (see Table 5). When comparing the correlation coefficients for boys and girls, the results showed that the relation between inhibition and ADHD symptoms was significantly stronger for boys with regard to hyperactivity and inattention at home (zs < 2.47, p < .01), as well as marginally stronger for hyperactivity in school (z = 1.35, p < .10).

Table 5
Relations between inhibition, ADHD symptoms and executive functioning.

	Errors of inhibition at age 5		
	Total (n = 115)	Girls (n=62)	Boys (n=53)
Hyperactivity/impulsivity			
School (8 years)	.41***	.21*	.44***
Home (8½ years)	.25**	.01	.45***
Inattention			
School (8 years)	.38***	.30*	.36**
Home (8½ years)	.35***	- .06	.59***
Executive functioning (8½ years)			
Non-verbal working memory	- .18*	- .10	- .26*
Verbal working memory	- .22**	- .01	- .27*
Regulation of arousal	- .21*	- .09	- .25*
Reconstitution	- .13^{+}	- .04	- .11

$^{+}$p < .10, * p < .05, ** p < .01, *** p < .001

With regard to the predictive relation between inhibition and executive functioning, the results showed that when studying the whole sample, inhibitory control was significantly related to verbal and non-verbal working memory, regulation of arousal, as well as marginally related to reconstitution (see Table 5). When studying boys and girls separately, none of the relations between inhibition and executive functioning was significant, or even close to significance, for girls. For boys, inhibition was significantly related to three of the four executive functions (all but reconstitution), with correlation coefficients ranging between .25 and .27. Thus, inhibition was shown to be a modest, although in most cases significant, predictor of general executive functioning for boys.

Finally, we wished to examine whether inhibition and executive functioning contributed independently to the understanding of ADHD symptoms. Executive functioning was entered in a first step in the regression model to see the independent contributions of the four executive functions, and inhibition was then entered in a second step, to see whether it added significantly to the variance in ADHD symptoms.

Table 6
Regression analyses for hyperactivity and inattention (home and school contexts combined), with executive functioning and inhibition as predictors (n = 114).

	Boys		Girls	
	R^2 change (adj.)	β	R^2 change (adj.)	β
(A) Hyperactivity				
Executive functioning	.18 (.11)*		.13 (.06)	
Non-verbal working memory		- .14		- .32*
Verbal working memory		- .29*		- .08
Regulation of arousal		- .18		- .04
Reconstitution		- .07		- .10
Errors of inhibition	.10*		< .01	
(B) Inattention				
Executive functioning	.43 (.38)***		.08 (.01)	
Non-verbal working memory		- .20^{+}		- .20
Verbal working memory		- .37**		- .03
Regulation of arousal		- .26*		- .14
Reconstitution		- .23^{+}		- .10
Errors of inhibition	.10**		< .01	

$^{+}$p < .10, * p < .05, ** p < .01, p < .001

For hyperactivity, executive functioning explained 18% of the variance for boys, $F(4, 44) = 2.49$, $p < .05$, and 13% for girls, $F(4, 54) = 1.97$, *ns* (see Table 6). Besides this, inhibition added another 10% of explained variance in hyperactivity for boys, resulting in a total explained variance of 28% (R^2 adjusted = .20). Inhibition did not, however, contribute significantly for girls. With regard to inattention, executive functioning explained as much as 43% of the variance for boys, $F(4, 44) = 8.36$, $p < .0001$, but only 8% for girls, $F(4, 58) = 1.14$, *ns*. Inhibition contributed another 10% of the variance in inattention for boys, meaning that the total explained variance was as high as 53% (R^2 adjusted = .48). For girls, inhibition did not contribute significantly.

Conclusions

The results of Study III showed that executive inhibition was related to both hyperactivity and inattention, although for girls this relation was only significant in the school context. For boys, inhibition also predicted more general deficits in executive functioning, and these deficits were related to high levels of ADHD symptoms.

Similar longitudinal findings were found by Nigg and co-workers (1999), but in the present study inhibition was examined at an earlier developmental stage and the outcome measure specifically tapped ADHD behaviors instead of general disruptive behavior. For the first time, the question of whether the effect of early inhibition on ADHD symptoms is mediated by concurrent executive functioning was also addressed. The results showed that both inhibition and executive functioning contributed independently to the explanation of ADHD symptoms, explaining as much as half of the variance in boys' inattention problems.

Finally, the importance of conducting separate analysis for boys and girls should be emphasized. Our finding of a much weaker relation between inhibition, executive functioning and ADHD symptoms for girls suggests that either the predictors of ADHD are different for the two sexes, or that relations are harder to demonstrate due to girls' lower incidence of disruptive problem behaviors.

Study IV:

How well do measures of inhibition and executive functioning discriminate between ADHD children and controls?

Background and aims

Although a number of studies have found support for Barkley's theory of ADHD and executive functioning (for reviews, see Barkley, 1997a, Pennington & Ozonoff, 1996), there are also studies that have failed to find significant group differences (e.g., Fisher et al., 1990; Kerns et al., 2001; Stevens, et al., 2002; Weyandt & Willis, 1994). Some recent studies have even reported negative findings with regard to group differences in inhibition (e.g., Barkley et al., 2001; Kuntsi et al., 2001). This latter finding is especially critical when evaluating Barkley's theory, as he proposes that because of the primary role of inhibition to other executive functions, the largest group differences should be observed for this function (Barkley, 1997a).

Given the inconsistencies in previous research, the present study aimed to study inhibition and each of the four other executive functions that Barkley (1997a) includes in his model of ADHD. Besides studying group differences, we also wished to examine the accuracy with which these tests could discriminate between ADHD children and controls, as well as the question of independent effects of inhibition and the other executive functions. The few previous studies examining this issue have generally found that tests of executive functioning are better at excluding normal children from the ADHD category than at confirming ADHD in children diagnosed with the disorder (e.g., Barkley & Grodzinsky, 1994; Doyle et al., 2000; Pennington & Ozonoff, 1996; Perugini et al., 2000).

Measures of discriminant ability

It has been argued that group differences alone are insufficient indices of the discriminant ability of a measure (Doyle et al., 2000), and we therefore complemented our data with measures of sensitivity, specificity and odds ratios. Sensitivity refers to the probability of an abnormal test score given that a person has the diagnosis in question, whereas specificity is defined as the probability of a normal test score given that the person does not have the diagnosis. Odds ratios represent the odds of an abnormal test score among cases divided by the odds of having an abnormal score among the controls (see Table 7).

Table 7
Conditional probability analysis: terminology

Term	Definition
Sensitivity	The probability of an abnormal test score given that a person has the diagnosis in question.
Specificity	The probability of a normal test score given that the person does not have the diagnosis
Odds ratios	The odds of an abnormal test score among cases divided by the odds of having an abnormal score among the controls

Results

As can be seen in Table 8 (bottom), the ADHD children did not differ significantly from the control children with regard to intelligence. Regarding the executive function measures, the results showed that none of the measures were significantly related to intelligence (all *r*s < .21, *ns*) in the total sample, but errors on the hand movement task were related to intelligence in the ADHD group (r = .43). As the practice of controlling for intelligence in ADHD studies has been questioned (Barkley, 1997a), the results are reported without using block design as a covariate. It should, however, be noted that none of the conclusions changed when controlling for intelligence.

Regarding overall group differences in performance on the executive functioning tests, the results of the multivariate analysis of variance (MANOVA) showed that the ADHD children differed significantly from the control children when analyzing the measures collectively, Wilk's Lambda (8, 54) = 12.67, p < .0001. Univariate analysis of variance (ANOVA) revealed significant group differences and medium to large effect size on all eight measures, except hand movements (see Table 8).

When examining the discriminant ability, a full model with all seven variables for which group differences had been found was first of all tested. This model (MODEL 1) was shown to be statistically significant, χ^2 (7, N = 63) = 55.07, $p < .0001$, and it

Table 8
Means (SD) for all variables included in the study, effect sizes (ES) and results of t-tests (n = 63)

	ADHD		Controls			
	M	SD	M	SD	ES[1]	*F*
Errors of inhibition						
Commission errors on the go/no-go task	13.71	(5.76)	11.04	(5.22)	0.49	3.41*
Errors on the Stroop-like task	5.38	(3.73)	2.31	(2.05)	1.18	17.83***
Verbal and non-verbal working memory						
Time reproduction (discrepancy score)	10.68	(8.56)	4.18	(3.63)	1.23	17.98***
Errors on the hand movement task	9.05	(3.67)	8.78	(2.96)	0.08	0.09
Poor rule-governed behavior	3.43	(1.57)	2.62	(1.51)	0.53	3.91*
Regulation of affect/motivation/arousal						
Poor regulation of negative emotions	1.99	(0.73)	1.01	(0.64)	1.46	5.16***
Omission errors on the CPT	5.00	(5.71)	2.19	(2.50)	0.79	2.45*
Reconstitution						
Errors of reconstitution of story	36.71	(8.14)	32.60	(6.71)	0.57	1.69*
Intelligence						
Block design (scaled score)	10.60	4.93	11.43	3.34	0.21	0.52

$^{+}$ p < .10, * p < .05, ** p < .01, *** p < .001

[1] Effect sizes were calculated using pooled standard deviations as recommended by Hedges (1981).

correctly classified 86% of the participants, with a sensitivity of about 80, and a specificity of almost 90. (see Table 9). The odds of performing poorly were more than 30 times higher for the ADHD children compared to the controls. However, this model also revealed that only errors on the Stroop-like task, time reproduction, and regulation of emotions independently predicted group membership. A model with these three variables (MODEL 2) was also significant, χ^2 (3, N = 63) = 53.18, p < .0001. This model classified 86% of the children correctly and had an odds ratio of about 30, just as the previous model. However, in MODEL 2, the sensitivity was somewhat lower, whereas the specificity was higher (see Table 9).

Table 9
Sensitivity, specificity and odds ratio for the different models

	Sensitivity	Specificity	Odds ratio
MODEL 1	81.0	88.1	31.45
MODEL 2	76.2	90.5	30.40
MODEL 3	81.0	78.6	15.58

Finally, in MODEL 3, the parental rating measure of emotion regulation was excluded as there is a possibility that this rating, besides measuring the child's specific ability to self-regulate emotions, also reflects a generalized parental view of the child as prob-

lematic. The result showed that when entering all other predictors, only time reproduction and interference control were significant contributors. A regression model with these two variables was significant, χ^2 (3, N = 63) = 13.74, p < .001. The sensitivity and the specificity of this model, MODEL 3, were slightly above or below 80, with a total of 79% of the children correctly classified and an odds ratio of about 15.

Conclusions

The findings of Study IV are supportive of Barkley's model in that the ADHD children differed from controls when studying mean group differences in all of the main components included in the model and that good discriminant ability of these functions was obtained. The results concerning independence of effects pointed to inhibition and working memory as salient aspects. However, our results leave to future studies to further evaluate the suggestion that this is true also for emotion regulation, or perhaps a more general regulatory function. It should also be noted that although our findings are in line with Barkley's theoretical formulations, they cannot be taken as support for the main theme of his theory, that is, that inhibition is a superordinate function in relation to the other four executive functions.

GENERAL DISCUSSION

In the following section, a general discussion is presented, including a brief summary of the main findings of this thesis as well as conclusions relating to the aims presented in the introduction. Possible directions for future research conclude the discussion.

Main findings of the empirical studies

One of the major findings of Study I was that the measures tapping executive inhibition, but not the other measures included in the study, were related to both hyperactivity and conduct problems in preschool. Further, when controlling for hyperactivity in the relation between inhibition and conduct problems, this relation was no longer significant, although the relation between executive inhibition and hyperactivity did remain significant when controlling for conduct problems, at least in analyses of the total sample and boys only. The relations appeared somewhat different for boys and girls, although these sex differences were not found to be statistically significant.

In Study II, the results of the linear analyses showed that executive inhibition was negatively related to hyperactivity, whereas inhibition to the unfamiliar was negatively related to both hyperactivity and social initiative, as well as positively related to social anxiety. The latter effect was, however, only marginally significant. The results of the non-linear analyses provided an overall picture of two groups of children at risk for developing problem behavior. The first group of children had high levels of both types of inhibition at age 5, and these children were shown to be at risk for low social initiative and social anxiety. The second group included children with low levels of both types of inhibition, and these children were shown to be at risk for hyperactivity, but they also appeared to be somewhat protected from developing social anxiety.

In Study III, executive inhibition was strongly related to ADHD symptoms both in school and at home for boys, but only in the school context for girls. Early executive inhibition was also significantly related to later executive functioning and concurrent relations were found between executive functioning and ADHD symptoms, although in both cases only for boys. Besides this, executive inhibition added significantly to the variance, beyond that of executive functioning, which meant that for boys, inhibition and executive functioning could explain about half the variance in inattention problems.

Finally, Study IV showed that children with ADHD differed from controls when comparing these groups on measures of inhibition and each one of the four other executive functions that Barkley (1997a) includes in his model. Besides this, the measures were also shown to discriminate very well between groups. The best model, which included measures tapping executive inhibition, working memory, and emotion regulation, was shown to classify as many as 86% of the children correctly.

Are preschool measures of inhibitory control related to hyperactivity?

Regarding the question of whether executive inhibition measured as early as preschool is related to hyperactivity in a non-clinical sample, support for this notion was found in all three studies (Study I, II and III) aiming to address this issue. In Study I, concurrent relations to hyperactivity were found for inhibition of a prepotent response (at both measurement points) as well as for interference control. It should, however, be noted that the overall measure of inhibition was only shown to explain about a fifth of the variance in hyperactivity, which could be regarded as rather modest for a variable taken to represent the core deficit in ADHD (Barkley, 1997a).

The finding that only about a fifth of the variance in hyperactivity was accounted for can be explained in several different ways. First of all, the relation might in reality not be stronger than what was found, which could be taken as an indication that executive inhibition is not the primary deficit in ADHD. It is, for example, possible that the relation between poor executive inhibition and hyperactivity found in the present thesis is secondary to some sort of regulatory problem, as suggested by Douglas (1999) and Sergeant and colleagues (1999). Second, the measures of inhibition used in Study I might not have been optimal for the age group studied. Barkley (1997a) has argued that relations between inhibition and hyperactivity can only be expected when using tasks that most of the normal children, but not the hyperactive children, have learnt to master. Third, the relation between inhibition and hyperactivity in preschool might have been stronger had it not been for the normative nature of these types of behavior problems (Olson, 1996). By this I mean that a large number of preschool children display hyperactive behavior, and distinguishing between true precursors of ADHD symptoms and age-appropriate behavior is difficult, even for experienced teachers. If executive inhibition measured in preschool is a true predictor of ADHD symptoms, it should only be related to hyperactive behavior that falls outside the range of what is considered age-appropriate behavior.

Study II and III, provided more information regarding this issue. In Study II, the children who were most at risk for developing hyperactivity were those who at age five had low levels of executive inhibition as well as low or medium levels of inhibition to the unfamiliar. Thus, high levels of inhibition to the unfamiliar appeared to function as a protective factor for hyperactivity. This indicates that even though executive inhibition plays an important role in the development of hyperactivity, other factors, including protective factors, are needed in order to account for the whole spectrum of deficits associated with hyperactivity.

In Study III, the relation between executive inhibition and ADHD symptoms was even somewhat stronger compared to Study I, at least for boys' inattention problems. This finding is very interesting considering the fact that these were longitudinal relations from age 5 to 8 years, a time period characterized by rapid development in both

cognitive and socio-emotional functioning. Thus, our inhibition measure appeared to be well adapted for use with preschool children. The fact that the relation between executive inhibition and hyperactivity was not stronger in Study I is instead likely to be a reflection of the difficulty of distinguishing between preschool hyperactivity as a precursor to more severe problems and age-appropriate behavior, as described above. However, by the age of 8, problematic children have probably become distinctly different from non-problematic children, making their behavior easier to evaluate.

In summary, the findings presented in this thesis are clearly supportive of a relation between executive inhibition and hyperactivity, with high inhibition to the unfamiliar perhaps having a protective effect. The fact that these variables were related not only concurrently, but over time as well, suggests that it might be possible to improve early identification of children at risk for developing ADHD, by adding laboratory measures of inhibition to information about other risk and protective factors.

Can poor executive inhibition predict general executive function deficits?

When discussing the developmental implications of his model, Barkley (1996) has stated that preschool executive inhibition should be seen as a precursor of a more general executive function deficit, characteristic of ADHD children at school age. Sonuga-Barke and co-workers (2002) found that inhibition, but not other executive functions, was related to ADHD symptoms in preschool. They took this finding to be in line with Barkley's hypothesis, making the implicit assumption that their failure to obtain associations for working memory and planning was due to the young age of the sample.

In our research, data for boys showed that three of the four executive functions were predicted, although at a relatively low level, by executive inhibition measured three years earlier at the age of 5. However, based on Barkley's (1997a) hypothesis of inhibition as primary to other executive functions, one might have expected a somewhat stronger relation between these variables. It should, however, be noted that Barkley does not suggest that inhibition causes the other executive functions. This means that an individual might have proficient executive inhibition, but merely an average or even low working memory ability. On the other hand, an individual with very good working memory skills will also need at least average or better executive inhibition skills as working memory is dependent on inhibition for its execution. Although the results of Study III did suggest that inhibition is related to the other executive functions included in Barkley's model, more studies examining these relations are clearly needed. Foremost, the role of inhibition as primary to other executive functions has to be better defined, as this is necessary before specific, testable hypotheses can be formulated regarding this issue.

Do the predictors of hyperactivity/ADHD have independent effects?

The question of independent effects was addressed in two of the studies. In Study II, both executive inhibition and inhibition to the unfamiliar were shown to be related to hyperactivity and when studying both predictors in a regression model, they were both shown to make independent contributions. This could be taken as being supportive of theoretical formulations by Rothbart and co-workers (e.g., Derryberry & Rothbart, 1997; Rothbart & Bates, 1998), who have stressed the importance of including both motivational and executive control systems in order to understand different psychopathological conditions of childhood. In the case of ADHD, they claim that a strong approach tendency or a weak fear regulation (i.e., low inhibition to the unfamiliar) may result in impulsive behavior, especially if the child is unable to voluntarily constrain his/her behavior through the regulatory system of effortful control (i.e., executive inhibition). Thus, ADHD is proposed to be best described as a problem of underregulation of both control systems (Derryberry & Rothbart, 1997), a hypothesis that is clearly in line with the findings of Study II.

Regarding the relation between executive inhibition, and the other executive functions included in Barkley's (1997) model, Study III showed that preschool inhibition and concurrent executive functioning contributed independently to the explanation of ADHD symptoms at school-age. Similar independent effects of inhibition and executive functioning were also found in the clinical sample examined in Study IV.

Whether the independent effects are in line with Barkley's theoretical viewpoint may be debated, as he, at least to our knowledge, has only stated that executive inhibition should be seen as "setting the stage" for the other executive functions, without addressing the issue of independent effects. Our interpretation of Barkley's theory is that it might well encompass independent effects of inhibition and the four executive functions. We believe that development of the four executive functions depends on inhibition, but on other factors as well, and both proficient inhibitory control and well-functioning executive functions are needed in order for behavior to become self-regulated. Inhibition would then have a direct influence on the development of ADHD symptoms as well as an indirect effect through executive functioning.

Is executive inhibition specifically related to hyperactivity?

Previous studies have shown that deficits in executive inhibition have not only been observed among children with ADHD, but among children with CD as well (Hurt & Naglieri, 1992; Oosterlaan et al., 1998). This raises the question of whether poor executive inhibition is actually the hallmark of ADHD, as it does not appear to be specific to the disorder. However, since most studies have failed to control for comorbid diagnoses, it has been suggested that the relation between executive inhibition and

conduct problems is due to the large overlap between hyperactivity and conduct problems (e.g., Pennington & Ozonoff, 1996).

In Study I we therefore wished to address the question of specificity by controlling for conduct problems when studying the effects of executive inhibition on hyperactivity, and to control for hyperactivity when studying the effects of inhibitory control on conduct problems. The results were supportive of a relation between executive inhibition and hyperactivity, whereas the relation between executive inhibition and conduct problems appeared to be accounted for by the large overlap between these two disorders. It should be noted that, in contrast to most previous studies controlling for comorbid conditions, we used a dimensional (i.e., low to high levels of hyperactivity) rather than a categorical (i.e., ADHD or not ADHD) approach, and we were thereby able to control for comorbid symptoms at the sub-clinical level.

Are the predictors of hyperactivity/ADHD the same for boys and girls?

Study I and III addressed the issue of sex differences, and in both these studies significant sex differences were found with regard to ADHD symptoms and executive inhibition, with boys having more severe problems and performing more poorly compared to girls. For the other executive functions examined in Study III, significant sex differences were only found for digit span.

Sex-differences regarding errors on go/no go tasks or the Stroop-task have not been found using clinical samples of ADHD children (e.g., Gershon, 2002; Nydén, et al., 2000). However, since many more boys compared to girls are diagnosed with ADHD and deficient executive inhibition has been suggested as the cause of the disorder (Barkley, 1997a), one would expect sex-differences in executive inhibition using a population-based sample. The observed sex-differences in performance may, in fact, be taken as a further indication that the measures of executive inhibition used in this thesis are useful when trying to identify children at high risk for developing ADHD. Regarding sex differences in the association between executive inhibition and hyperactivity, Study I showed that this relation appeared to be somewhat stronger for boys compared to girls. Although the effect was not statistically significant, our conclusion based on this finding was that it might be premature to conclude that executive inhibition and hyperactivity are similarly associated across gender.

Our conclusion from Study I received further support in Study III, where we again found sex differences, and this time they were statistically significant. The fact that executive functioning was not shown to be as strongly associated with ADHD symptoms for girls compared to boys could be taken as an indication that other factors might better explain these problems in girls. Unfortunately, it was beyond the scope of this thesis to examine which these other factors might be. However, it should also be noted that it is just as likely that the weaker, sometimes even non-significant, relations

between inhibition and inattention and hyperactivity for girls were a result of lower problem loads for girls, making it harder to demonstrate significant relations.

The importance of distinguishing between different types of inhibition

In Nigg's (2000) taxonomy of inhibition, as many as eight different types of inhibition are identified in an attempt to provide a better understanding of this field and of how different types of inhibition can develop abnormally in particular disorders. However, many researchers do not clearly define what type of inhibition they are studying, and they do not always make a distinction between different types of models when comparing their results with that of other researchers. Can, for example, inhibitory errors on the stop-signal task be used as a measure of poor BIS functioning according to Gray's theory? According to Nigg's taxonomy, the answer to this question is "no", in that it is only when using tasks with motivational conditions (i.e., containing reward or punishment) that they should be seen as measures of BIS. Neither is BIS equal to Kagan's inhibition to the unfamiliar. Both can be described as different types of motivational inhibition, but Kagan's inhibitory concept pertains to response to novelty, and only secondarily to punishment cues (Nigg, 2000). Besides this, Kagan's inhibition is believed to be anchored in the amygdala (Kagan, 1994), whereas Gray (1982) suggests that BIS is mediated by the septal-hippocampal structure.

This means that, theoretically, different types of inhibition can often be distinguished from one another. Empirical studies to address the possible empirical overlap between these different types of inhibition, as well as how they are related to particular disorders are, however, scarce. We therefore aimed to address this issue in Study II by studying executive inhibition and inhibition to the unfamiliar. By making this distinction between two different types of inhibition, but still including them both in the same analyses, we were able to show that it is the combination of high levels of executive inhibition and low or medium levels of inhibition to the unfamiliar that puts the child significantly at risk for developing hyperactivity. Thus, the protective role of high inhibition to the unfamiliar that has been found for delinquency and conduct problems (Kerr et al., 1997; Wångby et al., 1999) appears to apply to hyperactivity as well. These findings indicate that more studies examining the combined effect of different types of inhibition would clearly be of interest to the ADHD research area.

Discriminating between ADHD children and controls

The question of whether tests of executive functioning can discriminate between groups was addressed in Study IV, by examining sensitivity, specificity and odds ratios for measures pertaining to all major components of Barkley's model. The results showed that three different measures, tapping executive inhibition, non-verbal working memory, and emotion regulation were found to be significant independent predictors

of group membership. The sensitivity for these three variables as a set was 76.2, the specificity was 90.5, with a total of 86% of the sample correctly classified.

Our finding that the specificity of the tests was better than the sensitivity is consistent with previous studies (Barkley & Grodzinsky, 1994; Doyle et al., 2000; El-Sayed et al., 1999; Perugini et a., 2000). Thus, our study provides further support for the notion that measures of executive functioning are better at excluding control children from the ADHD-group than at confirming ADHD in children diagnosed with the disorder. Compared to previous studies, the discriminatory ability of our tests was, however, generally higher, especially regarding sensitivity, but also for specificity. These findings indicate that measures pertaining to each of the functions included in Barkley's (1997a) model, can discriminate relatively well between ADHD children and controls.

Regarding the issue of independent effects, it should be noted that two of the executive functions included in Barkley's model, verbal working memory and reconstitution, did not contribute independently in the regression model. Regarding verbal working memory, it should be remembered that our measure tapped a specific sub-aspect of this function, that is, rule-governed behavior, and that the results might have looked different had a more direct measure of verbal working memory (e.g., a digit span task) been included. However, the findings are consistent with several previous studies conducting factor analysis of neuropsychological measures, which have failed to find separate factors for the verbal and non-verbal components of working memory (e.g., Barkley et al., 2001; Brocki & Bohlin, 2002; Mariani & Barkley, 1997). Regarding reconstitution, our failure in finding an independent contribution is not very surprising. In fact, although Barkley regards reconstitution as a separate part of his model, he recognizes that this might just be a more advanced function of the working memory system.

A comment should also be made regarding our finding that interference control discriminated better between groups compared to inhibition of a prepotent response. As previous ADHD studies have not examined independent effects of different measures of inhibition, our finding is new and requires replication before any certain conclusions can be drawn. There are, however, some previous findings relating to this issue that might be considered to be in line with our findings. First of all, some studies have failed to find that ADHD children differ from controls regarding response inhibition (Barkley et al., 2001; Kuntsi et al, 1999; Oosterlaan et al., 1998), whereas significant differences have most often been obtained using the Stroop Task (for a review, see Sergeant, Geurts, & Oosterlaan, 2002). Second, it has been shown that the capacity to inhibit a response develops rapidly already during the preschool years, whereas interference control continues to develop from nursery school through sixth grade (Bjorklund & Harnishfegar, 1990). Insofar as ADHD children's poor executive functioning can been described as a delay (Barkley, 1997a), this indicates that interference control might be best at differentiating between ADHD children and controls

among school-aged children, as even normally developing children have not learnt to master this skill until this age. Inhibition of a prepotent response would, however, be more strongly related to ADHD symptoms in preschool as this function develops early.

Finally, it should be noted that although our data showed that the functions included in Barkley's model can discriminate well between ADHD children and controls, it was beyond the scope of Study IV to address the question of specificity. Thus, we do not know whether these tests can discriminate between ADHD and other developmental disorders such as conduct disorder, or between different subtypes of ADHD.

Evaluating Barkley's theory based on the results of this thesis

When evaluating Barkley's theory, it is important to note that there are two levels to his model. First of all, it makes the hypothesis that hyperactivity/ADHD is related to executive inhibition as well as to four other executive functions: non-verbal working memory, internalization of speech, self-regulation of affect/motivation/arousal, and reconstitution. Second, inhibition is regarded as primary, which means that there is a hierarchical organization of the model, with executive inhibition at the top of the hierarchy and the four executive functions at a lower level, being dependent on inhibition for their effective execution (Barkley, 1997a). Most research, including this thesis, has focused on the first aspect of the theory.

In the present study, inhibition was repeatedly shown to be related to hyperactivity in the longitudinal sample of normally developing children, and group differences were also found between ADHD children and controls in Study IV. Also for the other executive functions significant relations were found in both the longitudinal and the clinical sample. These findings are clearly in line with Barkley's theory, as well as with previous studies reporting concurrent relations between inhibition, executive functions and ADHD symptoms in both clinical (for reviews, see Barkley, 1997a; Pennington & Ozonoff, 1996) and non-clinical samples (e.g., Hughes et al, 1998; Hughes et al., 2000). The present thesis also makes an important, new contribution to this research field by providing evidence for a longitudinal relation as well. Besides this, Study III was able to show that poor executive inhibition in preschool could be seen as a developmental precursor to more general executive function deficits at school-age, at least for boys. This too is supportive of Barkley's model, as it shows that inhibition is related to the other executive functions, just as hypothesized in the model.

When relating our findings to Barkley's theoretical formulation, it is, however, important to note that he is not the only one who proposes that children with ADHD are deficient with regard to executive inhibition and various other executive functions. What distinguishes Barkley's theory from other models is that he regards inhibition as primary to other executive functions, whereas most other researchers view executive

inhibition as merely one of many examples of executive functioning (e.g., Douglas, 1999; Sergeant et al., 1999). However, as already mentioned in this discussion, the exact definition of inhibition as primary is not clear, making it difficult to test the hierarchical structure of the model.

This implies that our finding of a relation between executive inhibition and the four executive functions, is supportive of Barkley's theory, but in line with other theoretical formulations as well. According to Douglas (1999) and Sergeant and colleagues (1999), these results would, for example, most likely be interpreted to mean that the functions studied are all executive in nature, and that the relation is a result of an underlying deficit in some sort of regulatory problem. The fact that emotion regulation was shown to be important in discriminating between ADHD children and controls in Study IV could be seen as further support for this hypothesis.

Besides an independent effect of regulation in Study IV, significant effects were also found for measures tapping inhibition and working memory. These results fit well with theoretical formulations by Roberts and Pennington (1996), who view both inhibition and working memory as primary to other executive functions. Welsh (2002) has proposed that this interaction between inhibition and working memory can best be described using a "limited capacity, central pool of resources model." The basic assumption of such a model is that there exists a limited pool of resources that both inhibition and working memory have to use, which means that imposing a large inhibitory load will interfere with working memory and vice versa. This might imply that for children with poor inhibitory control, a relatively well functioning working memory system could compensate for this deficit, leaving more resources free for inhibition to use. For an individual with both poor inhibition and poor working memory, such a compensation cannot be made, resulting in more severe problems.

In summary, the findings presented in this thesis are in line with Barkley's views. It should, however, be made clear that they should not be taken as support for the main theme of the theory, that is, that inhibition is a superordinate function in relation to the other four executive functions. This is an issue for future research to take on.

Methodological issues

Sample size

When conducting research, priorities must be made, which often leads to certain limitations. Sample size is always an important issue in research, and perhaps especially so when studying longitudinal and clinical samples. Recruitment of children with clinically relevant ADHD symptoms is usually made either through a psychiatric clinic or by using behavioral rating scales that include the 18 items for ADHD presented in the DSM-IV (APA, 1994). Using rating scales, large samples of hyperactive children can be recruited, although it is impossible to know for how many

of these children there is true evidence of clinically significant impairment in social, academic, or occupational functioning as stated in the DSM-IV. Besides, the criterion of impairment in two settings is often ignored, as ratings are collected from either parents or teachers, and not both sources. To address these limitations, the ADHD sample included in Study IV was recruited from a psychiatric clinic. We also recruited children right after they had received a diagnosis so that none of the children could have started receiving stimulant medication. Unfortunately, using such a carefully diagnosed group of children, with no participants on medication, posed a limitation on the sample size, and only 21 ADHD children could be recruited for the study.

Attrition

Sample size is also an important issue in longitudinal studies, especially regarding the substantial work load that comes with examining large samples, but also the problem of attrition in the sample during the course of the study. In the longitudinal study from which data for Study I, II, and III were collected, 151 children were recruited to the study at the age of 5 years, and 135 children were still part of the study at the time of the data collection at age 8½ years. This attrition rate of about 10% is relatively low, making this an important strength of the study. However, one cannot know for certain that the participants who remained in the study did not differ from those who dropped out of the investigation. We did ask the parents about reasons for dropping out of the study, and half of the attrition was due to the fact that the family had moved out of the area. There is no reason to believe that these children were any different from those who remained in the study. Regarding the children for whom lack of time was said to be the reason for dropping out, it is possible that these children come from more problematic families. We did, however, compare the children who dropped out with those who remained in the study with regard to problem behaviors at the time of the first laboratory visit, and no significant differences were found.

Dimensional or categorical approach

As described in the introduction, ADHD can either be seen as constituting the extreme end of a dimension of behavior that falls along a continuum with normal children or as a discrete category. In line with several other researchers, including Barkley (1997a), I believe that the dimensional view is more likely to be correct. This implies that there is a quantitative rather than a qualitative difference between ADHD children and normal controls, and that studies of non-clinical samples can improve our understanding of the deficits associated with clinical conditions. The sample used in Study I, II and II was a normal sample, which means that this thesis mostly includes studies of the non-clinical range of ADHD symptoms. The normality of the sample may have deflated the strength of the association due to restriction of range. However, this only adds to the validity of the findings – if consistent relations between executive inhibition appear at these rather low problem levels, they are certainly there to be found. Besides, the findings of a relation between executive inhibition and hyperactivity was also found in Study IV, which strengthens the validity of the findings from Study I, II, and II by

showing that this relation exists also when using a categorical approach to understanding ADHD symptoms.

Directions for future research

The strongest reason for why so many studies are conducted within the ADHD research area is probably that these behavior problems are among the most common psychiatric problems in children, but also that so many important questions remain unanswered. Hopefully, this thesis has contributed to a better understanding of some of these issues, although for myself as a researcher, the number of new research questions generated during the years I have been working with this thesis greatly exceeds the number of questions I have been able to answer. Below, I will therefore briefly address some of the issues that I believe to be of most interest for future research.

Developmental issues in neuropsychology

The results of the present study indicate that executive inhibition in preschool can predict ADHD symptoms in school-age, and a predictive relation also exists between this type of inhibition and executive functioning, at least for boys. Studying the development of executive inhibition more closely over time, to investigate how poor inhibition results in more general executive function deficits should therefore be of importance. Further, as the four executive functions were shown be related to ADHD symptoms, future studies should try to explore these relations using a longitudinal design. The importance of using tasks of executive functioning that are well suited for young children should, however, be stressed. In that previous research has shown that many executive skills are not very well developed during preschool even among non-hyperactive children (e.g., Welsh & Pennington, 1988), it might therefore be difficult to find preschool measures of executive functioning that can discriminate between hyperactive children and controls. Promising, new tasks for measuring executive functioning in preschool have, however, been presented (e.g., Archibald & Kerns, 1999; Byrne, DeWolfe, & Bawden, 1998; Epsy, Kaufmann, Glisky, & McDiarmid, 2001), making this an interesting area for future research.

Sex differences

The fact that executive functioning in Study III was shown to be significantly related to both hyperactivity and inattention for boys, but not for girls, could be taken as an indication that other factors might better explain these problems in girls. Discovering which these other factors might be was, however, beyond the scope of the present thesis. Replications of the findings presented in this thesis are also necessary, in that the existence of differential pathways for boys and girls is but one way to explain our findings. An alternative possibility could be that the relations between inhibition and inattention and hyperactivity were weaker for girls due to lower problem loads for this sex, making it more difficult to demonstrate significant relations. Thus, studies using large, preferably high risk, samples are clearly needed before any certain conclusions

regarding sex differences in the relation between executive inhibition and ADHD can be drawn.

The need for interdisciplinary research

Finally, I would like to emphasize the need for more interdisciplinary research, as I feel that there has been too little collaboration between clinical and developmental psychologists in the field of ADHD research. Interdisciplinary research has become more and more common, with an increasing number of clinical psychologists and psychiatrists being interested in developmental issues, and with a relatively large number of developmental psychiatrists being interested in neuropsychology. In my opinion, an interesting area of research would be to try to build more comprehensive models of psychopathology, incorporating recent neuropsychological findings with those from traditional fields of developmental psychology, such as temperament and attachment.

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