The Association Between Inattentive (I) and Hyperactive/Impulsive (H/I) Symptoms and Deficits in Inhibitory Control in Kindergarten Children

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Abstract

In children, the key symptoms of Attention Deficit/Hyperactivity Disorder (ADHD), inattention (I) and hyperactivity/impulsivity (H/I), are associated with deficits in executive function of behavioural inhibition in clinical populations, when performance-based measures of inhibition are used. This study examined whether I and H/I symptoms independently and collectively predict behavioural inhibition in a non-clinical sample of kindergarten students (n = 20). ADHD symptoms and behavioural inhibition deficits were measured using teacher ratings on the Conners Teacher Rating Scale and the BRIEF. I and H/I symptoms were independently linearly associated with inhibition deficits (*r* of I = .881, *r* of H/I = .599); when included together in the same model, H/I symptoms alone were sufficient to significantly predict inhibition regulation (R^2 = .881). These results suggest that behavioural inhibition deficits may be underlying symptoms of the Hyperactive/Impulsive subtype of ADHD, but not the Inattentive subtype.

Résumé

Chez les enfants, les symptômes d'un Trouble de Déficit de l'Attention/Hyperactivité (TDAH), l'inattention (I) et l'hyperactivité/impulsivité (H/I), sont associés avec des déficits de la fonction exécutive de l'inhibition dans des populations cliniques, lorsque l'inhibition est mesurée à travers des tâches exécutées par les individus. Cette étude explore la relation entre les symptômes I et H/I et des déficits de l'inhibition comportementale chez des enfants en maternelle (n =20) avec un développement typique. Les symptômes de TDAH et des déficits de l'inhibition comportementale ont été mesurés avec des questionnaires remplis par leur professeure, le Conners Teacher Rating Scale et le BRIEF. Les symptômes de I et H/I étaient chacun associés avec des déficits de l'inhibition (*r* de I = .881, *r* de H/I = .599); lorsqu'ils étaient inclus dans le même modèle, les symptômes H/I étaient suffisants pour prédire la régulation de l'inhibition (R^2 = .881). Ces résultats suggèrent que les déficits de l'inhibition comportementale sont à la base des symptômes de TDAH avec sous-type Hyperactif/Impulsif, et non du sous-type Inattentif.

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CHAPTER 1

Introduction

Behavioural problems in children are one of the most pervasive problems of our education system. Insight into the processes that underlie behavioural problems can lead to the best methods of intervention. Attention Deficit/Hyperactivity Disorder (ADHD) is one of the most commonly diagnosed disorders in classrooms and also one of the most problematic (4th ed., text rev; DSM-IV-TR; American Psychiatric Association, 2000). The concept of executive functioning (i.e., the capacity to coordinate thoughts, actions and emotions towards a response or a goal) has been identified as a potential etiological factor in the development of ADHD (e.g. Miyake et al., 2000). Russell Barkley (1997) proposed a theory in which one type of executive function, behavioural inhibition, underlies ADHD symptoms. This thesis explores the link between behaviours that characterize ADHD and inhibitory skills in an effort to contribute to the literature by addressing Barkley's theory and provide avenues for conducting school-based interventions targeting executive functions.

Literature Review

Attention Deficit/Hyperactivity Disorder

The key features of Attention Deficit/Hyperactivity Disorder are symptoms of inattention, impulsivity and hyperactivity. According to the Diagnostic and Statistical Manual of Mental Disorders (DSM) (DSM-IV-TR), inattention is characterized by such symptoms as difficulty in keeping sustained attention or mental effort on an activity, being easily distracted, making careless mistakes, and failing to follow instructions. Hyperactivity and impulsivity, on the other hand, is shown by symptoms of physical restlessness, such as difficulty staying in a seat, interrupting others, excessive or inappropriate physical movement at moments when the person is expected to remain still, etc. In any individual (whether diagnosed with ADHD or not), these symptoms are present in varying strengths. If the clinical criteria are met for only symptoms of inattention, then a diagnosis of ADHD-Inattentive Subtype is made. Conversely, clinically significant presence of only hyperactive or impulsive symptoms leads to a diagnosis of ADHD-Hyperactive/Impulsive Subtype. Finally, if the inattention and hyperactivity/impulsivity are both present, then the diagnosis given is ADHD-Combined Subtype (DSM-IV-TR). Symptoms of inattention and impulsivity/hyperactivity (whether clinically significant or not) are here referred to as IIH behaviours.

One of the most obvious and significant reasons that ADHD is problematic (and moreover the most common reason for diagnosis) is the manifested difficulty in self-regulatory skills. This is a particularly onerous

problem for children diagnosed with ADHD, since by definition they tend to struggle in a structured academic setting, where all children are expected to be able to control their behaviour, and remain focused, listen to their teacher, stay in their seat, and not speak out of turn or interrupt others. The early development of these capacities is essential for the smooth functioning of individuals in society; since these are the precursors of the increasingly mature and independent behaviour expected of children grow older and predict the growth of social skills and adaptive behaviour (Loe & Feldman, 2007). Children who struggle with the early mastery of these competences and exhibit IIH behaviours exhibit less communication skills, sensitivity to others, and responsible behaviour, as rated by their parents (Clark, Prior, & Kinsella, 2002). Moreover, children diagnosed with ADHD perform worse than typically developing children on standardized measures of academic achievement (e.g. Woodcock Johnson Tests of Achievement and Wide Range Achievement Test) and cognitive functioning (e.g. Weschler Intelligence Scale for Children, Peabody Picture Vocabulary Test, Stanford-Binet Intelligence Scale) (Clark, Prior, & Kinsella, 2002; McClelland & Cameron, 2011; McClelland et al., 2007; Nigg, 1999; Riccio, Homack, Pizzitola Jarratt, & Wolfe, 2006; Scheres et al., 2004; Seidman et al., 2005). Furthermore, the association between regulatory behaviour and academic success persists regardless of formal ADHD diagnosis and across various measures of school performance. In a study conducted to assess IIH symptoms using teacher ratings of pupils on scales of interest/participation, cooperation/compliance, and attention span/restlessness, the results similarly reflected lesser school marks in reading

and/or math for 3 years following the initial teacher ratings (Alexander, Entwisle, & Dauber, 1993). Comparable results have been found with other scales that assess IIH behaviours (e.g., Cooper-Farran Behavioral Rating Scales, Social Skills Rating System) and use state-wide reading and math assessments (Agostin & Bain, 1997; McClelland, Acock, & Morrison, 2006). Finally, symptoms assessed by behavioural checklists that directly use the diagnostic criteria for ADHD also predict poorer performance on researcher-developed math and reading performance tests (Merrell & Tymms, 2001).

Executive Functioning

The processes that underlie self-regulatory skills appear to be related to executive functioning, and deficits in executive functioning capacities could result in symptoms that characterize ADHD. Executive functioning can be broadly defined as a person's ability to work towards a specific goal in the future and orchestrate the necessary elements to make this happen, and its successful functioning has long been associated with the brain's frontal lobes since the historical case of Phineas Gage. It has been conceptualized both as a unitary construct and as divisible into different component processes (Miyake et al., 2000; Zelazo & Müller, 2002). A number of different executive functions have been studied, such as working memory, planning, sensory selection, motor and verbal response, emotional regulation, goal setting, etc. (e.g. Anderson, 2002; Blair, Zelazo, & Greenberg, 2005; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000; Zelazo & Müller, 2002). The executive functions commonly studied by researchers are most often observation-derived, and many stem from

interpretations of the theoretical foundations underlying the various tasks used in executive functioning research. In order words, either the cognitive tasks that are known to be sensitive to frontal lobe damage were the basis for researchers to posit the existence of these executive functions, or conversely tasks were developed to measure certain observed behavioural deficits. For example, the widely used Wisconsin Card Sorting Test (WCST) requires a person to sort cards on the basis of a particular characteristic such as colour, and then to change to a different basis of sorting such as the shape. The person must first determine what the sorting rule is, and must also put aside old sorting rules for new ones. Therefore, the WCST is used as a measure of the capacity to shift from one mental set to another (Grant & Berg, 1948). However, the nature of executive functioning implies coordination between processes to produce a particular behaviour, and any given task may in fact be a more accurate measure the success of an observable behaviour that occurs in conjunction with different processes. For this reason, researchers have posited a variety of different theories on the structural organization of executive processes (Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; Miyake et al., 2000; Zelazo & Müller, 2002).

A current and widely accepted theory is that these processes are distinct but nevertheless related and work in conjunction (Anderson, 2002; Miyake et al, 2000; Zelazo & Müller, 2002). Miyake and colleagues (Miyake et al., 2000), in a seminal study, examined three functions commonly found in the literature: shifting, updating, and inhibition. *Shifting* is defined as the ability to shift from one frame of thinking to another (e.g. changing the between the rules of one

problem-solving framework to a different set of rules), and entails attentional capacities. *Updating* refers to ability to keep track of existing and new information required to complete a task; this process is akin to working memory. Finally, *inhibition of prepotent responses* is the capacity to suppress a response that is automatic or already learned, when such a response is inappropriate and must be inhibited either long enough for an appropriate response to take place, or else to prevent any response whatsoever (depending on the demand of the situation). The authors chose these three processes on the basis of their extensive use in executive functioning research. However, in their study, they show that these three functions also emerge as distinct but interrelated functions when they used latent variables analysis, and furthermore that they all tap into a single "complex executive task" construct. The functions involved in this model, and the tasks used to measure performance in each process, have been widely used in research (e.g., Bull, Espy, & Wiebe, 2008; Lehto, Juujärvi, Kooistra, & Pulkkinen, 2003; St Clair-Thompson & Gathercole, 2006; van der Sluis, de Jong, & van der Leij, 2007).

In support of the theory that the processes of executive functioning might mediate the manifestation of IIH behaviours, there is extensive evidence associating deficits in executive functions with ADHD symptoms (e.g., Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Huang-Pollock, Mikami, Pfiffner, & McBurnett, 2009; Lockwood, Marcotte, & Stern, 2008; Semrud-Clikeman, Pliszka, & Liotti, 2008; Sonuga-Barke, Dalen, Daley, & Remington, 2002; Weyandt, 2005). Wilcutt and colleagues conducted a meta-analytic review

in order to examine the validity of the theory that the primary deficit in ADHD is that of executive functioning (Wilcutt, Doyle, Nigg, Faraone, & Pennington, 2005). The authors outline four necessary conditions that must be met in order for the hypothesis to be strictly true, three of which they concluded were sufficiently supported by the evidence in the literature: the consistency of executive functioning weaknesses in ADHD groups after controlling for confounding variables, its accounting for sufficient symptom variance, and its presence in the majority of people diagnosed with ADHD. The fourth condition, common etiology, could not be fully substantiated with the current available literature. The authors concluded that:

> [executive functioning] weaknesses are significantly associated with ADHD, but they do not support the hypothesis that [executive functioning deficits] are the single, necessary and sufficient cause of ADHD in all individuals with that disorder. Instead, [executive functioning] difficulties appear to be one of several important weaknesses that comprise the overall neuropsychological etiology of ADHD (Wilcutt et al., 2005, p. 1342).

Consequently, the proposed link between executive functioning deficits and ADHD symptoms appears to be substantiated by the literature.

Inhibition Deficits

In an effort to explore the mechanisms underlying this executive dysfunction-IIH behaviours link, researchers have attempted to pinpoint specific executive processes that mediate the relationship. One of the most influential theories was first posited by Russell Barkley (1997): he proposed the theory of

response inhibition, in which inhibition problems are the driving force behind the ADHD symptoms through their effect on key executive function components. According to the Barkley, behavioural inhibition is the core deficit in the ADHD diagnosis, and that the effects these deficits exert on specific executive functions are that cause the impairments observable in children diagnosed with ADHD. These inhibition skills comes into play at three different moments of a given response: inhibiting an instinctive undesirable response, interrupting a response that is already occurring, and maintaining a delay in order to allow an appropriate response to occur. In the context of Miyake and colleagues' model, the description of response inhibition encompasses *shifting*, *updating*, and *inhibition of prepotent responses* processes (Miyake et al., 2000). Barkley suggests that these elements are specifically where they key deficits in executive functioning lie, and that inhibitory capacities in these processes are what allow for effective functioning of four specific executive functions: working memory, internalization of speech, self-regulation of affect-motivation-arousal, and reconstitution. Working memory (closely related to the *updating* process) refers to the capacity to hold and manipulate information in the mind. Internalization of speech entails questioning, reasoning and reflection. Self-regulation of affect-motivation-arousal encompasses emotional and motivational control. Reconstitution is the synthesis of behaviour and the setting of goal-directed behaviour. However, inhibition is not the foundation for these executive processes: it acts more as a necessary precursor for their performance. These four executive functions, in turn, mediate

motor control (Barkley, 1997, 1999). The lack of motor control manifests itself through IIH behaviours, hence a diagnosis of ADHD.

There is a great deal of literature supporting response inhibition theory. Barkley's definition, as discussed above, encompasses three distinct moments: inhibiting a response prior to its occurrence, at the moment of its occurrence, and continuing to inhibit it long enough to deliver the correct response. The measures and outcomes of the studies examining inhibition are relevant to inhibition theory as long as they can be subsumed under one of these three moments. Wilcutt and colleagues (Wilcutt et al., 2005), in their meta-analytic review, outlined response inhibition as one of the strongest and mostly consistently demonstrated executive functioning deficits in ADHD: several studies provide empirical support for the idea that poor inhibitory control is characteristic of children displaying IIH behaviours, compared to typically developing children (e.g., Berlin, Bohlin, & Rydell, 2003; Biederman et al., 2004; Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009; Crosbie & Schachar, 2001; Nigg, 1999; Seidman et al., 2005; Scheres et al., 2004; Shaw, Grayson, & Lewis, 2005; Sonuga-Barke et al., 2002; Thorell, 2007; Wodka et al, 2007). The results of these studies demonstrate impaired inhibition using paradigms that target some or all three of the contexts under which it is required, and therefore involve either stopping an automated response before or during its occurrence, and the production of an appropriate response when called for. One such task is broadly referred to as the go/no-go task, in which the participant must perform a motor response to a particular stimulus that is presented frequently. When a second, less frequent stimulus is

presented, the motor response must be inhibited (thus tapping into the moment of initial inhibition before the response is made). Different variations of the task (e.g. the "Stop" paradigm) have been used by researchers, and impairments in children with ADHD have been observed throughout their use as measures (Berlin, Bohl, & Rydell, 2003; Crosbie & Schachar, 2001; Nigg, 1999; Wokda et al., 2007). Another frequently used paradigm is the Stroop task; in the original task, colour names are printed in ink colours different from the words they spell. The participant is required to name the colour of the ink, thus requiring the inhibition of the automatic and prepotent response (which is to read the word) in order to deliver the correct one. Variations of this task all follow a similar concept, and all are meant to measure inhibition of a response at the moment of its occurrence, long enough to deliver the correct answer. In this task as well, children with ADHD have been shown to make more errors and/or complete the task more slowly (Biederman et al., 2004; Corbett et al., 2005; Scheres et al., 2004; Seidman et al,, 2005; Sonuga-Barke et al., 2002). Other paradigms have been developed and used, but the Stop task and the Stroop task remain amongst the most commonly used and the performance of children displaying clinically significant IIH behaviours is shown to be impaired on them.

The Relation of Inhibition to Academic Functioning

There is further support to be found for the link between IIH symptoms and inhibition deficits in the latter's association with academic difficulties. A number of studies have demonstrated that in elementary school children, poor inhibitory skills are associated with reduced performance on measures of math

and reading achievement (using both in-school and standardized tests) (Biederman et al., 2004; Bull, Espy, & Wiebe, 2008; Bull & Scerif, 2001; McClelland et al., 2007; St Clair-Thompson & Gathercole, 2006). Moreover, behavioural inhibition correlates with scholastic achievement not only at a given time point, but it can also predict achievement up years following the original assessment of executive functioning (Bull, Espy, & Wiebe, 2008; Clark, Prior, & Kinsella, 2002; Clark, Pritchard, & Woodward, 2010; Jacobson, Williford, & Pianta, 2011; McClelland & Cameron, 2001). Consequently, both symptoms of ADHD and behavioural inhibition deficits are tied to scholastic underachievement and therefore appear to result in difficulties in functioning in similar areas.

ADHD Subtypes

Exploring the association between inhibition deficits and IIH symptoms helps us understand the etiology of ADHD; as such, it is important to consider and differentiate between subtypes: ADHD - Inattentive (ADHD-I) subtype, Hyperactive/Impulsive (ADHD-H/I) subtype, and Combined (ADHD-C) subtype. Over the decades, the classification of subtypes has changed from one DSM to another, as the literature on etiological differences has grown (Neuman et al., 1999). According to the DSM-IV-TR, ADHD-I and ADHD-H/I are different manifestations of the same disorder, and thus they are grouped under the same diagnostic category (DSM-IV-TR). This distinction remains the subject of debate, as researchers question whether they represent qualitatively separate disorders. Some researchers have attempted to explore this question by using latent class analyses, conceptualizing symptoms as belonging to separate continua for I and

IH behaviours. The results of one such study validate the distinction between ADHD-C and ADHD-I (Neuman et al., 1999). The latent class analysis approach was also used to distinguish between subtypes on cognitive and educational performance measures; it was found that ADHD-I and ADHD-C types had very similar profiles of deficits, and the ADHD-H/I group had better general outcomes than either (Todd et al., 2002). Similarly, other researchers used various outcome measures such as educational history and comorbidity in young adults (though not using a latent class approach) and found some distinctions: the ADHD-C groups had greater comorbidity with Oppositional Defiant Disorder, greater levels of being arrested, and hostility. However, they did not discover distinctions on the comorbidity of Conduct Disorder, personality disorders, substance abuse disorders, or educational attainment (Murphy, Barkley, & Bush, 2002). There is therefore conflicting evidence on the distinction between ADHD subtypes when outcome measures of comorbidity and overall adjustment are used.

Inhibition and ADHD Subtypes

The ADHD behavioural inhibition deficit theory provides an explanation for potential etiological difference between ADHD-I subtype and the ADHD-H/I subtype. Barkley sets ADHD-I in a category apart from ADHD-H/I and ADHD-C, contending that "this subtype, at its core and when properly defined, does not reflect a developmental deficiency in behavioral inhibition but probably one of focused/selective attention and speed of information processing" (Barkley, 1999, p. 177). Experimentally, therefore, any specific measures of behavioural inhibition should reveal deficits in ADHD-C and ADHD-H/I subtypes, but not in

ADHD-I. Along the lines proposed by Barkley, much of the literature on subtype differences in inhibition deficits has compared ADHD-I with ADHD- C. There is evidence to support his theory, with studies showing that participants diagnosed with ADHD-C perform worse on measures of behavioural inhibition than ADHD-I participants and typically developing controls (Houghton et al., 1999; Lockwood, Marcotte, & Sterne, 2001; Nigg, Blaskey, Huang-Pollock, & Rappley, 2002; Solanto et al., 2007). The Stroop and go/no-go paradigms were used most often, suggesting that the C subtype shows deficits in the inhibition of an inappropriate automatic response both before and during the moment of response. However, the authors of one study found that gender mediated the relationship between response inhibition deficits (as measured by the same two tasks) and subtypes: the ADHD-C group showed inhibition difficulties compared to the ADHD-I group but only for boys, while for girls, the ADHD-I group performed worse than controls and there was no difference between ADHD-C and ADHD-I (Nigg et al., 2002). Globally, therefore, there is more evidence supporting the theory that inhibition deficits are specific to ADHD-C and ADHD-H/I subtypes, though there is also the suggestion that gender may play a role.

Although few studies have been conducted comparing ADHD-H/I and ADHD-I subtypes, the authors of one study that did so found that the ADHD-I group was impaired on inhibition measures while the ADHD-H/I group were not (Chhabildas, Pennington, & Wilcutt, 2001). Similarly, in another study, the researchers found that inhibition deficits were linked to inattentive symptoms and not to hyperactive/impulsive ones (Thorell, 2007). These conclusions are

supported by a third study demonstrating similar results in a comparison between ADHD-C and ADHD-I subtypes (Pasini, Paloscia, Alessandrelli, Porfirio, & Curatolo, 2007). The results of these studies conflict with the evidence cited the paragraph above, and do not support the theory that H/I, and not I, symptoms, are associated with inhibition deficits.

Conversely, another portion of the literature encompasses studies whose results suggest that there are no inhibition differences at all between ADHD subtypes (Geurts, Verté. Oosterlaan, Roeyers, & Sergeant, 2005; Martel, Nikolas, & Nigg, 2007). Inhibition impairment was also assessed using either Stroop and go/no-go tasks (or analogous paradigms) in these studies. Generally, the majority of the literature favours the theory that there are ADHD subtype differences, but the theory that H/I symptoms are associated with inhibition deficits while I symptoms are not requires further investigation.

Present Study

The present study is designed to address certain gaps in ADHD/inhibition research. To begin with, though some evidence supports Barkley's response inhibition deficits theory, the conflicting results of the literature are suggestive, and more research is needed to either validate or challenge the theory in order to advance our knowledge of the etiology of ADHD and IIH behaviours generally. Moreover, most of the research on IIH behaviours has been conducted only on clinically significant samples, for which the ADHD diagnosis has been given because the required number of IIH symptoms has been met. However, these symptoms manifest themselves along their respective I and H/I continua (Neuman

et al., 1999; Span, Earleywine, & Strybel, 2002; Thorell et al., 2007; Todd et al., 2002). IIH symptoms are helpful not only for diagnosing ADHD pathology but may also represent a critical variable in academic performance of all children: if inhibitory difficulties are indeed underlying either or both H/I or I symptoms, then these difficulties should be proportionally present in typically developing children who may exhibit a only few IIH symptoms and are not eligible for clinical diagnosis. It is therefore useful to clarify the nature of the relationship between IIH and inhibitory deficits, across the symptom continuum of both variables (a continuum that spans from a complete absence of symptoms to severe manifestations).

Secondly, response inhibition in ADHD also needs to be studied in young children. In the literature, the focus of research on the three-fold association between ADHD, inhibition difficulties, and academic functioning is on children of school age. Given the early association between well-regulated behaviour and scholastic success, it is incumbent upon researchers to understand how these processes unfold from a child's early school years, because these school years can later bear influence on school attitudes, adjustment, social skills development, and general mental well-being (see section titled *Attention Deficit/Hyperactivity Disorder*, p.7) (Blair, Zelazo, & Greenberg, 2005). The developmental trajectories of executive functions, and inhibitory processes in particular, have only been lightly researched; however, the evidence is that inhibition begins developing during infancy (Anderson, 2002; Blair, Zelazo, & Greenberg, 2005; Mahone & Hoffman, 2007; Sonuga-Barke et al, 2002). Furthermore, given the

aforementioned studies exploring the inhibition skills of children between 4 and 7 (e.g. Biederman et al, 2004; McCelland, Acock, & Morrison, 2006; McClelland et al., 2007), it seems that the processes encompassing inhibition have developed sufficiently by that age to accurately predict future academic trajectories. Therefore, children who are in the early school years are an ideal focus for research on inhibition deficits and ADHD.

Finally, response inhibition theory should be tested using different methods of assessing behavioural inhibition. Most research in the literature has measured inhibition using lab-based measures of executive functioning. While lab measures may provide a greater level of precision and help differentiate performance in specific subcomponents of executive functions, the classroom is often the most desirable context under which to study the participants' executive functioning. As such, teacher-based questionnaires such as the Behaviour Rating Inventory of Executive Functioning (BRIEF) (Gioia, Isquith, Guy, & Kenworthy, 2000) provide a glimpse of what is actually happening in the setting where children are required to demonstrate their skills in a naturalistic setting. In one study of lab and questionnaire-derived measures of inhibition, the results demonstrated significant though modest correlations between the inhibition construct as measured by either (Toplak, Bucciarelli, Jain, & Tannock, 2008). The authors of another study compared parent ratings of the BRIEF to performance-based measures of inhibition; they found that when parent ratings were used, children with the ADHD-C subtype exhibited greater inhibition deficits than those with ADHD-I. However, using lab-derived measures, they found that the boys of

the I group showed greater difficulty in inhibition than the C group (Riccio, Homack, Jarratt, & Wolfe, 2006). The authors point out that the tasks used in labs to measure executive functioning are contrived and may not accurately reflect real-life executive functioning capacities, a conclusion also reached by the researchers of a third study of BRIEF ratings among preschoolers with ADHD (Mahone & Hoffman, 2006).

Aims and Hypotheses

By examining the association between IIH symptoms and inhibitory deficits, the broad aim of this study is to add evidence either confirming or challenging Barkley's theory on inhibition deficits in ADHD, when inhibition is assessed in a natural context. First, it will add to existing but meager literature on whether IIH symptoms are associated with inhibitory deficits regardless of clinical diagnosis and symptom severity. In the event that inhibitory deficits are present only in clinical populations, this study will nevertheless contribute to the understanding of the qualitative differences in executive functioning between clinical and non-clinical populations. Secondly, it will help determine whether there are differences in inhibitory regulation between ADHD-I and ADHD-H/I subtypes when assessed by teacher ratings, and whether greater levels of symptoms across either behaviour are associated with greater inhibitory deficits. Thirdly, the results will help understand the nature of the link between IIH behaviours and inhibition regulation at an early school age, since that developmental stage is an ideal target for academic and social interventions.

We hypothesize first that H/I symptoms will linearly and positively correlate with inhibitory control deficits throughout the spectrum of symptoms. Secondly, we hypothesize that I behaviours will not correlate with inhibitory deficits, and that in predicting inhibitory control, they will not add predictive value. If these hypotheses are true, then Barkley's response inhibition theory of ADHD will be substantiated.

CHAPTER 2

Methods

Participants

The participant population comprised of kindergarten children who attended an English-language school in the West Island of Montreal, Quebec. A total of 20 children participated in the study, both boys ($N = 6$) and girls ($N = 14$). As the widest possible range of behaviours on inhibition and impulsivity/inattention/hyperactivity measures was desirable, no exclusionary criteria was applied. All children were between the ages of 5 and 6.

Materials

Inhibition. Inhibition was measured using the Behaviour Rating Inventory of Executive Function (BRIEF), a questionnaire designed to measure executive functioning, in which teachers are asked to assess the frequency with which a child exhibits a behaviour, from a scale of 1-3 (*never, sometimes, often*) (Gioia, Isquith, Retzlaff, & Espy, 2010). The BRIEF was standardized using a normative sample of 1419 parents and 720 teachers in the United States, for children ages 5 to 18, and across a variety of ethnicities and socioeconomic statuses; for clinical and nonclinical samples, its internal consistency ranges between Cronbach α coefficients of .80 to .98, and retest reliability was .87 for teachers. The BRIEF assesses two factors: behavioural and emotional regulation (with self-monitoring, inhibit, and emotional control scales), and metacognition (with initiate, working memory, plan/organize, organization of materials, and task-monitor scales).

Specifically, the behavioural regulation index (BRI) scores were converted to t-scores and used to measure behavioural inhibition. Greater BRI scores indicate greater difficulties in behavioural regulation.

Impulsivity, inattention, and hyperactivity. Impulsivity, inattention, and hyperactivity behaviours were measured using the Conners Teacher Rating Scale (CTRS), a 4-point Likert scale questionnaire (0 being *not at all true*, 3 being *very much true*), which provides a final t-score along a continuous scale (Connors, 1998). The CTRS was developed with samples in the United States and Canada, using 1702 children between the ages of 3 and 17, across ethnicities. Internal reliability coefficients range between .82 and .94; retest correlations range between .47 and .86.The CTRS loads onto six scales: hyperactivity-impulsivity, perfectionism, inattention/cognitive problems, social problems, oppositional problems, and shyness/anxiety. The hyperactivity-impulsivity and inattention scales were used in order to measure IIH symptoms, with greater scores on these scales indicating greater severity of behaviour.

Procedure

An information session was held in spring 2013 for teachers, describing the proposed study and what help is needed from them. Following this, the teachers who volunteered where given further information regarding the study and asked to complete questionnaires for all the students of their classroom. This timeline was designed in order to allow enough time for the teachers to gain familiarity with their pupils.

CHAPTER 3

Analysis

A hierarchical regression was performed in order to determine the relationship between inhibition deficits and I and H/I behaviours respectively, across the spectrum of IIH symptoms. Since the H/I variable is theorized to be predictive of BRI scores while the I/H one is not, the Hyperactivity/Impulsivity scale was entered first and the Inattention scale second.

Results

Descriptive statistics. The means and standard deviations of the t-scores for the Connors Inattention scale, the Connors Hyperactivity/Impulsivity scale, and the BRI are presented in Table 1. Assumptions of normality were met for all variables except the BRI, for which the data was negatively skewed; the data was transformed using a $\log_{10}$ transformation (skewness = 2.52, *SE* of skewness = 6.91). Though no formal diagnoses of ADHD were made, scores of greater than 60 on either the Inattention or Hyperactivity/Impulsivity scale are considered to be clinically significant (Connors, 1998). According to this cut-off, few children (N=3) were clinically impaired: one child can be diagnosed as having ADHD-C subtype, and two as having ADHD-H/I subtype. All other children were in the low or average ranges of symptoms (i.e. in the nonclinical range) ($N = 17$), with a range of 42 to 61 for the Inattention scale and a range of 42 to 90 for the Hyperactivity/Impulsivity scale. Scatterplots of the Inattention and Hyperactivity/Impulsivity variables are presented in Figures 1 and 2.

Hierarchical regression models. Table 2 shows the Pearson product moment correlations between Hyperactivity/Impulsivity scores, Inattention scores, and BRI scores; both variables independently are significantly associated with the BRI scores. Hyperactivity/Impulsivity and Inattention variables correlated significantly (r = -.68).

Table 3 shows the results of the hierarchical regression model, in which the Hyperactivity/Impulsivity variable was entered as the first predictor of BRI scores, and the Inattention variable second. In order to achieve a power of 0.8 with a sample size of 20, an effect size of 0.7 is necessary. The results of the hierarchical regression indicate that the first model, with Hyperactivity/Impulsivity being the only significant predictor (R^2 = .88) had the best fit (F (1, 19) = 62.46, p < .05). In the second model, though also significantly predictive of BRI scores (F (2, 19) = 25.50, p < .05), the addition of the inattention variable does not add significantly to its prediction (β of inattention = -.00; β of hyperactivity/impulsivity = .88) (R^2 = .88).

Table 1. Descriptive Statistics for Inattention Scale, Hyperactivity/Impulsivity Scale, and BRI scores.

	Mean	*SD*
BRI	1.66	0.07
Hyperactivity/Impulsivity	51.55	14.22
Inattention	48.50	6.05

Figure 1.Transformed BRI Scores as a Function of Inattention.

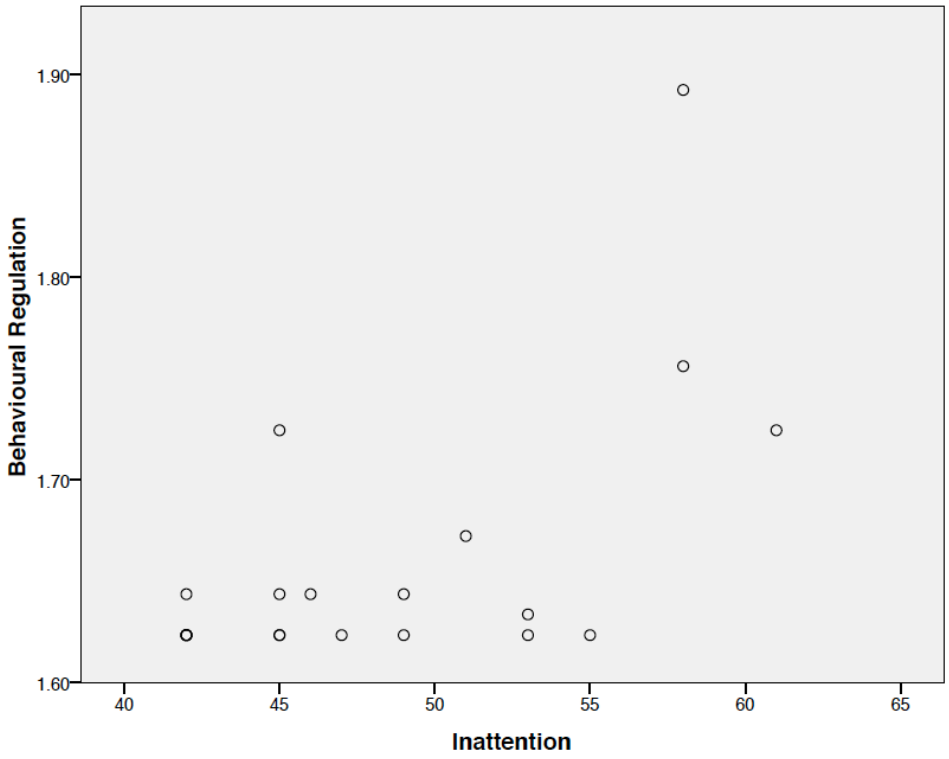

Figure 2. Transformed BRI Scores as a Function of Hyperactivity/Impulsivity.

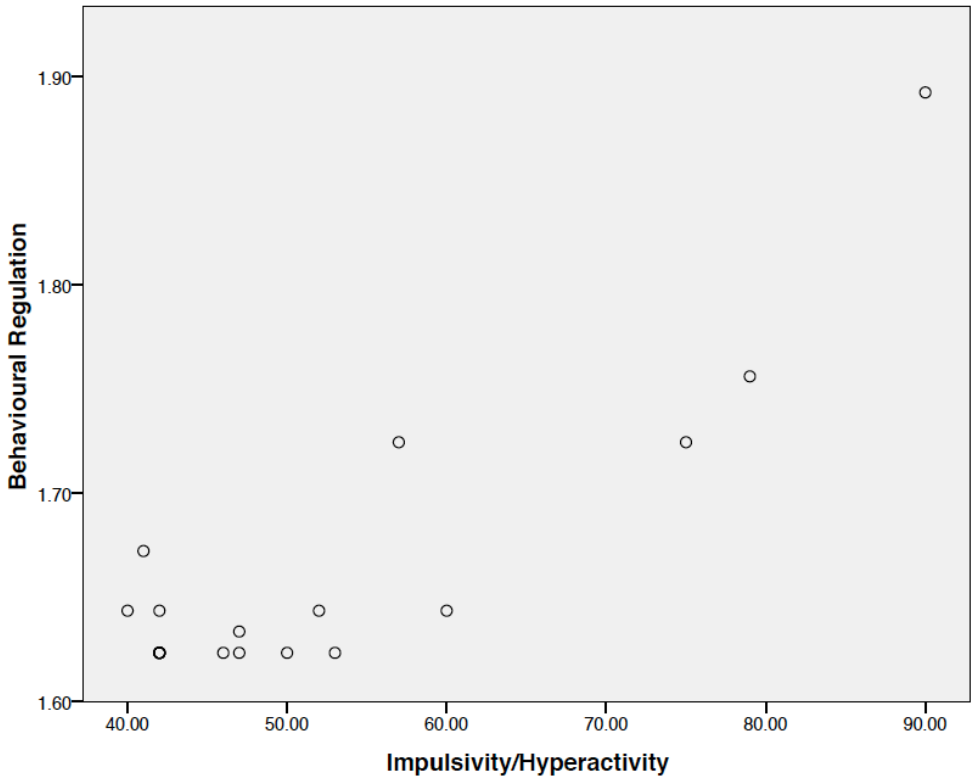

Table 2. Correlations Between Scores on the Inattentive Scale, Hyperactive/Impulsive Scale, and BRI scores.

Predictive variables	BRI scores
Hyperactivity/Impulsivity	.881*
Inattention	.599*

*$p < .05$

Table 3. Hierarchical Multiple Regression Analysis, Predicting Inhibition Deficits from Symptoms of Inattention and Hyperactivity/Impulsivity (N=20).

			Model 1	
Variables	*B*	*SE B*	*t*	β
Impulsivity/Hyperactivity	.004	.001	7.900	.881*
R^2		.881		
			Model 2	
Impulsivity/Hyperactivity	.004	5.635	.787	.878*
Inattention	4.35×10^{-5}	.002	.025	.004
R^2		.881		

*$p < 0.05$

CHAPTER 4

Discussion

Summary of Results

The aim of this study was to test Barkley's theory of response inhibition deficits as underlying ADHD. We sought to delineate the relationship between IIH symptoms and executive inhibition deficits across a range of IIH behaviours instead of only in the ADHD clinical range. We also sought to contribute to the body of evidence for Barkley's theory in terms of subtype differentiation. We hypothesized that H/I and not I symptoms would predict behavioural inhibition deficits. The results of the analyses show that, as expected, H/I behaviours strongly correlate with inhibition difficulties; however, contrary to the hypothesis, I behaviours also correlate (though less strongly) with behavioural inhibition deficits. However, when both variables were entered as predictors, a model using only the H/I spectrum was found to best predict inhibitory deficits, and the addition of I symptoms as a predictor did not change the fit of the model.

Implications

These findings of the present study are mixed, though they broadly support Barkley's theory, under which inhibition deficits underlie the ADHD-H/I subtype and thus H/I symptoms (Barkley, 1997; 1999).

The result that H/I symptoms linearly predict behavioural inhibition deficits, derived from naturalistic settings, adds to the body of evidence demonstrating similar results with performance-based measures such as the

Stroop task and the go/no-go paradigm with ADHD-C and ADHD-I participants (Houghton et al., 1999; Lockwood, Marcotte, & Sterne, 2001; Nigg et al., 2002; Solanto et al., 2007). The results moreover contradict those of studies with direct ADHD-I and ADHD-H/I comparisons, which demonstrate I symptoms to be linked to inhibition deficits more than H/I (Chhabildas, Pennington, & Wilcutt, 2001; Pasini et al., 2007; Thorell, 2007).

This study's findings that I symptoms independently correlate positively with difficulties in inhibitory regulation, yet do not contribute to the prediction of inhibition deficits in the presence of H/I symptoms, are difficult to explain. The results suggest that H/I symptoms are sufficient to explain the relationship between ADHD and inhibition deficits, and appear to corroborate Barkley's contention that the etiology of the ADHD-I diagnosis is different from that of ADHD-H/I and ADHD-C. One possible explanation for this finding is that Behavioural Regulation Index, which was used as a measure of inhibition, in fact taps into more than inhibition regulation processes, and these other functions are what correlate with I behaviours. If the association between H/I symptoms and inhibition deficits is stronger than the association between I symptoms and these hypothetical other processes, then H/I symptoms would indeed suffice in predicting behavioural regulation as measured by this index.

The current study does provide insight into the use of questionnaire-based measures of behavioural inhibition. The majority of the literature on executive functions uses lab measures (e.g., review by Wilcutt et al., 2005), and given the modest correlations between performance on lab and questionnaire-derived

measures (Toplak, Bucciarelli, Jain, & Tannock, 2008) it is indeed possible that these questionnaires do not in fact measure what they purport to, or else that they do not isolate individual processes in the same way that lab-based measures can. However, given that the paradigms of lab-based tasks are performed in unnatural conditions, their ecological validity is questionable. Teacher ratings are able to shed light on behavioural regulation in a context where it is both needed and important for the successful functioning of a child; if a child is incapable of inhibitory control in a classroom yet capable of it when in a quiet room and fully engaged one on one with an examiner, there is a discrepancy between how we measure and conceptualize executive processes and how they actually manifest in the real world. In this study, the teacher ratings led to the predicted results (hypothesized on the basis of performance measures) for H/I but not I symptoms, and the conflicting evidence is further proof that more research is needed on the link between lab and observation-based measures.

Another consideration of the current study is that it contained primarily non-clinical participants, and thus represents different section of the span of IIH behaviours than is usually examined. It is possible that since most levels of I and H/I behaviours were subclinical, they do not have the same association with neurocognitive deficits as clinically significant levels of symptoms. This idea in effect contradicts research suggesting that ADHD should be conceptualized continuously as opposed to categorically (Neuman et al., 1999; Span, Earleywine, & Strybel, 2002), but it does indirectly support the concept of etiological differences between ADHD subtypes.

The question of etiology of ADHD subtypes has been explored extensively not only in inhibitory processes but for other executive functions too (e.g. Chhabildas, Pennington, & Wilcutt, 2001; Hinshaw, 2002; Houghton, 1999; Lambek, 2010; Lockwood, 2010; Nigg, 2002; Pasini, 2007; Solanto, 2007), and both subtypes share some common executive deficits in other functions (such as working memory and planning). While this evidence refutes the idea of subtype differences, it also reinforces the concept of executive functioning deficits underlying the etiology of all ADHD types. Altogether, the results regarding subtype differences suggest that further research is warranted, since the distinction (or lack thereof) between I and H/I symptoms remains unclear.

A final thread of consideration revolves around the age of the children participating in the study. The children here are either five or six years old (kindergarten age); the ages of participating children in the literature vary greatly, from infants to adolescents. Children as young as three have been shown to exhibit inhibitory control (Dowsett & Livesey, 2000), and in fact there is evidence to suggest that these skills first begin developing at the age of one (Anderson, 2010). Moreover, longitudinal studies have investigated executive functioning in kindergarten children and predicted later academic success (McClelland et al., 2000, 2007). However, the actual trajectory and rate of improvement of behavioural inhibition from infancy into adolescence has not been studied and it may well be that the stage of development of participating children is a crucial factor. With a complete picture, researchers can begin to understand when are

optimal times to develop interventions in the form of executive functioning training.

Executive function interventions that target inhibition can include structuring the child's environment in a more ordered, controlled, and predictable way: such strategies involve the presence of adult supervision, visual reminders of rules of behaviour, and verbal reminders for the child to control their impulses. Kindergarten classrooms are already amenable to such changes. Another approach is to teach the skills necessary for the child to overcome their regulatory deficits, such as a step-by-step formula for inhibition in daily situations, rewarding desired behaviour and ignoring behaviour resulting from lack of inhibition (Dawson & Guare, 2004). These skills can be applied each of the three moments described by Barkley (1999) in which inhibition is required: preventing an unwanted response before its delivery, stopping it midway, and inhibit the response long enough to provide an appropriate one.

Limitations

There are a number of limitations to this research that affect the generalizability of the results. The sample size is small (though the statistical significance of the results is robust), and in order to obtain a better spread of symptoms along the continua of symptoms more participants (clinical and nonclinical) would have been required. There were also too few boys included in the sample to permit gender comparisons, and gender may play a role in mediating executive deficits. Much ADHD research is conducted on boys given the prevalence of ADHD diagnoses in boys as compared to girls, though there is a

suggestion that girls are being under-diagnosed because of differences in the presentation of their symptoms (Quinn, 2005). The results of this study may not be generalizable (even in a nonclinical population) due to the lack of boys in the sample. Furthermore, the sample was limited to a select school, with only one class and only one teacher, leading to a potential homogeneity of results. Background data on the sample was informally collected through interview with the teacher, revealing that most of the sample is English as a mother tongue and belongs to middle to upper middle class socioeconomic status; this further limits the generalizability of the results. Another limitation is that only teacher-based questionnaires could be used, as opposed to also using lab-based measures of executive functioning for comparison. Finally, only kindergarten children were used in the sample, and the results may be age-specific.

Future Directions

In light of these considerations, there are a number of further directions to guide follow-up research which may be particularly useful, given that the aim of the study is to examine nonclinical relationships between variables that have traditionally only been studied in clinical samples. To begin with, this study should be replicated using additional lab-derived measures of behavioural inhibition, and these should be compared to teacher-based observational measures. Secondly, any continuation of this research should try to include other sources of observation such as parent ratings, or ratings from two different teachers for each child. Thirdly, similar cross-sectional studies could be conducted on a much wider range of children, from kindergarten to adolescence.

Moreover, a longitudinal study that tracks children from kindergarten onwards could map out the developmental trajectory of behavioural inhibition and determine its relationship to IIH symptoms at various developmental points; such a study could also help to confirm whether executive functioning at kindergarten age is a predictor of later academic success as well as ADHD diagnosis. Finally, this study should be replicated with a larger sample size, in order look at gender as a potential confounding variable, and also to compare clinical and nonclinical groups.

Conclusion

In conclusion, this study has explored the link between ADHD and deficits in behavioural inhibition, as well as associations between ADHD subtypes of I, H/I, and C with these same deficits. Inhibition deficits have been generally linked to ADHD-C subtype as opposed to the ADHD-I type. Though the findings in the literature are collectively suggestive, they are by no means conclusive, and conflicting evidence of subtype differentiation exists. In this study we used teacher ratings, to reflect inhibitory demands in an ecologically valid setting, instead of lab measures. We also conducted our analyses on mostly nonclinical populations, contrary to most research. The results of the study show that H/I symptoms were the best predictors of behavioural inhibition deficits, but that I symptoms nonetheless independently correlated with inhibition deficits as well. Though these results are slightly conflicting, the H/I findings lend support to Barkley's inhibition response theory. Finally, the significant results derived from measures taken in 5 and 6-year old children suggest that inhibitory processes are

already active at that age; given the association between inhibition difficulties, IIH behaviours and academic problems, the kindergarten year is indicated as a good time to conduct social, behavioural, and academic interventions on any of those domains.

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